Deep sea mining value chain: organization, technology and development

Interoceanmetal Joint Organization
Szczecin 2016

DEEP SEA MINING VALUE CHAIN: ORGANIZATION, TECHNOLOGY AND DEVELOPMENT

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Deep sea mining value chain: organization, technology and development.

Edited by: Tomasz Abramowski

Includes bibliographical references.

E-mail: iom@iom.gov.pl Internet: http://www.iom.gov.pl

Set in Szczecin, Poland by Volumina.pl Daniel Krzanowski

Production editor: Monika Jaślarz

ISBN 978-83-944323-1-7

West Pomerania Deep Sea Mining Conference 2016

Szczecin 18-19 January 2016

This book is being published as a result of the West Pomerania Deep Sea Mining Conference 2016 that was held in Szczecin, January 18-19, 2016.

Deep sea mining is a multidimensional and innovative challenge with very promising perspectives in the medium and long term investment horizons for various participating enterprises. It is demanding and requires effort of unconventional technology and well organized activities of companies giving a great opportunity for high added value benefits and sustainable business development.

Polymetallic nodules, massive sulphides and cobalt crusts are a source of metals for engineering favorable for the environment. Many modern devices are based on highly innovative technologies. They are impossible to achieve without use of copper, nickel, cobalt, manganese and other metals, which are found in marine minerals.

The objective of the conference was to provide a forum for the discussion on the possibilities of Polish marine technology, metallurgical companies and business leaders to come up with a common effort to establish a consortium capable of offering deep sea mining services. The services might be of any type of innovation, shipbuilding, operations, deep sea support, marine minerals processing, legal and investments. The activities may include either all of value chain phases or be a part of it merging together multidisciplinary areas and business with technology.

Organizators and Sponsors of the conference: Interoceanmetal Joint Organization, The City of Szczecin, West Pomerania and KGHM Polska Miedź.

E-mail: conference2016@iom.gov.pl Internet: http://www.deepseamining.wzp.pl

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VALUE CHAIN OF DEEP SEABED MINING

Abstract. Deep sea mining value chain has been analyzed from the point of view of the activities performed in the deep seabed mining (DSM) and the behavior of possible sources of differentiation. The objective of the presented study is to identify decisive factors and most important assumptions having a substantial influence on the decision making process in the deep sea mining industry. Classic approach to value chain has been presented and some specific virtues of DSM value chain are discussed. The two types of DSM value chain have been recognized: one related with the value added to the intangible assets (exploration) and the other where value increases with the commercial mining operations when ore is processed.

1. Classic approach to value chain

In general, deep sea mining value chain is similar to the structure of activities performed in land-based mining, however there are no deep seabed mining (DSM) activities yet on commercial scale. Before their commencement it should be useful to investigate the potential sequence of steps for the purpose of developing legal frameworks for future exploitation and business models creation.

According to the classic definition of a value chain, created by Porter [7], a value chain disaggregates a firm into its strategically relevant activities in order to understand the behavior of costs and the existing and potential sources of differentiation. Porter's value chain consists of a set of activities that are performed to design, produce, market, deliver and support a product or service.

The value chain is a sequence of value-enhancing activities. In its simplest form, raw materials are formed into components, which are assembled into final products, distributed, sold, and serviced. In most industries, it is rather unusual for a single company to perform all value-creating activities by itself (from product design, production of components, and final assembly to delivery to the final user).

Porter's value chain is characterized by classical functional separation and thinking in organizational units instead of processes, since not processes but activities are listed by organizational function. Primary activities are executed mostly sequentially whereas support activities are concurrent, Fig. 1.

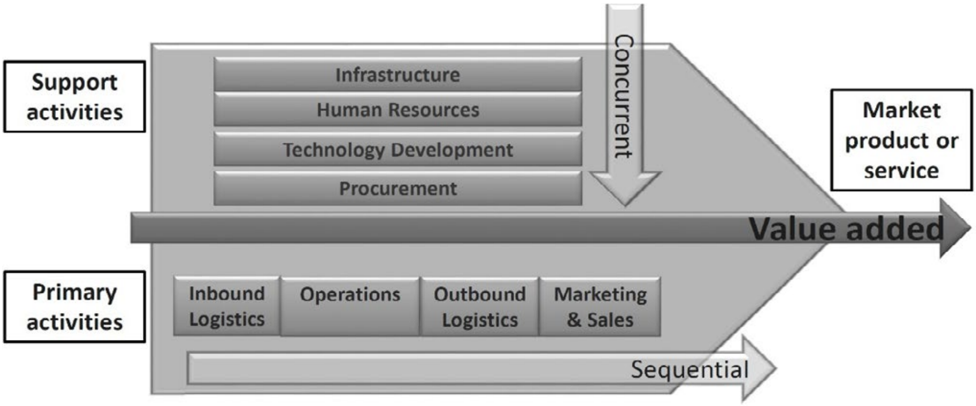

Fig. 1. Classic value chain.

Value chain analysis can be successfully applied to large and complex enterprises to study how work selection, planning, scheduling and execution can drive different business approaches to close-to-optimal solutions, when considered as elements of a chain. Those solutions can be related to the available options in scope of technical means, legal frameworks, taxation schemes, CSR policies and in general the building of an overall model of an enterprise structure. The process resembles an optimization procedure widely used in the design of systems methodology and under some assumptions (simplifications) a mathematical model can be formulated to study the behavior of a business structure. The value chain approach is particularly successful when used as a tool for helping choose among various options, as well as for sensitivity analysis.

The value chain approach could also offer an important alternative for the evaluation of enterprises in the absence of real-life data from operations involving direct competition, as is the case of deep seabed mining.

2. Deep seabed mining value chain

Within the value chain concept of deep seabed mining, seven main stages from prospecting to sales can be identified. In principle, independent from the type of mineral to be mined, the value chain of DSM consists of the following main steps:

1. Prospecting and application 2. Exploration 3. Resource assessment, evaluation and mine planning	Value is added in relation to resource classification
(3-4) – Pilot mining test – Intermediate phase – a phase where the **value** of a DSM project actually starts. For mature terrestrial mining the value can start as early as prospecting and application.	
4. Extraction, lifting and surface operations 5. Offshore and onshore logistics, transport operations 6. Metallurgical processing stage 7. Distribution and sales	Value is added basing on product processing

The exact components and stages can be arranged individually for the particular deep-sea mining projects of various contractors. The current focus of deep sea mining projects 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.

As presented in the above list the main steps of DSM value chain can be differentiated using the criteria of the type of activities where the value is actually added. 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 – the pilot mining test which could be considered to be an inevitable step in the shift from "resources" to "reserves" classification, where the actual value starts.

The steps necessary for the phase where value is added in relation to resource classification is given in Fig. 2. For the sake of presentation, the process ends with a production scale phase that again can be divided into different activities. Each distinct phase comprises the description of operations, technical instruments applied, as well as the most important legal actions and deliverables to be produced. As can be seen the complex value chain may contain not only primary technical or managing activities providing support for the chain but is rather a heuristic combination of technology, law, economics and social sciences and information management with a criterion of increased value that can be measured by means of economic indicators.

Exploration phase involves such operations as locating, sampling and/or drilling, using technologies such as echo-sounders, sonars, deep-towed photography, ROVs and sampling techniques. The resource valuation stage incorporates the examination of exploration data in the context of potential mining venture feasibility.

	Project development Increased value →				
Stage	Prospecting	Exploration, resources assessment	Pre-industrial operations	Pilot mining test	Full production scale
Operations	Identification of potential area of resources-expeditions at sea	Deposit identification, dense grid sampling, high coverage sonar images, environmental baseline studies	Detailed bathymetry, benthic impact experiments, metallurgy experiments, collector testing	Actual mining at 1/10 – 1/5 assumed full production scale	Deep sea mining, transportation, processing, logistics and commerce
Technical Instruments	Research ship, sampling devices, side scan sonar, ROV, AUV, multibeam echosounder	Research ship, sampling devices, side scan sonar, ROV, AUV, multibeam echosounder	Benthic disturbance devices, AUVs, laboratories for deposit processing	Technical support ships, transportation systems, vertical riser, collector	Mining ships, transportation and PSV vessels , mining equipment, environmental monitoring instrumentation
Legal actions	Application for prospecting or information to the administering body	Contract for exploration, reports on activities	Stakeholder survey, building positive social awareness	Contract for exploitation	Contracts and conditions for the involved parties
Deliverables	Application for exploration license	Report on indicated sub-economic resources in accordance with reporting standards on resources	Environmental impact assessment, scaling-up analysis, processing and mining at TRL 4-6	Commercial (bankable) feasibility study, Application for exploitation	Economic report on production and interests

Fig. 2. The activities of project development value chain– the value increases in relation to resource classification from speculative resources to economically demonstrable reserves.

An example of the information management that constitutes a step in the classification of mineral resources is given in Fig. 3. The information flow from exploration is presented and the flow is a link between exploration and economic feasibility. A reliable mineral resources classification is a necessary condition for economic feasibility assessment. At first a sample is taken (polymetallic nodules in this case) and it is processed in ship laboratories according to the specified technology in order to determine such quantities as nodules abundance and chemical content of the deposit. Additional analysis can be carried out for confirmation if needed. The spatial distribution of nodule ore abundance and metal content is processed in GIS computer systems. Eventually statistical analysis provides for the estimation of nodule tonnage and metals in the deposit, which are the subject of the final report on mineral resources classification.

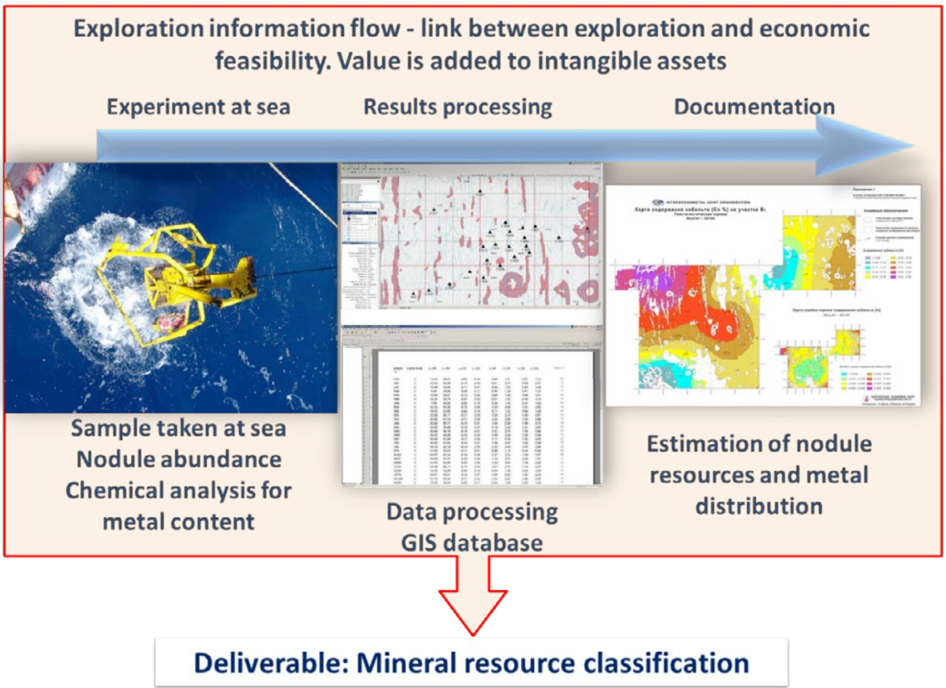

Fig. 3. Exploration-based information flow in the minerals classification process.

Value chain based on product processing is illustrated in Figure 4 for the case of full scale production of polymetallic nodules. Operations performed by mining equipment or devices are presented with corresponding ranges of technical performance needed to achieve an expected result. The system consists of a nodule miner (collector), a buffer with slurry pumps, vertical transport pipe (riser), and a mining ship. An example of one design variant of a mining ship is given in Fig.5. The track of the mining ship is dynamically positioned and it follows the collector moving along designed mining tracks. The collector picks up the nodules and rinses them of the clays and sediments. They are then crushed and pumped to the buffer as slurry then pumped to the mining ship. The function of the mining ship is storing, dewatering and drying the nodules until they are trans-shipped on the specialized bulk cargo carrier. The transshipment operation is undertaken every few days with the nodules being transported to the metallurgy plant.

Unlike the exploration phase, the value increases after each operation which this time is based on the real weight of processed material delivered to the metal market. This phase is also the subject of a taxation procedure. Extraction, lifting and surface operations, the core part of the exploitation phase, include the excavation of seabed minerals, their transportation to the surface and subsequent metallurgical processing as well as handling operations taking place offshore. For the sea bed excavation, cutters (for sulphides and crusts) or collectors (for the nodules) and riser systems are being developed. Various concepts of lifting systems are being studied for the purpose of vertical transport.

Logistics and transport involves technologies analogous to those widely applied in terrestrial mining. This is also the case for processing, although rich and polymetallic mineral composition which distinguishes marine minerals from its land analogs requires some special treatment of the deposit which is not readily available as a process ready for commercial implementation.

Environmental monitoring activities and impact assessment analysis relate to the temporal and spatial discharges of the mining system if they occur, sediment plumes investigation, disturbance to the benthic environment, and the analysis of the regions affected by seafloor machines. This involves an examination of disturbances near the seafloor, as well as disturbances near the surface. Observations include the examination of the discharges at the seafloor level while environmental baseline comparisons are to be carried out for the sake of quantitative assessments. After a certain reporting period feedback information should be analyzed to improve environmental friendliness and sustainability of the mining process.

Future standards of reporting the environmental measures will depend on the development of an appropriate set of agreed indicators. It is anticipated that the ISA will prepare a group of environmental performance indicators on the basis of a pilot mining test or other relevant studies. The deep sea mining enterprises must be ready to assist by providing an updated set of sustainable development indicators that include social factors.

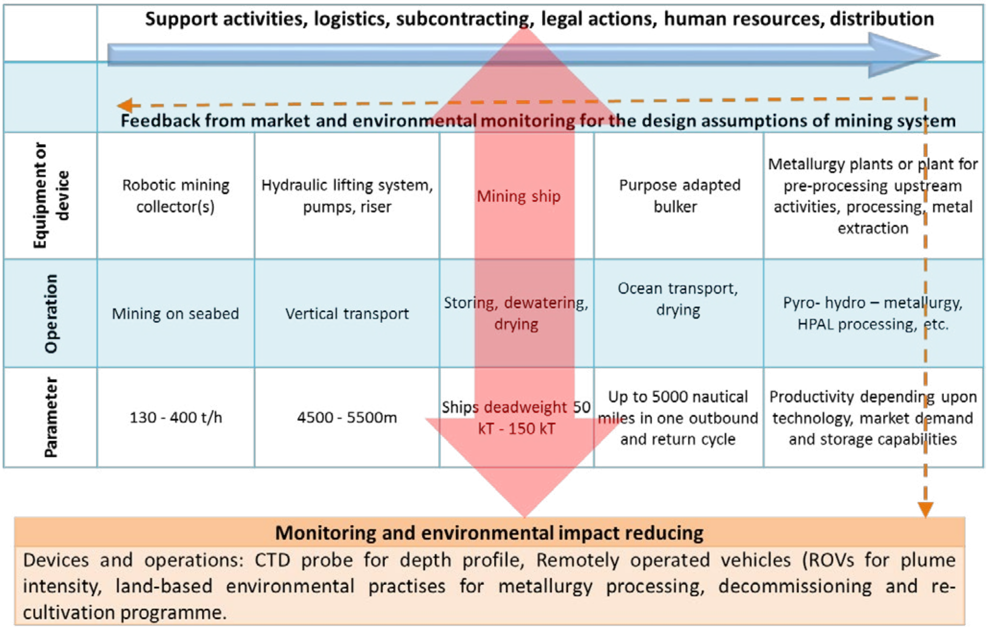

Fig. 4. Value chain based on product processing – full scale production for the case of polymetallic nodules.

Another important advantage of the value chain analysis is the possibility to study the influence of the position of the point of valuation. Point of valuation is the point in the value chain where a tax is calculated if it is based on a value of the extracted deposit or final product. This possibility allows to investigate various payment mechanisms and to execute a full review of all possible scenarios of its application, [3].

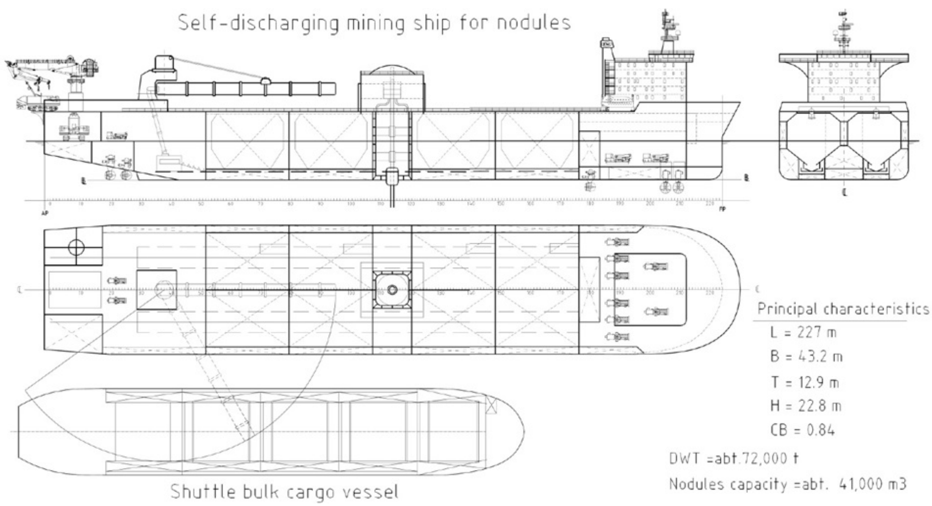

Fig. 5. Example of a design variant for the self-unloading mining ship, [1].

It is sometimes acknowledged that the valuation point needs to be at, or as close to, the extraction point of a resource. This point in land-based mining is referred to as the "ex-mine" or "mine head" value,[3]. It is the point at which compensation is due to be paid to the owner of the non-renewable resource. A standard valuation point provides consistency across all mining projects and may have some impact on the mechanical design of machinery.

Obviously, the point of valuation can only be analyzed in the case of value chain based on product processing - some options are presented in Fig. 6. The chain of activities presented here comprises the extraction, vertical transport, drying, transportation to the onshore base, port operations, processing and sales.

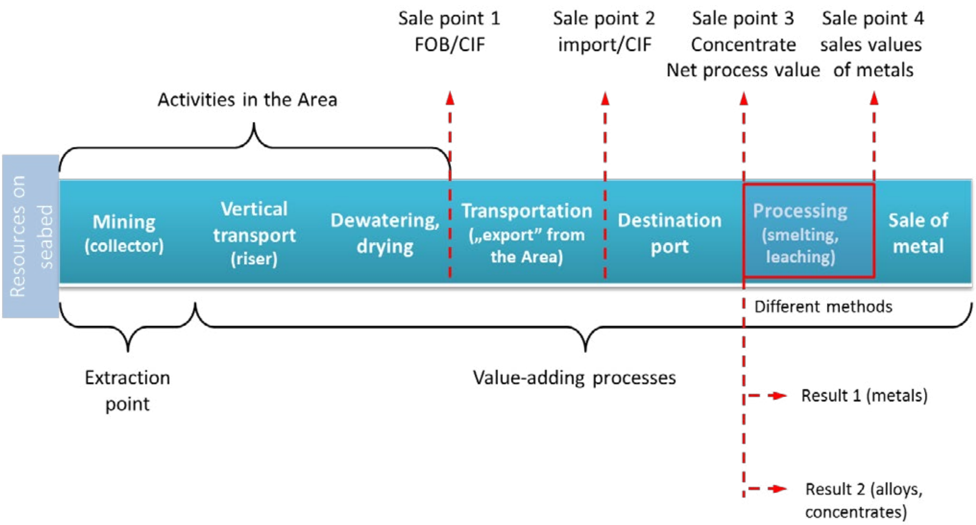

Fig. 6. Options for valuation points in the DSM value chain, based on [3].

The extraction point in case of deep sea mining is the point where deposit is collected and subsequently transferred to the riser subsystem. After storage onboard the mining ship the material is then transported to the port. This is the first possibility in the chain to establish valuation point and execute value calculation for the mined ore. Although in the presence of commercial activity the valuation of ore without its actual processing seems to be feasible, the weighing of material at sea can be difficult to achieve with sufficient accuracy.

In general, the proposal for the planning of the overall structure of enterprise technology and value flow, with a possibility to assess the solutions from an economic point of view, is given in Fig. 7. At first the key assumptions should be identified and adopted. Subsequently, at least an initial design of the mining and processing systems configuration should be developed during engineering works. On that basis cost evaluation can be carried out with further cash flow analysis accounting for the duration of the project and cash discount ratios. After the assessment an adjustment can be introduced to the initial assumptions, and this loop is repeated until satisfactory results are found.

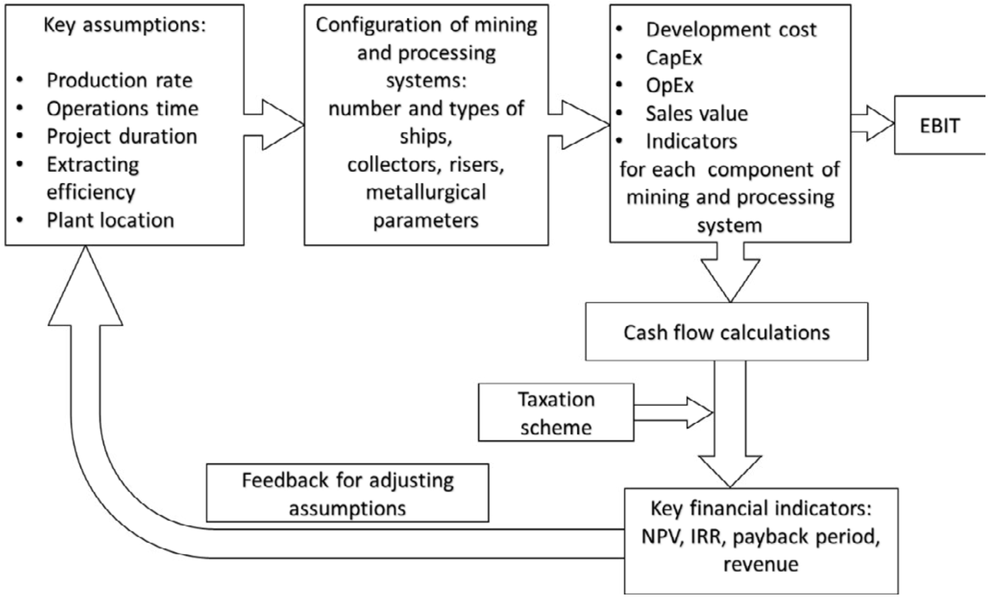

Fig. 7. Planning and assessment loop for the deep sea mining enterprise comprising technical and economic factors.

3. Final remarks

The biggest challenge when planning deep sea mining enterprise activities and business models is a proper value chain analysis. This requires the coordination of knowledge and information flow regarding the marine mining operations as well as the processes like deposit extraction, pumping, storing, ore processing, all the way to product transport and shipping, and even the planning of marketing for the products.

There are some crucial decisions that can be included like assumptions or be a result of business model adjustment like e.g. the value of the final product of metallurgical processing (highly selective processes like HPAL can extract more effectively but require higher CapEx). Sales value should be studied taking into consideration a possible influence of planned production of metals from marine minerals on global metals market, especially in case of manganese products. Structure of CapEx/OpEx/revenues ratio is another issue worth analyzing in comparison with land based mines. The prices of metals presently are at the bottom of the cycle but in DSM operations (at sea) energy is created almost exclusively from oil with bottom prices as well. Thus the project is smaller in terms of absolute value but IRR or NPV may still be plausible. CapEx intensive models should be compared against CapEx light where initial expenditures are transferred from CapEx to OpEx e.g. chartering of ships instead of new built ships.

Technical feasibility of introducing the considered taxation schemes should be carefully checked, e.g. royalty unit based scheme may require actual weighing of nodules which is hardly achievable with sufficient accuracy at sea.

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CHINA'S ACTIVITIES IN DEEP SEABED AREA

Abstract. The article firstly states China's national position towards the international seabed institutions, then briefly presents COMRA's functions in coordinating China's activities on deep seabed. The article mainly introduces China's activities in international seabed areas, conducted in the last 20 years or so, including exploration work done in COMRA's three contract areas, facilities used in open sea field surveys, deep seabed environmental study programs, and technology development programs and so on. Specifications, sea trials and actual diving operations of a 7000 m depth capable submersible named JIAOLONG are described in the paper. Two examples of land-based corporations dealing with non-ferrous metals are also given to show their production capacities. Finally, the article makes outspoken call for broad international cooperation in taking on the whole challenge and bearing the burden in the field of deep seabed issues.
Key words:
China's Activity; International Seabed; Polymetallic Nodule; Cobalt-rich Crust; Polymetallic Sulphide; International Collaboration

1. China's Positions toward the International Seabed Issues and COMRA's functions

On December 10, 1982, the first day when it was opened for signature in the city of Montego Bay, Jamaica, the ambassador of China signed the UN Convention on the Law of the Sea (herein after UNCLOS). On May 15, 1996, the China National People's Congress standing committee ratified the UNCLOS, and in the same year in July the convention came into force in the country. China always insists on the principle of common heritage of mankind adopted by the UNCLOS and supports International Seabed Authority (herein after ISA) functioning as the organ to administer the Area, particularly in scope of mineral resources. China's domestic laws and regulations persistently balance the utilization of the resources and the protection of environment.

Although China is rich in land-based mineral resources, its per capita possession of mineral resources is much lower than that of the world average. China's own supply of manganese, copper and cobalt has become falling short of the country's demand for a long time. With the development of the national economy, shortage of the above resources has become a serious problem facing China. The purpose for China to apply for the seabed area is to develop, under the principles set out in the UNCLOS, new sources of mineral resources so as to meet a certain portion of long-term needs of the country, and also to make a contribution to the whole mankind in exploration and exploitation of the international seabed. Therefore, China initiated its activities in the Area under the international legal framework of the UNCLOS for the peaceful use of the deep seabed resources.

Meanwhile, in order to efficiently conduct exploration in the Area, the State Council of China decided to establish the China Ocean Mineral Research and Development Association (COMRA) in 1991. COMRA is a state-owned entity consisting of a number of universities and research institutions as its council members. Its main functions are as the follows: to organize and coordinate China's activities in the Area, to manage the government funds for R&D and to implement the deep sea programs, as well as to fulfill the obligations as required of a contractor. The main targets of COMRA are to explore new resources, to promote the establishment of a deep sea industry, to increase knowledge of the deep sea environment, to develop new deep sea technology & equipment, and to participate in the institutional development of the Area for peaceful use.

2. Exploration work in COMRA's Contract Areas

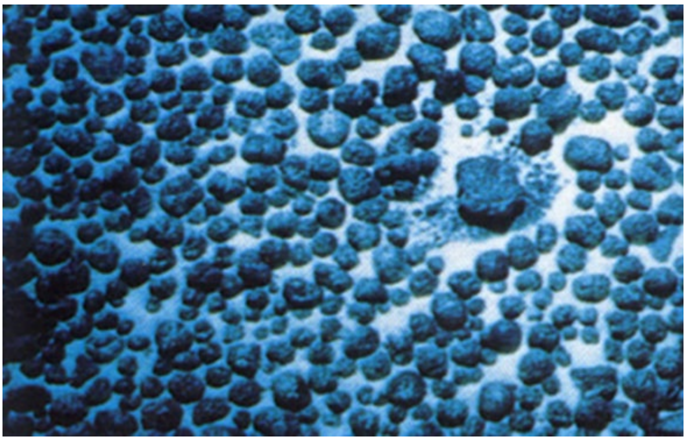

Fig.1 Polymetallic Nodules

Up to now China owns 4 contracts signed with ISA. The first contract is for polymetallic nodules (Fig.1) and was signed in 2001. The contract area of 75,000 km^2 is in Clarion-Clipperton Fracture Zone in Eastern Pacific.

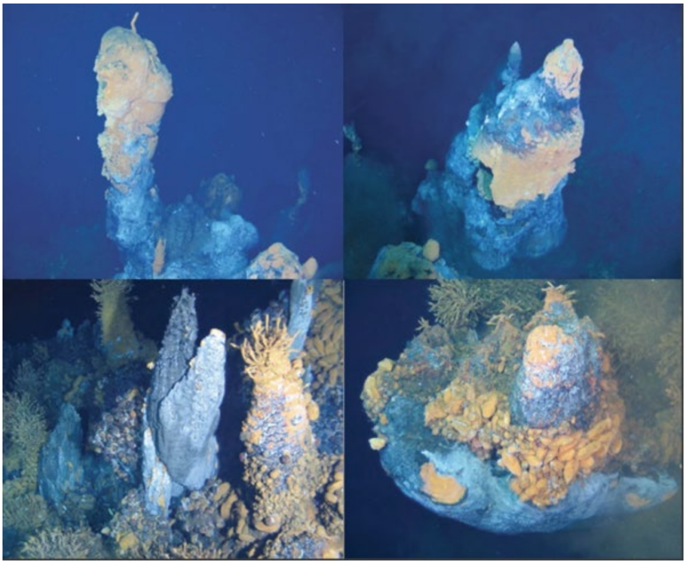

Fig.2 Polymetallic sulfides

COMRA has been conducting resources exploration and assessment, and environmental investigation in contract area in accordance with the contract. More than 530 vessel day surveys have been conducted in the polymetallic nodules area. About 5500 km^2 of Indicated Resource has been delineated. About 200 km^2 of Measured Resource has been delineated. The environmental baselines and their annual variability have been identified.

The second contract is for polymetallic sulfides (Fig.2) signed in 2011. The contract area of 10,000 km^2 is in South-Western Indian Ocean. More than 520 vessel day surveys have been conducted in the polymetallic sulfides area. The whole contract area has been mapped. One-third of the anomaly area has been deeply probed. About 10 clusters of sulfide resource area have been delineated as future prospect area.

Fig.3 Cobalt-rich Crusts

The third contract is for cobalt-rich crusts (Fig.3) signed in 2014. The contract area of 3,000 km^2 is in Western Pacific. More than 240 vessel day surveys have been conducted. The regularities of local crust distribution have been discovered. Favorable area for crust growth has been primarily delineated. The environment of CAIWEI seamount in the contract area in full water depth has been probed and some new important knowledge of currents and biological distribution data has been obtained.

Fig.4 R/V DAYANG YIHAO

The above mentioned contracts have all been signed between COMRA and ISA. China's fourth contract is also for polymetallic nodules, which is going to be signed between China Minmetals Corporation and ISA. The contract area of about

73,000 km^2 is from the ISA reserved area in Clarion-Clipperton Fracture Zone in Eastern Pacific. In recent years, about 4 to 5 R/V vessels go to the contract areas every year to perform the exploration work and to collect environment data. Namely the vessels are "DAYANG YIHAO"(Fig.4), "HAIYANG 6","XIANGYANGHONG 9", "HAIYANG 22".

We may also name some of the high-tech equipment used during the investigation in COMRA's contract area: JIAOLONG manned submersible, HAILONG ROV, QIANLONG AUV (Fig.5).

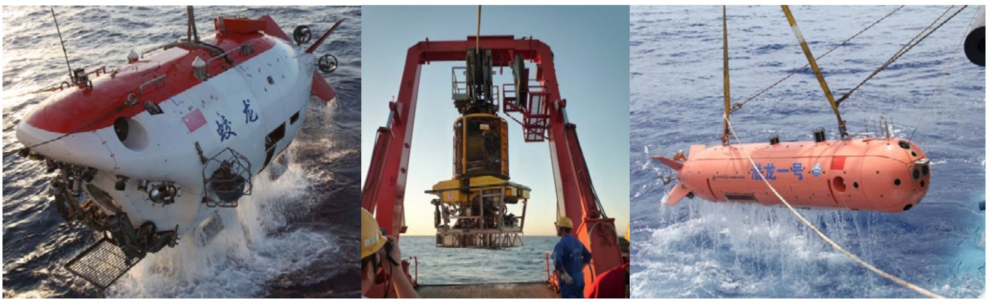

Fig.5 JIAOLONG Submersible HAILONG ROV QIANLONG AUV

3. Technology developments

In order to efficiently explore the contract areas, COMRA has been conducting several projects for the development of exploration technologies and equipment. All the above mentioned underwater vehicles were funded or organized by COMRA. Other exploration devices such as deep towed acoustic/video/camera system, deep water rock drill, TV grab, sediment multi-corer, sediment trapper were also self-developed by COMRA. These devices are playing an important role in resource evaluation and environmental assessment. COMRA also designed and manufactured a prototype of hydraulic mining system (Fig.6) and tested it in a lake of 135 m water depth in 2001. A slurry pump was developed and the lifting system was tested in an old mining shaft of 200 m.

Fig.6 Prototype Miner

Meanwhile, both pyro- and hydraulic-metallurgy processing technology were developed. The tonne/day scale tests for polymetallic nodules were conducted for both process flows. The metal recovery rate is as high as up to 85-95%. Pyro- and hydraulic-metallurgy processes for polymetallic sulfides and for cobalt-rich crusts are also under development.

Fig.7 China National Deep Sea Center

China has very big ore processing capacity. In 2014 the Tongling Nonferrous Metals Group Co., Ltd achieved the refined copper production output of of 4,720 tonnes and cathode copper output of 1,309,900 tonnes, where the Corporation holds an ore contract (from PNG EEZ of Polymetallic Sulfides) with Nautilus. The process for the ore has been proven workable. While the Jinchuan Group Co., Ltd has the ore processing capacity of 10 million tonnes/year with the nickel production of 150,000 ton, copper production of 400,000 ton, and cobalt production of 15,000 ton.

Fig.8 JIAOLONG Submersible

To facilitate the deep sea equipment's maintenance and operation, the China National Deep Sea Center (Fig.7) has been built in eastern China coastal city of Qingdao. JIAOLONG manned submersible is now operated by the center and more and more heavy equipment is coming to the center. The center owns a dock of about 670 m for research vessels, several machining workshops for equipment maintenance, and pressure tanks tested for 90MPa.

4. JIOALONG Manned Submersible

JIAOLONG manned submersible was developed and funded with 10 years long efforts by more than 100 participating domestic institutions, through a National Hi-Tech Plan (863plan). The submersible has a diving capacity of 7000 meters (Tab.1). In June, 2012, JIAOLONG made her deepest dive of 7062 m during the sea trials at Mariana Trench.

Items	**Parameters**	**Items**	**Parameters**
Operating depth	7000 meters	Nav. and positioning	Doppler, gyroscope, USBL,LBL
Dimensions	8.2×4.2×3.4 m	Maximum speed	2.5 knots
pressure hull	Φ2.1 m	Manipulator	2×7-dof manipulators
View ports	Main 1×Φ200mm Side 2×Φ120mm	Bathymetric side scan sonar	2×200 m with resolution of 10cm
Power supply	Sliver Zinc:110kWh	Camera	1 HD, 1standard
Accumulators	110V, 24V	Basket	Biological and geological boxes
Crews	1 pilot,2 researchers	Video	2 HD, 1 standard
Payload	220 kg	Weight in air	22 tons
Control modes	Automatic fixed height, fixed direction, fixed depth, hovering and manual operations	Communication	underwater acoustic data transmission and telephone, surface VHF and GPS
Life supporting time	12h(normal) 72h(emergency)		

Tab.1 JIAOLONG Main Specifications

After the successful sea trials, JIAOLONG arrived at a 4 years long “Test Application Phase” to further improve the submersible performance, to train the personnel for operation/maintenance, and to contribute to deep sea scientific studies and mineral resource investigation. Until now, 6 cruise trips and 100 dives have been made (Fig.9). The diving locations are distributed in South China Sea, Eastern Pacific, and South Indian Ocean in COMRA’s contract areas for various purposes.

5. Call for broad collaboration

Fig.9 Photos taken by JIAOLONG submersible

Deep sea is so vast and contains so many mysteries while deep sea expeditions are so costly. Neither a single scientist nor an institution, not even a single country could solely take on the whole challenge and bear the burden.

Sharing experiences in operation, manufacture, regulation and training of all related institutions and professionals around the world would be a solution.

6. Acknowledgement

Thanks to the organizing committee of West Pomerania Deep Sea Mining Conference 2016 for inviting us to attend the wonderful meeting to share information with friends old and new. Special acknowledgements go to Dr. Tomasz Abramowski,

Director General of IOM, who arranged many things for us, including our visas, that made our visit possible in such a short notice.

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DEEPSEA MINING ALLIANCE – INTERNATIONAL COOPERATION PROJECTS ON SUSTAINABLE DEEP-SEA MINING

Abstract. The association "DeepSea Mining Alliance" was established in April 2014. As a joint international industrial platform its main objective is to support the coordinated representation of interests regarding politics, industry and society. The presentation will focus on the following major items: Background and History of Deep-sea Mining in Germany, a short introduction on the DSMA and its recent and future activities, environmental aspects of Deep-Sea Mining, a brief overview of DSMA activities in Brussels as well as a short introduction regarding the recent "National Maritime Conference" of the German Government in cooperation with industry including the two MoUs signed in co-operation with the maritime sector between France and Germany.

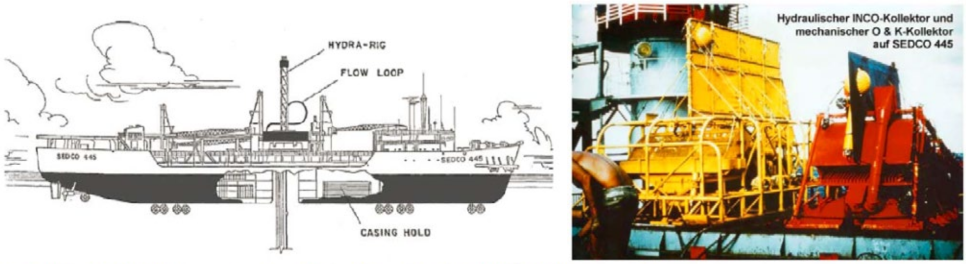
1. Background and History of Deep-sea Mining in Germany

The German industry looks back on a long history of activities regarding the exploration of marine mineral resources (MMR) and the development of technology for deep-sea mining. First industrial exploration activities in the Red Sea focused on sulfidic metalliferous sediments which were detected at the bottom of hot brine basins, took place since 1968. In a next step the AMR, a German consortium on the exploration of MMR and the development of Deep-Sea Mining technology, was founded in 1972. In the same year the first exploration cruise was carried out in the Pacific Ocean within the Clarion-Clipperton-Zone (CCZ), the target area where later on most of the parties interested in MMR focused their exploration activities.

The first feasibility study on mining of manganese nodules was finished in 1974 with promising results, followed by the foundation (1975) of a powerful consortium dedicated to prepare a pilot mining test (PMT) on the mining of Mn-nodules within the CCZ. The members of this consortium, named Ocean Management Incorporation

(OMI), were AMR (Germany), DOMCO (Japan, Sumitomo), INCO (Canada) and SEDCO (USA).

The first deep-sea mining test on Mn-nodules from the deep-sea in the CCZ was carried out by OMI in the spring of 1978 with the SEDCO 445, an oil drilling ship converted for the deep-sea mining test operations (Fig. 1). During this PMT the entire harvesting system with two different collectors (Fig. 1) and two different vertical conveyance approaches (Slurry pumps and Air Lift) were tested successfully. Consequently, at the end of this PMT about 800 wet tons of nodules were harvested.



The Drillship SEDCO 445 converted to a Mining Vessel for the PMT in 1978 | The two Test-Collectors on board of SEDCO 445

Fig. 1 The Drillship SEDCO 445 converted to a Mining Vessel for the PMT (left) and the two collectors tested during the PMT (right).

2. The DSMA in brief

The DeepSea Mining Alliance was founded as an association under German law in April 2014. Meanwhile the DSMA has 24 members – mainly from industry (Fig. 2). Four of them are international members (IOM, Poland; Keppel, Singapore; JS Capital Power, Switzerland; NTNU, Norway). The major goals of the DSMA are the formation of a core team for industry and research partners interested in MMR and/or in deep-sea mining technology. Further goals are the development of international cooperation projects on deep-sea mining, the coverage of the entire deep-sea mining value chain from a single source and the support of deep-sea mining innovations based on R&D and JIP. Last but not least, the close cooperation with leading research institutes with respect to all environmentally relevant aspects of deep-sea mining is also a major goal of the DSMA.

Fig. 2 Overview of the 24 members of the Deepsea Mining Alliance.

DSMA-members have the technological, economic and environmental expertise to cover the entire value chain of deep-sea mining. The professional competences range from deep-sea exploration for exploitation (drilling, seabed drill rigs, collectors) and processing, to ship management as well as technical and conceptual support from leading international classification societies.

Recent and future activities to foster exploration and mining of deep-sea minerals

Based on several decades of experience regarding the exploration of MMR and two successful pilot mining tests in the CCZ as well as in the central Red Sea, Germany gained a first exploration license in 2006 for Mn-nodules in the Pacific. In 2015 a second exploration license for Seafloor Massive Sulfides (SMS) in the Indian Ocean was obtained. Exploration in the German Mn-nodules license area is almost finished, so that the next step within the coming three to five years will be to carry out a PMT accompanied by a thorough environmental monitoring survey and a corresponding environmental impact assessment.

The exploration activities in Germany are carried out by the BGR (Federal Institute for Geosciences and Natural Resources). They were initiated and politically supported by the BMWi (Federal Ministry for Economic Affairs and Energy). In a next step the DSMA is fostering the industrial activities regarding the exploration and exploitation of MMR including all relevant environmental aspects. These actions are supported by the “National Masterplan for Maritime Technologies” of the German government. A major goal of the DSMA for the next few years is the preparation of a joint international Pilot Mining Test to prove the economic and environmental feasibility of deep-sea mining.

Based on this joint political and industrial approach the German Deep-Sea Mining Alliance and the German government signed a Memorandum of Understanding (MoU) with the French Maritime Cluster (CMF) and the French government during the recent “National Maritime Conference” in the autumn of 2015. These MoUs are intended to foster not only the French – German cooperation, but also the initiation of joint international industrial projects.

3. Environmental aspects of Deep-Sea Mining

According to the ISA as well as German national regulations the planning and technical preparation of a deep-sea mining test must include comprehensive environmental considerations. A detailed monitoring of the deep-sea environment before, during and after the pilot mining test is mandatory.

In this context it must be mentioned that only a thorough pilot mining test can provide information needed to study the impact of deep-sea mining and to make decisions on the feasibility of deep-sea mining.

The DSMA supports all activities with respect to the “Code for Environmental Management of Marine Mining” adopted in 2001 and revised in 2011 by the IMMS as well as the future ISA Mining Code.

To ensure the compliance with the boundary conditions regarding the deep-sea environment, the DSMA established an advisory board with special respect to environmental expertise including ocean research institutions and NGOs. Furthermore, the DSMA participated in several workshops of governmental institutions responsible for the protection of the marine environment, as well as in workshops of marine NGOs. Through presentations given by the members of the DSMA board and management, the DSMA position regarding the environmental monitoring to achieve an optimal approach for the protection of marine environment was introduced and discussed.

4. EU activities related to Deep-Sea Mining

In the past several calls related to mining and mineral resources with some of them also related more specifically to marine mining and marine mineral resources were launched by the European Commission. Ongoing activities or projects which were funded by FP7 and in which DSMA members are involved comprise Blue Mining

(MHWirth, BGR, GEOMAR, IMS, RWTH) and Midas (GEOMAR, BGR). In 2013 the European Innovation Partnership (EIP) launched a call for Raw Material Commitments (RMCs) where 80 Expressions of Commitment (EoCs) including some EoCs for deep-sea mining were approved. The EoCs related to deep-sea mining projects were Blue Atlantis (DSMA and several DSMA members), SeaFlores (Technip/France), Albatross (ERAMET/France) and one British EoC.

Furthermore, activities with respect to H2020 calls in 2015 lead to proposals like "Deep-Sea Mining 2.0" (DSMA, BAUER, MHWirth, DFKI, H&P), GEOTEX 5geOMODELS (e.g. BAUER) and iSeaMetals (e.g. IOM, RWTH).

The "Deep-Sea Mining 2.0" proposal submitted in spring 2014 under the coordination of DSMA focused on highly automated and industrially driven technological and economical solutions for an innovative European deep-sea mining concept (Fig 3). It was dedicated to the mining of SMS by minimizing the impact on marine environment. The proposal was submitted by 18 partners from 6 EU countries including 7 DSMA members with a strong industrial orientation.

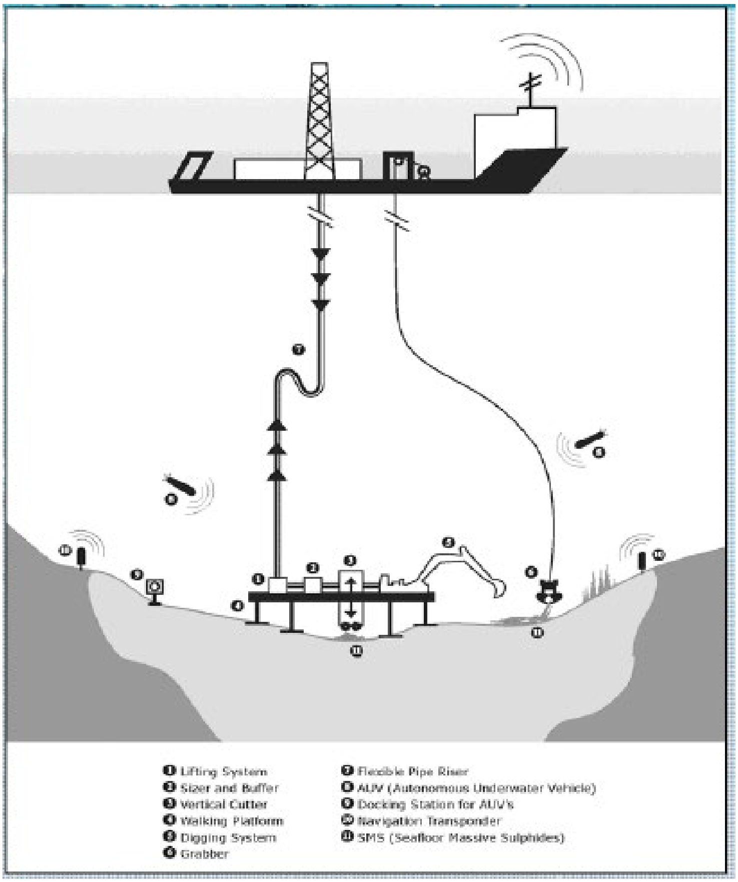


Fig. 3 A conceptual drawing of core elements of the "Deep-Sea Mining 2.0" proposal.

A joint French – German strategy paper named “OREBUS” was prepared and presented in 2014 to a number of selected EC directorates (DG MARE, DG ENTERPRISE; DG RESEARCH) (Fig. 4). Discussions on this strategy paper will be resumed in the near future.

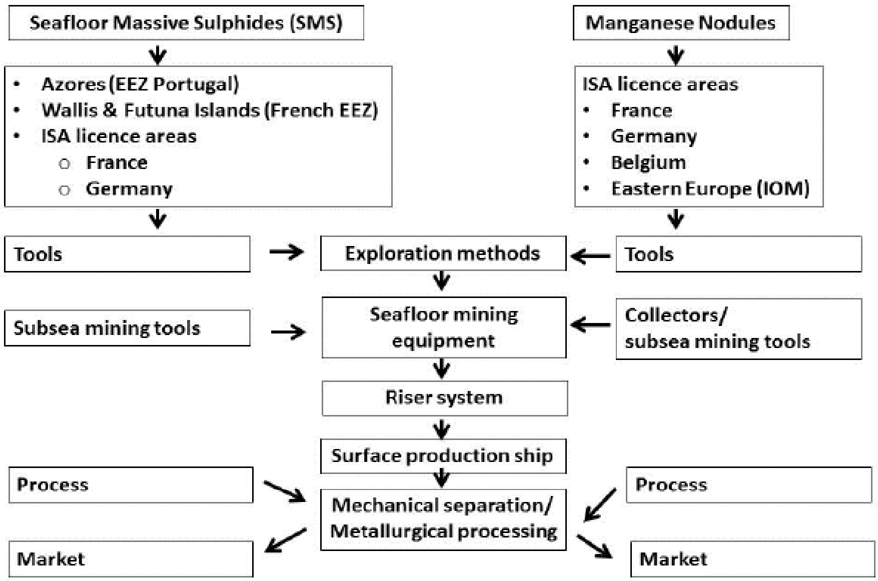


Fig. 4 French – German strategy paper named “OREBUS” prepared for future discussions with the EC.

Some further EU calls which were recently opened or will be launched in the near future and which could be interesting as far as proposals regarding marine mineral resources and marine mining are concerned, are listed below:

- The European Innovation Platform (EIP) has currently opened a second call for commitments, which were open from 1st of December 2015 to 1st of March 2016.
- Horizon2020 – new calls with potential themes for deep-sea mining (mainly in 2017),
  - SC5-14-2016-2017: Raw materials Innovation actions (8-13 M€)
    - 2017: Processing of lower grade and/or complex primary and/or secondary raw materials in the most sustainable ways,
    - 2017: Sustainable metallurgical processes.
  - SC2-BG-02-2016/2017: High value-added specialized vessel concepts enabling more efficient servicing of emerging coastal and offshore activities
    - 2017: Specialized vessels for offshore activities (TRL 5, 8 M€).
  - INNOSUP-01-2016-2017 (First stage: 6 April 2016, second stage: 8 September 2016)
    - Cluster facilitated projects for new industrial value chains (2.5 – 5 M€).
  - Horizon 2020 dedicated SME Instrument 2016-2017

- SMEinst-11-2016-2017: Boosting the potential of small businesses in the areas of climate action, environment, resource efficiency and raw materials (Phase 1: 0.05 M€, February, May, September and November 2016 and 2017; Phase 2: 0.5-2.5 M€, February, April, June and October 2016; January, April, June and October 2017)

5. Cooperation with France

Following two years of mutual preparatory discussions two Memorandums of Understanding (MoUs) were signed between the French Maritime Cluster and the Deep Sea Mining Alliance, as well as between the French and German Ministries of Economy, during the 9^{th} German National Maritime Conference on the 20th October 2015 in Bremerhaven.

The goals of the industrial cooperation between the French maritime cluster and the DSMA will be focused on deep-sea mining with the following mutual agreed objectives: Initiation of Joint Industry Projects (JIPs) as well as Joint RTD Projects, joint marketing activities, joint exploration cruises, environmental impact assessment studies, impact monitoring and remediation, development and qualification of innovative and sustainable deep-sea technologies and, last but not least, the initiation and preparation of deep-sea pilot mining tests.

6. Conclusions

Recent German activities in the exploration of marine mineral resources and in the development of deep-sea mining technology are looking back on extensive and long-lasting industrial experience which culminated in the successful deep-sea pilot mining test in 1978 with a recovery of more than 800 wet tons of nodules.

Basing on this background the DeepSea Mining Alliance was founded in 2014 with significant industrial input. Recent R&D activities are focused on innovative technologies for the whole value chain of deep-sea mining. Fostered by the “National Masterplan for Maritime Technologies” (NMMT) the exploration of marine mineral resources as well as the dawn of deep-sea mining enjoys governmental support in Germany. Considering the regulations for the German ISA license on Mn-nodules exploration, it is evident that a pilot mining test has to be carried out within the next four to five years. Furthermore, the “Federal Ministry for Economic Affairs and Energy” launched a “Study on the assessment of the economic and technical feasibility of deep-sea mining” in autumn 2015, which will provide answers on the technological and economic feasibility of deep-sea mining, as well as on the next steps to take.

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MULTIDISCIPLINARY EDUCATION FOR DEEP SEA MINING

Abstract. Preparation of human resources for the new discipline takes time. At the stage of establishing new professions, such as those in deep sea mining, it is hard to define a range of skills and knowledge that prospective employees in this sector should have. It is a good practice to build upon related professions and to prepare additional post-graduate studies and practical training for persons with such qualifications. The Maritime University of Szczecin (MUS) in collaboration with the University of Science and Technology- Cracow (AGH) has created the concept of future training for deep-sea miners utilizing the experience gained in the education of seafarers and miners.

1. Disciplines and professions

University education of young people calls for precise profiles of graduates. Facing the challenges is so tough that people working at the facilities located on the ocean will have to perform a number of jobs. Each of them will be affected by social issues related to specific work away from the shore. The expected difficulties of working at sea are associated with long stay away from the family, work in relatively small teams of people, the influence of hydrometeorological factors and work in multiethnic teams. Currently, the basis for sourcing specialists for the field of deep sea mining may include the following disciplines:

- Applied Ocean Science and Engineering
- Marine Geology and Geophysics
- Physical Oceanography
- Marine Geodesy
- Navigation, Operation of Vessels
- Marine Safety
- Mining
- Ocean Engineering

- Ship Technology
- Informatics.

This is not a finite list, however. Future development of deep sea mining may require specialists in other specific disciplines, depending on current needs of the adopted technological solutions, especially in the field of mining technology in use. In this situation, the question remains: Which professions are best prepared for work in the open sea? We can consider a number of current professions, but to be consistent it is advisable to refer to the aforementioned disciplines. A sample list of relevant ocean-related professions can be as follows:

- seafarer
- miner
- marine geologist
- marine engineer
- marine safety specialist
- oceanologist
- shipbuilder
- IT specialist
- other specialists.

Following this line of reasoning, today there are two ways of training deep sea mining industry professionals. One approach can be used for pilot projects, when the demand for specialists is relatively small. The other approach, when the extraction of deposits on a massive scale commences, will have to satisfy the demand for a large number of specialists. The Maritime University of Szczecin has developed a unique formula of pilot education of young people intending to work in the deep sea mining sector. This formula is based on the assumption that today seafarers are best prepared to work in the high seas. In addition, based on the training of seafarers it is assumed that young people have a wide range of qualifications, which permits them to work as officers on any type of ship, according to the requirements of Standards of Training, Certification and Watchkeeping for Seafarers Convention 1978 with amendments (STCW Convention). In this way, graduates do not have to bother about unemployment or unspecified delays of oceanfloor concretions production projects.

Fig.1. First year students at the inauguration of the academic year at the Maritime University of Szczecin.(source: MUS photo gallery)

2. The Maritime University of Szczecin. The Faculty of Navigation.

The Maritime University of Szczecin in Poland runs three faculties:

- Faculty of Navigation
- Faculty of Marine Engineering
- Faculty of Engineering and Economics of Transport.

The largest one, Faculty of Navigation, includes the following fields of study:

- Navigation,
- Transport,
- Geodesy and Cartography,
- Computer Science.

The Faculty of Navigation comprises a total of approximately 2000 students, with about 1500 studying for a degree in the field of Navigation. These students are trained to work as deck officers on board of any type of ship. The faculty graduates in the field of Navigation have good theoretical knowledge and satisfactory practical experience to undertake work as deck officers on board deep sea going vessels, in the wider maritime sector including research for off-shore and deep sea mining industries, or in navigation safety departments of maritime offices or relevant units of shipowning or operating companies.

The graduates of the Faculty of Navigation have:

- very good professional qualifications,
- up-to-date technical knowledge,
- good command of English,
- self-instruction skills,

- abilities to implement technical innovations and organise training,
- good physical shape and resistance to stress,
- teamwork ability,
- responsibility for executing assigned tasks.

Fig.2. Students of the field of Navigation. (source: MUS photo gallery)

The faculty employs about 100 academic teachers, including 22 professors, 27 doctors, 24 assistant teachers and 27 lecturers. Twenty one staffers hold Master Mariner certificates. The faculty's research covers the following areas:

- ocean route optimization, artificial intelligence,
- GPS and DGPS measurements in the open sea and restricted water areas,
- expert systems, vessel traffic optimization,
- artificial intelligence in decision processes,
- optimization and design of waterways,
- human, technical and maintenance factors.

The Faculty of Navigation runs five units:

- Institute of Marine Traffic Engineering,
- Institute of Marine Navigation,
- Institute of Marine Technology,
- Institute of Geomatics,
- Maritime Traffic Engineering Centre.

Fig.3. Training on the shiphandling simulator. (source: MUS photo gallery)

The Faculty uses a number of navigation-related training facilities, such as:

- Dynamic Positioning (DP) simulator,
- shiphandling simulator,
- ECDIS simulator,
- marine communications (GMDSS) simulator,
- Liquid Natural Gas (LNG) simulator,
- Potential Incident Simulation, Control and Evaluation System (PISCES).

The Faculty provides on-board training for students on the training-research vessel NAWIGATOR XXI, carrying specialized navigation, rescue and hydrographic equipment. The ship also has drilling equipment, capable of drilling wells in shallow waters. In addition, cadets have practical training organized by MUS in collaboration with many companies operating various types of sea-going ships and offshore rigs.

Fig.4. Training-research vessel NAWIGATOR XXI. (source: MUS photo gallery)

3. Field of study: Navigation

Currently, this field offers ten specialisation courses:

- Maritime Transport
- Deep Sea Fisheries
- Marine Traffic Engineering
- Marine Salvage and Rescue
- Hydrographic Survey and Aids to Navigation
- Marine Information Systems
- Maritime and Inland Water Transport
- Operation of Offshore Vessels
- Deep Sea Mining
- Sail Cruising.

All of the above specialisations meet the requirements of the STCW Convention, which means that each under/graduate can obtain a watch officer certificate to work on any type of vessel. Till 1997 only the first two specialisations were taught. Then gradually other specialisations were added, with properly expanded curriculum for each course. This is a new idea opening job opportunities for graduates of this field in different sectors of human activity at sea. Graduates of several specialisations, including Deep Sea Mining as the flagship specialization, launched jointly with the University of Science and Technology-Cracow (AGH), can find work in the emerging deep sea mining sector.

According to the concept of the Maritime University of Szczecin, the Deep Sea Mining curriculum is divided into the following course units:

- GENERAL SUBJECTS (requirements of the Ministry of Science and Higher Education)
  - English
  - German
  - Spanish
  - Physical Education
  - Introduction to Economics
  - Introduction to Maritime Sociology
  - Psychology of Human Behavior
  - Ergonomics
  - Health and Safety on Board Ship
  - Intellectual Property Protection
  - Information Technology
- FUNDAMENTAL SUBJECTS (requirements of the Ministry of Science and Higher Education)
  - Mathematics

- Physics
- Chemistry
- Computer Science
- Automation
- Electro technology and Electronics
- Machine Construction and Engineering Graphics

- FIELD-SPECIFIC SUBJECTS (requirements of the STCW Convention)
  - Navigation
  - Meteorology and Oceanography
  - Electronic Aids to Navigation
  - Geographic Information Systems
  - Transport Systems
  - Technical Fleet Operation
  - Ship Manoeuvring
  - Maritime Search and Rescue
  - Marine Communication
  - Safety of Navigation
  - Ship Construction and Stability
  - Marine Power Plants
  - Cargo Handling and Stowage
  - Ship Management
  - Ship Safety
  - Maritime Law
  - Marine Environment Protection
  - Port Infrastructure
  - Maritime Transport Security
  - Diploma Seminar
- SPECIALISATION SUBJECTS (requirements of the specialisation)

4. Specialisations suitable for deep sea mining

In line with the concept of education for the deep sea mining sector, graduates of the specialisations presented below are those that may find employment in this new sector of human activity at sea.

HYDROGRAPHIC SURVEY AND AIDS TO NAVIGATION (requirements of the specialisation)

SPECIALISATION SUBJECTS:

- Survey Systems and Equipment

- Land Survey
    - Sea Survey
    - Offshore Hydrographic Works
    - Aids to Navigation

The course, conducted since 1999, has been completed by 54 graduates.

MARINE SALVAGE AND RESCUE (requirements of the specialisation)
SPECIALISATION SUBJECTS:

- Maritime SAR
- Marine Environmental Damage Control and Assistance
- Water Recue
- Fire Fighting
- Hydromechanics and Hydraulic Engineering
- Technical Workshop

Since the year 2000, there have been 85 graduates.

Fig.5. Students of MARINE SALVAGE AND RESCUE during a practice session. (source: MUS photo gallery)

MARINE INFORMATION SYSTEMS (requirements of the specialisation)
SPECIALISATION SUBJECTS:

- Software Engineering
- Data Bases

- Marine Information Systems
- Network Operating Systems
- Fundamentals of Telecommunications

The course, run since 2006, has had 53 graduates so far.

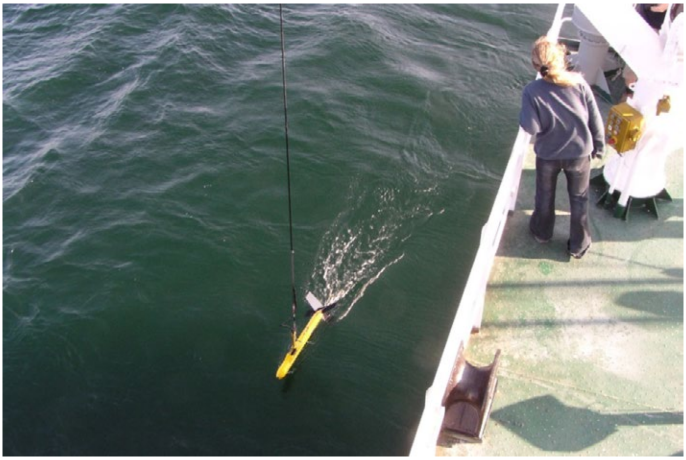

Fig.6. Students of HYDROGRAPHIC SURVEY AND AIDS TO NAVIGATION during a practical training session, using a side sonar. (source: MUS gallery)

OPERATION OF OFFSHORE VESSELS (requirements of the specialisation)
SPECIALISATION SUBJECTS:

- Offshore Engineering and Production
- Fundamentals of Hydrography and Geophysics
- Control and Dynamic Positioning Systems
- Health, Safety and Environmental Management Systems
- Offshore Subsea Operations

Conducted since 2010, to date the course has been completed by 68 graduates.

DEEP SEA MINING (requirements of the specialisation)
SPECIALISATION SUBJECTS:

- Subsea Exploitation
- Introduction to Geology and Marine Mineral Resources
- Well Drilling Methods
- Mining and Processing of Marine Mineral Resources
- HSE Management Systems and Technologies

The course was introduced in 2011 and up to now has been completed by 13 students, with 9 other persons awaiting final diploma exams. The launching of the deep sea mining course encountered two basic difficulties. One results from a great distance between Szczecin and Cracow, which makes teacher mobility troublesome. The other difficulty is the lack of ability to provide specialized student practical training at sea. Each of the above specialisations during four years of university time includes two semesters devoted to job-related practical training. Due to the lack of advanced projects in deep sea mining, students were directed for apprenticeship on the offshore and other types of vessels.

5. Conclusions

The presented innovative concept of seafarer training at the Maritime University of Szczecin broadens recruitment opportunities of young graduates including different sectors of human activity at sea. It does not restrict young graduates' choice of a future job at sea. It allows for employment in related sectors, in case their specialisation is temporarily not in demand. It is very important for young people because in spite of very interesting and innovative profession associated with deep sea mining, when project implementation is delayed, the graduates have options of seeking employment in another maritime sector.

Why has the Maritime University chosen to diversify seafarer training? First and foremost, for young people aged 19 choosing their future careers at sea it is vital to be competitive on the job market and avoid restrictions due to narrow scope of acquired knowledge and skills. Persons who decide to undertake work at sea are prepared for hard work away from their families, in specific weather conditions and working environment – small groups of people operating is a confined space. In addition, this approach satisfies expectations of the maritime sector, which requires well prepared specialists in sea transport as well as other new areas of business operations at sea.

The offer is dedicated to young people intending to study. The other way to provide professionals required for deep sea mining is postgraduate education, offering vocational courses for people initially trained to work at sea. This way is faster, but it is rather a short term path. In the long run, it will not succeed in preparing new type of professionals for the deep sea mining industry.

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LEGAL ASPECTS

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INITIAL CONSIDERATIONS FOR FISCAL AND TAXATION STRUCTURES IN THE DEEP SEA MINING UNDER UNCLOS REGULATIONS

Abstract. The article concentrates on several aspects of exploration and exploitation of natural resources of the seabed and ocean floor from the legal point of view. New possibilities of such activities are derived from the provisions of the UN Convention on the Law of the Sea of 1982 as there is time for negotiations on contracts concerning this issue. But there are several crucial questions: the nature of the Area as the common heritage of the mankind and fiscal and taxation structures in the deep sea mining, not solved in details by UNCLOS.

1. A new era?

Presumably nowadays we witness the beginning of a new era: the era of commercial exploitation of natural resources of the seabed and ocean floor[1]. This era brings major challenges. The catalogue of potential benefits brings access to (new) resources as well as the use of new techniques and technologies. In the situation of depletion of the natural resources and difficulties encountered in their raising, it is vitally important for the world economy to gain access to natural resources so far inaccessible.

1. Origins of the operation can be traced back to (March 13, 1874) the research vessel HMS *Challenger* which sampled manganese nodules from the ocean floor. Analyses have shown the presence of nickel, copper and cobalt in the Pacific deposits. Rich and documented resources are found, inter alia, in the area of the Clarion Clipperton Zone.

No political myths on "war for oil" [2] prove the actual significance of natural resources[3] for the economy (mankind), but disputes about and demand for them e.g. the Rare Earth Elements (REE)[4]. The exploration of the seabed and ocean floor will also make a cornerstone for science development and – as experiences prove – the transition of techniques and technology of their original area to other application areas. The analogy with space conquest allows to extrapolate social and economic results of transferring tools used for the exploration of the seabed and ocean floor and original use to other areas of human activities. The forecast allows for the assumption that important derived benefits should exist (regardless of the acquired resources value) in not-original applications. It means that entities acquiring the resources will gain multiple benefits. It shall also contribute to broadening discrepancies between those having and making use of new technologies and those deprived of access to them (or their followers). The rich will benefit the exploration of the resources – nothing new – however, what shall significantly differentiate the phenomenon from the past is that the beneficiaries shall not have to share the benefits with the population of the areas where the resources are explored, and not even conquer them. Potential redistribution – limitation of the growing division between the rich and the poor – can be implemented solely by the use of international instruments, within the frame and by institutionalization of international relations.

When shall it commence? The initiation of a new era will be decided by money. If the commercial exploitation of natural resources of the seabed and ocean floor is economically feasible, so the parties involved in it will find financial resources for its conduct. The decision will be the result of cost-benefit analysis. Technological barriers will be overcome, opening the way to financial resources.

2. They root from the pioneer of science/political fiction book *War with the Nawts* by Karel Čapek.
3. 3 About 95% of the world extraction comes from China, which restricts their export in processed form. These restrictions resulted in USA- China disputes (with the EU participation as the third party) on the WTO forum. WTO panel (August 29, 2014) decided that, 'the overall effect of the foreign and domestic restrictions is to encourage domestic extraction and secure preferential use of those materials by Chinese manufacturers (https://www.wto.org/english/tratop_e/dispu_e/cases_e/ds431_e.htm)' and China committed itself to respect the decision. ('"„At the DSB meeting on 20 May 2015, China informed the DSB that, according to notices by the Ministry of Commerce and the General Administration of Customs of China, the application of export duties and export quotas to rare earths, tungsten and molybdenum as well as restriction on trading rights of enterprises exporting rare earths and molybdenum which were found to be inconsistent with WTO rules, had been removed. In that regard, China had fully implemented the DSB's recommendations and rulings. However, the United States could not share China's assessment that it had fully complied with the DSB's recommendations and rulings. On 21 May 2015, China and the United States informed the DSB of Agreed Procedures under Articles 21 and 22 of the DSU.").
4. Demand already exceeding the supply potential; see J. Całus, Moszko, B. Białecka, *Potencjał i Zasoby Metali Ziem Rzadkich w Świecie* and in Polish: Artykuł przeglądowy. Prace naukowe GIG. Górnictwo i środowisko 2012, no 4, pp. 61-72.

Opportunities. The commercial nature of the business facilitates partners finding. Partners are defined by factors affecting their choice: political criteria seem less important, while the real value of a partner contribution gains importance.

Threats. Commercial nature of the undertaking subordinates financial decision to economic calculation which significantly hinders fundraising. The experience (e.g. space conquest) proves that *raison d'état* driven state actions are more successful in overcoming financial barriers. It is easier to raise public rather than private funding. Public funds spending- although more transparent – is less monitored as to its economic rationality than the spending of private funds. Other factors affect the assessment of public funds spending than those that apply to the private ones. What should be remembered is that the activities carried out on the seabed and ocean floor are directly related to the states' security (specifically the military security). Thus, despite funding for the undertaking coming (mostly) from private sources it will be a subject – in many areas – to legal (as well as political) requirements of national security. It is, after all, the military sector that has technology and experience in activities at the seabed and ocean floor. It is the navies which have the equipment to carry out such operations. The states- in any case – shall not just waive benefits for their national security that may be brought by seabed and ocean floor activities. However, current developments involving significant instability of market prices and resources consumption (e.g. oil or copper) and raising of the standards and norms of environment protection do not facilitate long term engagement (among others financial) in activities related to acquisition and industrial exploitation of the seabed and ocean floor resources. Although it is difficult to directly transfer states and situations of one area into another one, the decision makers involved in engaging in seabed and ocean floor exploitation should not forget the experience of e.g. Vattenfall operator who was affected by law changes resulting from fears of potential threats to the environment. The ratcheting up of environmental requirements regarding coal-powered stations and the abandonment of atomic energy forced Vattenfall to abandon its Hamburg-Moorburg power station as well as the construction of an atomic power plant. That may lead to proving projects' financing impossible within the regime of market economy.

2. United Nations Convention on the Law of the Sea (UNCLOS) – why?

Roots. From the seventeenth century, the oceans and seas have been subject to the legal regime of 'freedom of the seas'. Law of the sea stipulated law and national jurisdiction limitations. Such regulations sufficed for navigation needs. Neither fishery nor the protection of seas and oceans required universal regulations. However, they proved to be inadequate to face the new challenges that emerged after the World

War II. The challenges included, among others, an increase in fishing and the demand for fish, the prospects of acquiring natural resources of the seas and oceans, pollution of the marine environment and changes in the activity of sea powers. The Geneva Conventions on the Law of the Sea of 1958 were also deemed inadequate. 'Happy years' (of the 'freedom of the seas' doctrine) were ended by the extension by the US President Harry S. Truman of the US territorial jurisdiction onto the continental shelf. On November 1, 1976 Malta's Ambassador Pardo at the UN General Assembly called for creating a new 'international regime over the seabed and the ocean floor'. In 1973 the codification conference began and after December 10, 1982 the UN Convention on Law of the Sea (UNCLOS) was opened for signing[5]. It became binding in 1994 (Guyana as the 60th state acceded to it). UNCLOS was to execute two interdependent goals: to change the law of the sea in order to adequately respond to current challenges of e.g. the protection and preservation of natural environment and the budding of high sea nuclear powered ships, to co-create the world order. UNCLOS was to be the element of international economic and political relations restructuring in accordance with the ideas of Group 77 member states.

Exploitation rules. Extractor entities exploiting the seabed and ocean floor resources are obliged to be driven by a 'principle of precautionary action'. Such a conduct is to protect the environment against damage. The immediate exploitation of resources as well as their transport, storage and the processing of wastes are among the sources of the threat.

The Objective. The United Nations Convention on the Law of the Sea is a single treaty which combines demands, ideas and values of the United Nations Conference on the Human Environment (Stockholm, 1972) with the New International Economic Order (NIEO). This comprehensive agreement package was to change not only the law of the sea, but – more broadly – the international relations[6]. After the General Assembly

5. See also: J. Symonides, *Konwencja Narodów Zjednoczonych o prawie morza z perspektywy ćwierćwiecza*, (in:) *Konwencja NZ o prawie morza z 1982 r. W piętnastą rocznicę wejścia w życie*, C. Mik, K. Marciniak (eds.), Toruń 2009, pp.16-20.

6. Preamble „…Bearing in mind that the achievement of these goals will contribute to the realization of a just and equitable international economic order which takes into account the interests and needs of mankind as a whole and, in particular, the special interests and needs of developing countries, whether coastal or land-locked,

Desiring by this Convention to develop the principles embodied in resolution 2749 (XXV) of 17 December 1970 in which the General Assembly of the United Nations solemnly declared inter alia that the area of the seabed and ocean floor and the subsoil thereof, beyond the limits of national jurisdiction, as well as its resources, are the common heritage of mankind, the exploration and exploitation of which shall be carried out for the benefit of mankind as a whole, irrespective of the geographical location of States,

Believing that the codification and progressive development of the law of the sea achieved in this Convention will contribute to the strengthening of peace, security, cooperation and friendly relations among all nations in conformity with the principles of justice and equal rights and will promote the

Declaration (in 1970)[7] that the seabed and ocean floor resources are a 'common heritage of mankind', the Convention was deemed to create a regime of retributive justice. Contrary to the expectations and hopes of the NIEO proponents, the Convention is the first and the only contract based on the NIEO paradigm (the GA Resolution 1514 (XV) and other relevant GA resolutions). The combination of those two objectives brings up the UNCLOS 'Janus face'. On one hand the Convention may be a financial impulse fostering the development in poor states. Financial resources obtained from the exploitation of the seabed and ocean floor are independent from states' own (internally located) natural resources, the development aids from rich countries, or proceeds from foreign investments influx. By means of origin (exploitation fees are quasi-tax for the international community) and the institutionalized formula of collection and distribution, the implementation may become the impulse and catalyst for the transformation of international society into the international community. The community is characterised by social cohesion achieved by secondary redistribution of the incomes and the redistribution- for implementing compensatory justice. The international community would also be institutionalized, using institutions for the implementation of standards creating compensatory justice. On the other hand, the exploitation of natural resources on the seabed and ocean floor opens the Pandora box of known and unknown threats to the environment (as regards the nature, scale and means of their neutralization). This is the earlier mentioned UNCLOS 'Janus face'; meeting one of the Convention objectives (social cohesion or environment protection) may adversely impact or even prevent the implementation of other objectives (social cohesion or environment protection). Perhaps the conflict in question confronts the international community with a devilish alternative of social cohesion (elimination of development gap regarding the poor) or environment protection.

3. Seabed and ocean floor and subsoil

Common heritage of mankind (CHM). The Convention has conferred a special status upon the seabed and ocean floor and their subsoil beyond the limits of national jurisdiction, defining them collectively as the 'Area' (Article 1). It recognizes the area and its resources[8] as the "common heritage of mankind[9]". This is a crucial issue for the concept of the exploration and exploitation of the seabed and ocean floor.

economic and social advancement of all peoples of the world, in accordance with the Purposes and Principles of the United Nations as set forth in the Charter, …"

7. UN GA Resolution 2749 (XXV) of 17 December 1970.
8. Part XI, Article 133 „(a) "resources" means all solid, liquid or gaseous mineral resources in situ in the Area at or beneath the seabed, including polymetallic nodules;"
9. Article 136 „The Area and its resources are the common heritage of mankind." Article 137.2 „All rights in the resources of the Area are vested in mankind as a whole, on whose behalf the Authority

The International Seabed Authority (the Authority) is the only entity authorized in relation to the Area and its resources indicated 'mankind', excluding both the right of states (and other entities) to lodge claims or exercise sovereignty in relation to the Area and its resources (Article 137. 1 and 3, UNCLOS). As refers– within the analysis range – to the scope of the CHM covered by the 'Area', it is that 'mankind' benefits from conducting activities in the 'Area'[10]. The benefits are not only financial assets and other economic gains derived from activities in the Area, but also the right to knowledge and technology (Article 144). Of the *de facto* complimentary nature are environmental standards (protection of the marine environment, Article 145), freedom of scientific research (Article 143) and prohibiting the use of seabed and ocean floor for military purposes (Article 140). The instrument for the protection of the marine environment is the tort liability indicated by the Convention. Political impulse for granting CHM status to seabed and ocean floor was initiated by the US President Lyndon B. Johnson[11] on June 16, 1966 while Oscar Schachter[12] defined its legal foundation. The very idea of treating some resources as *res communis* or *res usus publicum* (Grotius's terminology) wasn't a new one[13]. However, in the late 1970s it gained momentum (for implementation) on the UN forum and – in the course of the ongoing work- was incorporated into regulations on seas, oceans as well as the outer space. UNCLOS articles 133-150 and 311(6)[14] (CHM status) cover peaceful use of the area, future generations' rights protection, the application of exploitation benefits for common goals of the international community prioritising developing countries' needs, all states' participation in area management executed for all mankind benefit, all states participation in seabed and ocean floor activities, freedom of scientific

shall act. These resources are not subject to alienation. The minerals recovered from the Area, however, may only be alienated in accordance with this Part and the rules, regulations and procedures of the Authority."

10. Article 140 „Benefit of mankind. 1. Activities in the Area shall, as specifically provided for in this Part, be carried out for the benefit of mankind as a whole, irrespective of the geographical location of States, whether coastal or land-locked, and taking into particular consideration the interests and needs of developing States and of peoples who have not attained full independence or other self-governing status recognized by the United Nations in accordance with General Assembly resolution 1514 (XV) and other relevant General Assembly resolutions. 2. The Authority shall provide for the equitable sharing of financial and other economic benefits derived from activities in the Area through any appropriate mechanism, on a non-discriminatory basis, in accordance with article 160, paragraph 2(f)(i)."
11. *Remarks at the Commissioning of the Research Ship.* Oceanographer, July 13, 1966. Additionally the President of the United States Ronald Reagan pointed out that the regime of CHM of the seabed and ocean floor is one of the reasons the United States did not ratify UNCLOS (Art. 136, UNCLOS).
12. O. Schachter, A Preview of Space Law Problems. Legal Problems of Space Exploitation. US Senate, Washington 1961.
13. J. Menkes, Kształtowanie prawa międzynarodowego zasobów wodnych. Warszawa 2000, pp.133-148.
14. Confirmed by the UN General Assembly Resolution (GA Res. 2749 (XXV) 1970.

research. The regulations exclude the possibility of establishing any status of owner/ownership (granting the seabed and ocean floor property rights). Rights granting (therefore the imposition of obligations) to the virtual entity of the international community involves the practical threats derivative of the concept ‘everybody’s property is nobody’s property’.

CHM authorised entity. The eligible entity is of collective nature – the mankind. The entity consists of current and future generations. The environment in generational relations provides a deposit burdened with the obligation to preserve it in the condition allowing the successors to draw benefits (in accordance with the *equity* principle).

Utopia is alive. Financial and economic benefits and transferred technologies are to change the economic situation in the world and eliminate global injustice by giving developing countries and nations (who have not gained independence or autonomy) both “fish” and “fishing rods”. It was concluded that the eradication of underdevelopment is possible as a result of direct transfers.

At the same time fundraising was excluded from the market laws. Minerals obtained from the Area, along with those from outside the Area, were to be covered by common, uniform cartel regulations. Prices for minerals were to be just and stable (Article 150). Fair prices were to reconcile profitability for manufacturers with fairness for consumers. Price stability was to exclude them from the impact of supply and demand fluctuations (which is mostly possible through the use of buffer stocks). The Convention set up the ‘Area’ and its activities managing authority which is at the same time the organization dealing with raw materials, in the form of the International Seabed Authority (Articles 157 and 160, UNCLOS).

4. Justice (Economic)

Justice – the meaning. In international (specifically in economic) relations justice is perceived as the status (objective) to achieve and maintain and the standard of conduct for states and integration organizations. So justice links the normative system of international law with the system of normative morality legitimizing conduct of legal entities.

Justice (considered to be a principle) is understood in the UNCLOS to be a desired value to achieve and maintain in international relations (primarily economic ones). Implementation of the Convention-regulated justice shall result in achieving the ‘compensatory justice’. Such an understanding of justice is not common in law, mostly because ‘justice’ means granting rights under the title or an appropriate legal standard[15]. The League of Nations Pact (Article 23e) already provided for the elimination of inequalities resulting from 'justice' application.

In the case of UNCLOS justice the compensatory force acting in relations between developed and developing countries is to the benefit of developing countries. Relations between developing countries are to be a subject of distributive justice standards.

Generally the term 'justice' used within the framework of UNCLOS depicts equality and reciprocity of treatment between member states benefiting from preferential treatment status (a developing country) as a result of international solidarity.

The specificity of UNCLOS - in relation to other international texts of NIEO - is that justice does not coexist with 'equity', which makes it difficult to understand the principles of justice.

Stabilization of prices. The authors of the Convention assumed the stability of commodity prices as a result of a (non-economic) compromise between the interests of producers and consumers. However, it is not clear whether the real purpose of the regulation is a stability in raw material prices or in producers' incomes. It is also unclear whether the International Seabed Authority is to act as a cartel (OPEC) or as a commodity agreement.

Redistribution. UNCLOS assumption that the exploitation of the seabed and ocean floor resources is to finance the implementation of compensatory justice was not accompanied by the development of a system of resources collection and allocation. Defining the resources usufruct fees as a quasi-tax evokes the need to establish a redistribution regime. Such a regime requires *inter alia* the allocation norms and the bodies which would implement the adopted objectives.

5. Exercise of Rights to the Resources in the Area

Bearing in mind that the Area is a common heritage of mankind the key question arises: who can actually extract these resources and, given the scope of such operation, how to finance such an undertaking?

As a general principle, all rights in the resources are exercised in the name of mankind by the Authority. In practical terms the activities related to marine minerals can be undertaken by:

1. The Enterprise that is the organ of the Authority (Art. 170, UNCLOS);

15. „Justice. 1. The fair and proper administration of law. *commutative justice*. Justice concerned with the relations between persons and especially with fairness in the exchange of goods and the fulfilment of contractual obligations. *distributive justice*. Justice owed by a community to its members, including the fair allocation of common advantages and sharing of common burdens. *Black's Law Dictionary*, B. A. Garner (ed.), Thomson West 2004, p. 881.

2. State-parties to UNCLOS;
3. Enterprises or natural or juridical persons sponsored by States, which means that the sponsoring State (or group of States) ensures that the contractor will carry out its activities in the Area in conformity with the terms of its contract and its obligations under this Convention (Art. 4.4, UNCLOS Annex III). The sponsoring State is not, however, financially responsible for damages caused due to a breach of domestic legislation, assuming the domestic law could have been reasonably expected to implement UNCLOS. Such contractors are granted the so-called certificates of sponsorship (Art. 11 of the three Mining Codes mentioned below);
4. any combination (group of) actors mentioned in items 2 – 3 above (Art. 153.2, UNCLOS).

The Authority regulates the prospecting, exploration and exploitation of marine minerals in the Mining Codes[16], including specific regulation relating to polymetallic nodules[17], polymetallic sulphides[18] and cobalt-rich ferromanganese crusts[19]. The codes both lay the conditions for exploration of the resources and contain standards contract terms.

Accordingly, the Authority grants the right to search for deposits of marine minerals without exclusive rights (prospecting) or with exclusive rights (exploration) as well as the right to the recovery of the minerals (exploitation) for commercial purposes, for which it levies a fixed overhead charge used to cover the operational expenses of the organisation[20].

All these sectoral-fragmented regulations are expected to be codified in a single general act. In March 2015 the Authority issued a *Draft Framework for the Regulations of Exploitation Activities.* In accordance with the *Draft Framework and Action Plan* of the IAS Legal and Technical Commission, by July 2016 a draft of the regulations for exploitation, including standard contract terms should be presented to the ISA Council[21].

16. ISA, *The Mining Code,* http://bit.ly/1SqRZQA (access 4.02.2016).
17. Decision of the Council of the International Seabed Authority relating to amendments to the Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area and related matters, ISBA/19/C/17.
18. Decision of the Assembly of the International Seabed Authority relating to the regulations on prospecting and exploration for polymetallic sulphides in the Area, ISBA/16/A/12/Rev.1.
19. Decision of the Assembly of the International Seabed Authority relating to the Regulations on Prospecting and Exploration for Cobalt-rich Ferromanganese Crusts in the Area, ISBA/18/A/11.
20. Decision of the Assembly of the International Seabed Authority concerning overhead charges for the administration and supervision of exploration contracts, ISBA/19/A/12.
21. ISA, *Ongoing Development of Regulations on Exploitation of Mineral Resources in the Area,* http://bit.ly/22CJC92 (access 1.01.2016).

6. Marine Minerals Licences

A licence for **prospecting** covers the estimation of the composition, size and distribution of mineral deposits and their economic value. Prospecting should be realised in accordance with the precautionary principle, as stipulated under principle 15 of the Rio Declaration on Environment and Development. In particular, the Council may prohibit prospecting in a particular area due to the risk of serious harm to the marine environment.

Although the beneficiary of the prospecting licences does not acquire any exclusive economic rights over the marine resources, one may "recover a reasonable quantity of minerals, being the quantity necessary for testing and not for commercial use." The right is not exclusive which means that numerous actors may be granted permission to conduct prospecting in the same areas.

Further specific provisions apply to issues such as notification of the prospecting to the Secretary-General of the Authority, the consideration of such notifications by the organization, the environmental protection, the reporting duties, as well as the treatment of archaeological or historical objects. As a general principle the Secretary-General reviews the notification within 45 days from its receipt, which includes an obligation to notify the proposed prospector, whether the notification includes any part of an area covered under an approved plan of work for exploration or exploitation of any category of resources, or any part of a reserved area, or any part of an area which has been excluded by the Council from exploitation because of the risk of serious harm to the marine environment, or in case the written undertaking is not satisfactory, and shall provide the proposed prospector with a written statement of reasons. In such a case the proposed prospector has an additional period to amend the notification. The Secretary-General periodically informs all the members of the Authority about the identity of prospectors and the general areas of their prospecting.

Prospectors submit an annual report on the status of prospecting, which covers *inter alia the* compliance with Authority rules and regulations in respect of training programs in the field of marine scientific research and transfer of technology, as well as protection and preservation of the marine environment (see among others Art. 2, UNCLOS Annex III).

A permission for **exploration** covers the right of searching for mineral deposits, the analysis thereof, the use and testing of recovery systems and equipment as well as processing facilities and transportation systems, and the execution of studies of the environmental, technical, economic, commercial and other appropriate factors which must be taken into account in exploitation.

Similarly, to prospecting, a right to exploration is granted upon an application submitted to the Secretary-General. In case of a state enterprises and other non-state actors the application shall be accompanied by a certificate of sponsorship issued by the State concerned. An applicant must clearly present his/her financial and technical capacity to realise the project.

After the approval of the plan of work is granted by the **Council** (as opposed to applications for prospecting, examined by the Secretary-General), it is prepared in the form of a contract between the Authority and the applicant as prescribed in Annexes to Mining Codes.

A plan of work for exploration can be approved for a period not exceeding 15 years. Subsequently, the contractor shall apply for a plan of work for exploitation. Such a contractor obtains a preference and a priority among the applicants submitting their plans of work for exploitation of the area and the resources covered under the exploration plan.

Finally, the term **exploitation** means the extraction of mineral resources, including the construction and operation of mining, processing and transportation systems, for the purposes of production and marketing.

Rights to exploration and exploitation are granted to operators within the boundaries of a designated area, in accordance with the approved plan of work, and under supervision of the Authority. A licence is granted in respect of specific categories of resources (i.e. not simply all the minerals in the area) and in respect of particular stages of exploration/exploitation, as indicated in the application (Art. 4, UNCLOS Annex III). The Authority ensures that there is no conflict as a result of different entities operating in the same area (in scope of different resources).

7. Transfer of Technologies

One particular aspect of exploration and exploitation licensing that must be taken into account for the purposes of financial analysis of the project is the compulsory transfer of technologies.

Accordingly, not only the licence is restricted to specific minerals, a specific area and specific stages of the process, but each contractor undertakes to make available to the Enterprise on fair and reasonable commercial terms and conditions, whenever the Authority so requests, the technology which he uses in carrying out the activities in the Area under the contract, which the contractor is legally entitled to transfer (Art. 5, UNCLOS Annex III). What's more, the operator is obliged to ensure that such technologies can be transferred upon the Enterprise, even if he is not the owner of the technology in question, in which case he must undertake an appropriate contractual arrangement with the owner.

The right to technology transfer can be exercised by the Authority until 10 years after the commencement of commercial production by the Enterprise.

8. Mining Related Contracts, Financial Terms

In accordance with the general rules on the acquiring of marine minerals, a contractor willing to engage in such an activity will thus conclude:

- a sponsorship agreement with the sponsoring State, governed by the domestic law of the State(s) concerned,
- financing agreements for the project, most likely under English law,
- insurance for the project,
- operation agreements, contracts etc. under relevant domestic or English contract law.

All such arrangements are also subject to the rules, regulations and procedures of the Authority and other rules of international law not incompatible with this Convention (Art. 21, UNCLOS Annex III).

Exploitation contracts shall regulate at least: rights of the contractor, obligations of the Authority, legal title to minerals, duration of contracts/renewal, performance requirements, conservation of the natural resources of the Area, use of sub-contractors, vessels operating in the Area, protection of submarine cables and pipelines, health and safety.

From the financial perspective the terms of cooperation with the contractor shall:

- ensure “optimum revenues” for the Authority;
- attract investments and technology to the exploration and exploitation of the Area;
- ensure equality of financial treatment and comparable financial obligations for contractors;
- provide incentives on a uniform and non-discriminatory basis for contractors to undertake joint arrangements with the Enterprise and developing States or their nationals, to promote the transfer of technology, and to train the personnel of the Authority and of developing States;
- enable the Enterprise to engage in seabed mining effectively;
- ensure that contractors are not subsidized so as to be given an artificial competitive advantage with respect to land-based miners (Art. 13, UNCLOS Annex III).

As mentioned above, notwithstanding specific financial provisions in singular contracts, the Authority levies an overhead charge on all contractors. Although fees are subject to periodic review, the original threshold is very telling in terms of financial scale of such enterprise.

A fee for a processing operator application was set at $US 500,000 per application (or its equivalent in a freely convertible currency) paid at the time of application[22],

22. If the administrative costs incurred by the Authority are below the fee paid, organization reimburses the difference. Would the administrative costs be higher than the $US 500,000, the applicant will be

and all the contractors were obliged to pay an annual fee to the Authority of 1 million $ US (Art. 13.1 and 3, UNCLOS Annex III). Within one year from the commencement of commercial production a contractor chooses, whether to pay a production charge only (as a percentage of market value of metals produced), or a combination of a production charge and a share of the so-called attributable net proceeds (Art. 13.5 and 6, UNCLOS Annex III). Specific regulations apply to the estimation of costs and revenues of minerals related activities.

To the above listed Convention charges an operator must also add a charge for processing its annual reports, currently set at $US 47,000 (Decision ISBA/19/A/12, Annex, par. 10(5)).

In order to prove financial and technical capacity of engaging in exploration and/or exploitation activities, the applicants are obliged to present a plan of work including audited financial statements, including balance sheets and profit-and-loss statements, for the most recent three years, in conformity with internationally accepted accounting principles. Furthermore, a contractor is obliged to submit a statement about their undertaking of specific methods used.

9. Taxes

As far as taxes are concerned, one should stress that neither the Convention on the Law of the Sea as such, nor the Annex III regulate the problem. Several proposals have appeared, prepared mostly by the Authority. In its Technical Study no. 11[23] it is pointed out that the ISA approach to a fiscal regime for seabed mining is set out in Section 8 (titled *Financial Terms of Contracts*) of the Implementing Agreement[24]. Thus according to this Section the establishing of rules, regulations and procedures for financial terms of contracts shall be based on several main principles:

- fair system of payments to the contractor and to the Authority,
- rates of payments similar to that assigned to the land-based mining of the same or similar minerals in order to avoid giving deep seabed miners an artificial competitive advantage or imposing a competitive disadvantage on them,
- non-complicated system to avoid higher administrative costs,
- possible adoption of a royalty system or a combination of royalty and profit-sharing system,

requested to cover to the difference up to the threshold of 10% of the base-fee (Art. 13.2, UNCLOS Annex III).

23. *Towards the Development of a Regulatory Framework for Polymetallic Nodule Exploitation in the Area. ISA Technical Study: No. 11.* A report to the International Seabed Authority prepared by A.L. Clark, J. Cook Clark, S. Pintz, Jamaica, 23 February 2013.

24. United Nations Convention on the Law of the Sea. Agreement Relating to the Implementation of Part XI of the Convention of 1994.

- an annual fixed fee payed on the date of commencement of commercial production,
- periodic revision of the system of payments.

The document mentioned above analyses in detail the various solutions for fiscal regulations and although all of them may be criticised, the "ideas on which the scheme is based must be transparent, understandable, and built upon some sort of theoretical concept. It would also be very useful if the proposed regime could present supporting empirical evidence about potential impacts"[25].

It is emphasized that there are three issues which seem to be the most problematic: the first, the setting of fiscal rates based on comparable land-based minerals; the second, the problem of identifying a tax and cost accounting code on which fiscal calculation can be made and the third, the concept that a simple system can be developed that does not burden the Authority or mining investors. Additionally, the special status of the Area as a common heritage of the mankind creates its own problem for mining policy concerning the inevitable environmental damage and "a sort of fiduciary responsibility to ISA [the Authority] stakeholders, particularly people in poor nations who may receive some financial benefits from future mining of the seabed"[26]. That is why both environmental destruction and division of rents should be accommodated in the eventual fiscal package.

10. Final Remarks

The fact that seabed mining will not be a public enterprise directly raises questions about how to appropriately divide both profit and risk. This, in turn, raises difficult resource rent questions about capturing windfall profits and rents in the name of social justice[27].

The issues concerned are complicated and shall be subjects of negotiations and discussions with participation by the Authority, states, possible contractors and specialists. There is absolutely a need to establish a system based on economic principles and publicly perceived as fair and equitable sharing of the benefits from seabed minerals extraction.

25. Ibidem, p. 47.
26. Ibidem, p. 53.
27. Ibidem.

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REGULATORY ASPECTS OF DEEP SEA MINING

Abstract. The article will focus on the regulatory aspects of deep sea mining from the perspective of potential mining regulation as well as the environmental regulation which may be applicable. Apart from international law, the additional regulatory framework concerning deep sea mining is also laid down in the local regulations of the states having jurisdiction over the areas where deep-sea mining is to be undertaken. Moreover, in some respect also the European law may be relevant, as well as the national law of European Union Member States. It is important to understand how these regulatory layers influence each other and what landscape they create for the commercial operators.

1. Introduction

It should be noted as a preliminary remark that sea-based mining minerals extraction may be variously referred to as deep sea mining, marine mining, seabed mining or seafloor mining. The different names indicate a spectrum of activities that differ in terms of the types of minerals being mined, how they are mined, and the depth or geographic location at which mining is undertaken. Generally, deep sea mining is considered to be a relatively new mineral process that takes place on the ocean floor (See: Ibp, Inc. *Pacific Countries Mineral Industry Handbook* , 2015, Volume 1 Strategic Information and Regulations, p. 8; USA International Business Publications, 2012, *Cook Islands Mineral & Mining Sector Investment and Business Guide,* p. 17).

Having the above in mind it should be noted that the legal framework for deep sea mining is constituted in multiple levels of law (See more: *Study to investigate the state of knowledge of deep-sea mining, Final Report under FWC MARE/2012/06 - SC E1/2013/04*). As a general rule, the application of a relevant legal regulation depends on the location of the activity which is carried out by the interested entities, such as companies. Consequently, international law will be applicable in relation to areas beyond the national jurisdiction of any country. The application of the international law and national legislation will take place as regards the areas under the jurisdiction of third countries (i.e. non-European Union Member States). At the same time, the areas under jurisdiction of European Union Member States will be covered by the international law, European Union law and national legislation.

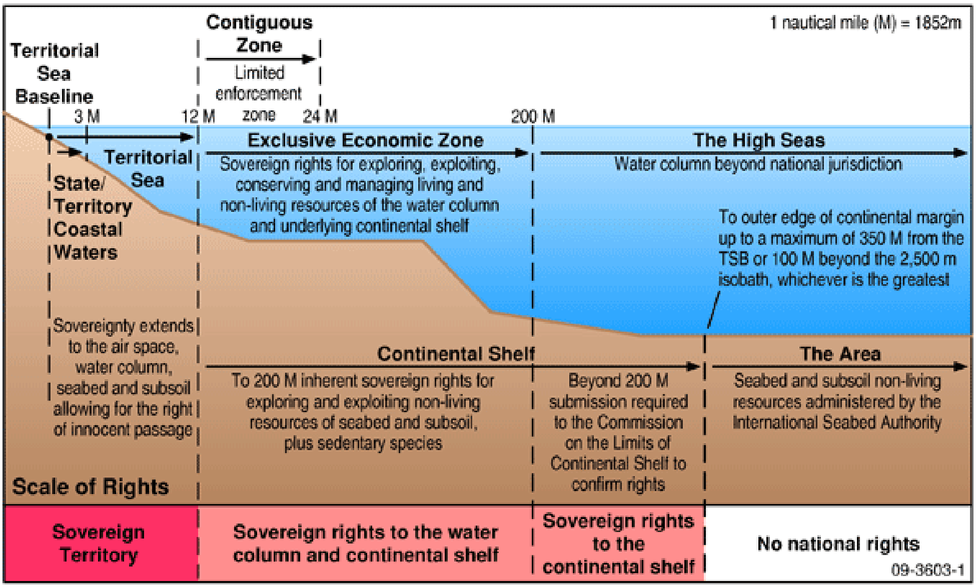
Therefore, various regulatory requirements will be applicable depending on the location of a planned activity. The aim of this article is to present the mentioned regulatory aspects of deep sea mining in relation to the international law as well as European Union and national legislation.

2. International law

The international law provides very important framework which applies to deep sea mining activities. The most significant and comprehensive international agreement relevant to deep sea mining issues is the United Nations Convention on the Law of the Sea of 10 December 1982 (hereinafter referred to as "UNCLOS"). The said convention, described as "constitution for the oceans" resulted from the third United Nations Conference on the Law of the Sea, which took place between 1973 and 1982. According to its preamble, UNCLOS aims to establish a legal order for the seas and oceans which will facilitate international communication, and will promote peaceful use of the seas and oceans, the equitable and efficient utilization of their resources, the conservation of their living resources, and the study, protection and preservation of marine environment. This agreement also defines the limits of the territorial seas of nations and the areas in which they could exploit marine resources. It should be noted that both the European Union and its Member States are parties to UNCLOS.

The part XI of UNCLOS is the part that is potentially of most relevance to deep sea mining issues. In this respect, other international agreement is very important, i.e. the Agreement relating to the Implementation of Part XI of the UNCLOS which implements the said convention and together with UNCLOS establishes a legal framework for deep sea mining. The legal framework regarding deep sea mining is also covered by the annex III of UNCLOS containing basic conditions of prospecting, exploration and exploitation.

Generally, UNCLOS establishes a system of marine jurisdiction. Under UNCLOS the marine space is divided into a number of zones, which may be beyond or under jurisdiction of states. As a consequence, various legislation may be applicable depending on the relevant zone where the entity carries out its activity in respect of deep sea mining, which has been presented in the figure below:



Source: Interim Report: Seabed Mining in the Northern Territory

As it is apparent from the figure above, a coastal State is entitled to a territorial sea, a contiguous zone, an exclusive economic zone (EEZ) and a continental shelf over which it has specific rights and jurisdiction. At the same time, the UNCLOS refers to a so-called Area, which is beyond the national jurisdiction, defining its legal status and its resources.

Under UNCLOS the Area means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction (Article 1(1) of UNCLOS). Part XI of UNCLOS concerns the prospecting, exploration and exploitation of the resources of the Area. According to Article 133(a) of UNCLOS, resources mean all solid, liquid or gaseous mineral resources in situ in the Area at or beneath the seabed, including polymetallic nodules. At the same time, resources, when recovered from the Area, are referred to as minerals (Article 133 (b) of UNCLOS). In accordance with Article 137(1) of UNCLOS, no State shall claim or exercise sovereignty or sovereign rights over any part of the Area or its resources, nor shall any State or natural or juridical person appropriate any part thereof. Thus, no such claim or exercise of sovereignty or sovereign rights nor such appropriation shall be recognized. Moreover, all rights to the resources of the Area are vested in mankind as a whole, on whose behalf the International Seabed Authority (hereinafter referred to as "ISA") shall act. The minerals recovered from the Area, however, may only be alienated in accordance with Part XI of UNCLOS and the rules, regulations and procedures of the ISA. In accordance with UNCLOS, no State or natural or juridical person shall claim, acquire or exercise rights with respect to the minerals recovered from the Area except in accordance with Part XI of UNCLOS.

At the same time, the relevant regulatory regime for deep sea mining in the Area is extended to other decisions, together referred to as Mining Code, including a Decision of the Assembly of the International Seabed Authority regarding the amendments to the Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area (ISBA/19/A/9) (Nodules Regulations), Decision of the Assembly of the International Seabed Authority relating to the regulations on prospecting and exploration for polymetallic sulphides in the Area (ISBA/16/A/12/Rev.1) (Sulphides Regulations), Decision of the Assembly of the International Seabed Authority relating to the Regulations on Prospecting and Exploration for Cobalt-rich Ferromanganese Crusts in the Area (ISBA/18/A/11) (Crusts Regulations) and Decision of the Assembly of the International Seabed Authority concerning overhead charges for the administration and supervision of exploration (ISBA/19/A/12).

As a consequence, in case a company carries out the activity in scope of deep sea mining in the Area, the respective international law should be applied. As already indicated, UNCLOS refers to prospecting, exploration and exploitation in the Area. As a general rule, UNCLOS states that such activities may be carried out by the Enterprise (i.e. the organ of the ISA which shall carry out activities in the Area directly, as well as the transporting, processing and marketing of minerals recovered from the Area) or in association with ISA, by States Parties, or state enterprises or natural or juridical persons which possess the nationality of States Parties or are effectively controlled by them or their nationals, when sponsored by such States.

At the same time, UNCLOS imposes various obligations on States. States must ensure that activities in the Area carried out by natural or legal persons that possess the nationality of those States or are effectively controlled by nationals of those States must be carried out in conformity with Part XI of UNCLOS and must set up appropriate mechanisms to control or regulate activities undertaken in the Area in respect of which they are responsible as States. The nature of the obligations of States was examined by the Seabed Disputes Chamber, according to which UNCLOS requires a sponsoring State to adopt laws, regulations and administrative measures within its legal system, which should have two distinct functions, i.e. to ensure compliance by the contractors with its obligations and to exempt the sponsoring State from liability (see Case No. 17, ITLOS Reports 2011, p. 10).

As already indicated, the international law establishes a legal framework in respect of prospecting, exploration and exploitation of the resources in the Area. According to the Regulation 1 paragraph 3 of Nodules Regulations the prospecting means the search for deposits of polymetallic nodules in the Area, including estimation of the composition, sizes and distributions of polymetallic nodule deposits and their economic values, without any exclusive rights. The relevant provisions provide for the requirements concerning prospecting, including a written undertaking to the ISA that the proposed prospector will comply with UNCLOS and the relevant rules, regulations and procedures of the ISA concerning cooperation in the training programs and the protection of the marine environment as well as giving a notification to the ISA on the approximate area or areas in which prospecting is to be conducted. Regulation 2 paragraph 1 of Nodules Regulations states that Prospecting shall be conducted in accordance with the Convention and Nodules Regulations and may commence only after the prospector has been informed by the Secretary-General that its notification has been recorded.

Under Regulation 1 paragraph 3 of Nodules Regulation, the exploration covers searching for deposits of polymetallic nodules in the Area with exclusive rights, the analysis of such deposits, the testing of collecting systems and equipment, processing facilities and transportation systems, and the carrying out of studies of the environmental, technical, economic, commercial and other appropriate factors that must be taken into account in exploitation. In accordance with Nodules Regulation, the necessary requirements to carry out the activity in scope of exploration cover, inter alia, submitting an Application to the ISA for the approval of plans of work and contract for exploration. It should be noted that under applicable laws each contractor has the exclusive right to explore an area subject to a plan of work for specified resources and a preference and priority for exploitation in that area or those resources.

Regulation 1 paragraph 1 of the Nodules Regulations states that exploitation means the recovery of polymetallic nodules in the Area for commercial purposes and the extraction of minerals therefrom, including the construction and operation of mining, processing and transportation systems, for the production and marketing of metals. The requirements concerning exploitation cover the same rules as those regulating exploration (i.e. an application to the ISA for the approval of plans of work, contract for exploitation) in general. It should be noted, however, that the relevant regulations on exploitation have yet to be adopted.

Analyzing the regulatory aspects of deep sea mining at the international level, a referral to relevant environmental requirements under UNCLOS should be made. It should be noted that UNCLOS calls for the establishment of rules, regulations and procedures to prevent, reduce and control pollution of marine environment caused by such activities. It requires States to adopt laws and regulations to prevent, reduce and control pollution of the marine environment from activities in the Area undertaken by vessels, installations, structures and other devices flying their flag or of their registry, or operating under their authority, as the case may be. It should be noted, however, that the requirements of such laws and regulations shall be no less effective than the international rules, regulations and procedures.

Referring to environmental requirements under UNCLOS, it should be emphasized that there are many international agreements connected with environmental issues, such as the Convention on Biological Diversity of 5 June 1992 or the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter of 29

December 1972 (London Convention). However, the legal instruments connected with environmental issues are especially numerous at the European Union level, as presented below.

3. European Union law

As already said, European Union law will be applicable to the areas under jurisdiction of European Union Member States. As a consequence, European Union law applies to maritime areas over which European Union States have their own jurisdiction. While analyzing the regulatory aspects of deep sea mining at the European Union level, it should be noted that there are no specific European regulations which would refer comprehensively to deep sea mining issues. Most probably it is connected with the fact that seabed in many areas within European waters is simply not suitable for deep-sea mining and, consequently, deep sea mining does not take place in European Union waters in general (See *Study to investigate the state of knowledge of deep-sea mining, Final Report under FWC MARE/2012/06 - SC E1/2013/04*, p. 36).

Notwithstanding the above, there are other legal instruments that may be of importance for the deep sea mining in respect to the areas under jurisdiction of European Union Member States. The relevant European Union law in this respect consists mainly of directives which are connected with environmental protection issues.

It should be emphasised that a directive is a legal act that sets out a goal that all European Union countries must achieve. However, it is up to the individual countries to devise their own laws on how to reach these goals. Once adopted at European Union level, it is then transposed by European Union member countries into their internal law for application. Thus, for a directive to take effect at national level, European Union countries must adopt a relevant legal instrument to transpose it.

At the European Union level, there are eight directives that are potentially of most relevance to deep sea mining issues.

The first of them is the directive 2011/92/EU of the European Parliament and of the Council of 13 December 2011 on the assessment of the effects of certain public and private projects on the environment (Environmental Impact Assessment Directive) which applies to a wide range of defined public and private projects, that are likely to have significant effects on environment by virtue, inter alia, of their nature, size or location to be assessed before authorisation. The types of projects that are subject to the directive, and thus susceptible to the environmental impact assessment procedure that it provides for, are contained in the annexes of the said directive. However, taking into account the provisions of the said directive, it is difficult to determine how deep sea mining could be included under any of these categories.

The other significant directive in the area of deep sea mining is the directive 2001/42/EC of the European Parliament and of the Council of 27 June 2001 on the assessment of the effects of certain plans and programmes on the environment (Strategic Environmental Assessment Directive) , requiring certain plans and programmes which are likely to have significant effects on the environment, to be subject to an environmental assessment. This assessment specifically enables environmental considerations to be integrated in the preparation and adoption of these plans and programmes. Referring to deep sea mining issues, it would appear that the preparation of various specific policies or strategies that relate to deep sea mining may require a strategic environmental assessment to be carried out in accordance with the requirements laid down in the said directive.

The directive 2008/56/EC of the European Parliament and of the Council of 17 June 2008 establishing a framework for Community action in the field of marine environmental policy (Marine Strategy Framework Directive) should also be taken into account. It aims to contribute to the fulfillment of the obligations and important commitments of the Community and the Member States under several relevant international agreements relating to the protection of the marine environment from pollution. The directive may be potentially relevant to deep sea mining in areas under Member State jurisdiction, to the extent that such activities may hinder the achievement of good environmental status, which means the environmental status of marine waters where these provide ecologically diverse and dynamic oceans and seas which are clean, healthy and productive within their intrinsic conditions, while the use of the marine environment is at a level that is sustainable, thus safeguarding the potential for uses and activities by current and future generations (article 3 section 5 of the Marine Strategy Framework Directive).

It is also important to note the Council Directive 79/409/EEC of 2 April 1979 on the conservation of wild birds (Birds Directive) and Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora (Habitats Directive) which refer to the protection of specified species as well as habitats. The directive may be potentially relevant to deep sea mining in areas under Member State jurisdiction where wild birds or fauna and flora occur, which need to be protected in accordance with the said regulations.

The other significant directive in the area of deep sea mining is the directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on waste and repealing certain Directives (Waste Framework Directive). It sets the basic concepts and definitions related to waste management, such as definitions of waste, recycling, recovery. Due to the fact that the said legal act has been designed for waste in general, it may be considered applicable for the management of waste generated by deep-sea mining

The directive 2014/89/EU of the European Parliament and of the Council of 23 July 2014 establishing a framework for maritime spatial planning (Maritime Spatial Planning Directive) should also be taken into account. It establishes a framework for maritime spatial planning aimed at promoting the sustainable growth of maritime economies, the sustainable development of marine areas and the sustainable use of marine resources. Referring to deep sea mining issues, it would appear that the effective maritime spatial planning must take into account the deep sea mining activities, if applicable.

Moreover, there is the directive 2004/35/CE of the European Parliament and of the Council of 21 April 2004 on environmental liability with regard to the prevention and remedying of environmental damage (Environmental Liability Directive) which establishes a framework based on the "polluter pays" principle to prevent and remedy environmental damage. The directive defines "environmental damage" as damage to protected species and natural habitats, damage to water and damage to soil. Operators carrying out dangerous activities fall under strict liability in scope of or are otherwise liable for fault-based damage to protected species or natural habitats. Taking the above into account, it seems that the operators carrying out the activity in scope of deep sea mining will be liable for damage if it occurs.

It should be noted that there is also the directive 2013/34/EU of the European Parliament and of the Council of 26 June 2013 on the annual financial statements, consolidated financial statements and related reports of certain types of undertakings, amending Directive 2006/43/EC of the European Parliament and of the Council and repealing Council Directives 78/660/EEC and 83/349/EEC (Accounting Directive), which requires the European companies to prepare and make public an annual report on payments made to governments of more than EUR 100,000 in a financial year thus including the level of royalty and other licensing payments. Therefore, it may be potentially relevant to the companies which carry out the activity in respect of deep sea mining.

4. National legislation

As already indicated, the national legislation will be applicable as regards the areas under the jurisdiction of third countries (i.e. non-European Union Member States) of European Union Member States. According to the Article 2 (1) of UNCLOS, the sovereignty of a coastal State extends beyond its land territory and internal waters and, in the case of an archipelagic State, its archipelagic waters, to an adjacent belt of sea (the territorial sea). Moreover, this sovereignty extends to the air space over the territorial sea as well as to its bed and subsoil.

Under applicable laws, in the exclusive economic zone (EEZ), the coastal State has sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living, of the waters superjacent to the seabed and of the seabed and its subsoil, and with regard to other activities for the economic exploitation and exploration of the zone, such as the production of energy from water, currents and winds.

It should be noted that the coastal State has regulatory jurisdiction and can design and adopt its own legislation accordingly. As a consequence, there are no international standards for deep-sea mining as such. The table below presents that few states have so far established relevant regulations regarding deep sea mining in areas under their jurisdiction:

Table 3.1 National legislation on deep-sea mining

	Legislation on deep-sea mining in the Area	Legislation on deep-sea mining in areas under national jurisdiction			
		Specific legislation on deep-sea mining	Legislation on land based mining applies by implication	Specific references in legislation on land based mining	Deep-sea mining addressed in other legislation
Canada	-	-	-	-	-
China	-	-	-	✔	-
Fiji	✔	-	✔	-	-
France & French OCTs	-	-	-	✔	-
Germany	✔	-	NA	NA	NA
Greece	-	-	-	-	-
Greenland	-	-	✔	-	-
Italy	-	-	-	✔	-
Japan	✔	-	-	✔	-
Netherlands	-	-	-	✔	-
Netherlands OCTs	-	-	-	✔	-
Papua New Guinea	-	-	✔	-	-
Portugal	-	-	✔	-	-
UK	✔	-	-	-	✔
UK OCTs	-	-	-	-	-
USA	✔	✔	-	-	-

Source: *Study to investigate the state of knowledge of deep-sea mining, Final Report under FWC MARE/2012/06 - SC E1/2013/04*

Referring to the Polish legal framework for deep sea mining, it should be noted that there is no legal regulation which would refer comprehensively to those issues. The legal act that is potentially of most relevance to mining issues is the Geological and Mining Law of 9 June 2011. Under the Polish law, extraction of minerals from deposits may be basically carried out only upon obtaining a relevant concession i.e.

a concession for the extraction of minerals from deposits. The second prerequisite which may need to be met under the Polish law (depending on the type of particular deposit) is concluding a mining usufruct contract. As a general rule, the right of mining ownership with respect is vested in the State Treasury. However, the State Treasury may establish a mining usufruct. The said establishment of mining usufruct shall take place under a contract concluded in writing.

It should be noted that under Polish law there is a need to obtain many permissions connected with potential activity carried out within the scope of deep sea mining, including relevant environmental permissions, location permissions, construction permissions and occupancy permissions. Construction of a conventional mining plant may need to be preceded, among others, by an environmental impact assessment, which is conducted in the course of obtaining a decision regarding environmental conditions.

5. Summary

As follows from this article, legal framework for deep sea mining is constituted by multiple levels of law. As a consequence, the location of the planned activity in respect of deep sea mining will have direct impact on the application of relevant legal regulations. Undoubtedly, the most significant legal acts in this respect are the agreements concluded at the international level. As regards the European Union law, there is no specific European regulation which would refer comprehensively to deep sea mining issues. Most probably it is connected with the fact that seabed in many areas within European waters is simply not suitable for deep-sea mining and, consequently, deep sea mining does not take place in European Union waters in general. Analysing the national level in respect of deep sea mining, it should be noted that coastal states have regulatory jurisdiction and may design and adopt their own legislation accordingly. As a consequence, there are no international standards for deep-sea mining as such at the national level. The example of Poland indicates that there are many countries that have not adopted the relevant regulations in respect of deep sea mining.

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SPONSORING STATES' OBLIGATIONS AND LIABILITY FOR ACTIVITIES IN THE AREA

Abstract. The Seabed Disputes Chamber of the International Tribunal for the Law of the Sea issued an advisory opinion in 2011 on the responsibility and liability of sponsoring States and entities engaged in mining. But the opinion did not resolve all practical uncertainty about the extent of said responsibility and liability.
Mining for polymetallic nodules, sulphides, and cobalt crusts raises specific questions about the extent of State responsibility, securing of compliance, the division of liability between a State and a contractor, and circumstances triggering liability. Further, the inevitable question arises when a State is to be liable. The issues are paramount in assessing risk, drafting relevant national legislation and decision-making by the States on whether to engage in activities in the Area. Even though the advisory opinion is a significant step forward, it does not fully elaborate upon crucial issues of State obligations and liability, specifically for harm caused to the marine environment.

1. Introduction

When engaging in deep sea mining activities, whether these include prospecting for, exploration of or exploitation of minerals from the deep seabed, a clear distinction between the obligations and liabilities of all involved entities is indispensable. For contractors, it is a precondition for assessing business and operational risks. For States sponsoring such activities, it is necessary to make a reasonable decision on whether to sponsor. It is also necessary for the adoption of an appropriate and precise domestic legal framework that will enable a correct structuring of a relationship between the contractor and the sponsoring State.

The issue of liability of States arose after the International Seabed Authority received two applications in 2008 for the approval of a work plan for the exploration of the deep seabed. The applications were submitted by two private entities, one sponsored by the Kingdom of Tonga and the other by the Republic of Nauru. The Republic of Nauru proposed seeking an advisory opinion from the Seabed Disputes Chamber of the International Tribunal for the Law of the Sea (further referred to as the "Chamber") in the considering of the applications, to clarify certain Nauru concerns with respect to possible exposure to liability when the exploration activity conducted by the entity it sponsored causes damage. Nauru emphasized that it does not possess the technical and financial capacity to undertake such an activity and, therefore, it must engage the entities of the private sector. That, however, means exposure to legal risks.

In view of the above lack of clarity, the Council of the International Seabed Authority adopted a decision to request the Chamber to render an opinion on the legal obligations and liability of states. The Advisory Opinion was given on 1 February 2011[1].

2. Opinion sought by the International Seabed Authority

The Advisory Opinion is one of the major cornerstones forming the legal basis of liability of States for deep sea mining activities. It is currently the only such comprehensive and thorough analysis of provisions of the United Nations Convention on the Law of the Sea ("the Convention" or "UNCLOS") on obligations and liabilities, which is related to that specific type of activity conducted in the Area, which means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction.

The Council of the International Seabed Authority requested the Chamber to deliver such an opinion[2]. The opinion was intended to answer three questions:

(1) What are the legal responsibilities and obligations of States Parties to the Convention with respect to the sponsorship of activities in the Area in accordance with the Convention, in particular Part XI, and the 1994 Agreement relating to the Implementation of Part XI of the Convention?

(2) What is the extent of liability of a State Party for any failure to comply with the provisions of the Convention, in particular Part XI, and the 1994 Agreement, by an entity whom it has sponsored under Article 153, paragraph 2(b), of the Convention?

(3) What are the necessary and appropriate measures that a sponsoring State must take in order to fulfil its responsibility under the Convention, in particular Article 139 and Annex III, and the 1994 Agreement?

The basis for rendering the Advisory Opinion by the Chamber was article 191 of UNCLOS, which obliged the Chamber to give advisory opinions at the request of the Assembly or the Council of the International Seabed Authority on legal questions arising within the scope of their activities.

3. Sponsorship system

As stems from the questions raised, the substance of the Advisory Opinion was founded on the notion of "sponsorship" as a key element related to conducting any activity in the Area. Formally, neither the questions nor the Chamber's replies extend beyond the specific formal sponsorship relationship. In practical terms, however, the Chamber's observations are widely applicable and valuable for assessing the obligations and liabilities (specifically the latter) under international law.

Bearing in mind the above, it is therefore indispensable to start with a brief introduction of the basic concepts on which the observations of the Chamber were based.

The system of deep sea mining is regulated by the Convention (specifically Part XI thereof and Annexes III and IV) and the *1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea*. Under the Convention, the Area means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction. There is a specific legal regime under the Convention applicable to the legal status of the Area. Firstly, the Area and its resources (which are to include all solid, liquid or gaseous mineral resources *in situ* in the Area at or beneath the seabed, including polymetallic nodules) are a common heritage of mankind (art. 136 UNCLOS). The consequence of such classification is a general ban imposed on States to claim or exercise sovereignty or sovereign rights over any part of the Area or its resources (art. 137 par. 1 UNCLOS). All rights in the resources are vested in mankind as a whole, on whose behalf the International Seabed Authority is to act (art. 137 par. 2 UNCLOS). Activities in the Area must therefore be organized and carried out in accordance with the Convention and regulations implemented by the Authority. It is worth noting that the notion of "activities in the Area" is also defined in the Convention and means "all activities of exploration for, and exploitation of, the resources of the Area" (art. 1 par. 1 point 3 of UNCLOS).

The Convention sets forth a "parallel system" of exploration and exploitation activities in the Area (art. 153 par. 2 UNCLOS). The parallel system means that the activities in the Area are carried out:

a) by the so-termed Enterprise i.e. the organ of the International Seabed Authority carrying out activities in the Area, transporting, processing and marketing minerals recovered from the Area (art. 170 par. 1 UNCLOS);

b) by States Parties in association with the Authority, or states enterprises or natural or juridical persons.

The non-state entities (i.e. natural or juridical persons) can only do so, when they possess the nationality of States Parties or are effectively controlled by them or their nationals, and when **sponsored** by such States. The wording of the Convention is a bit ambiguous, as to whether the obligation to be sponsored also applies to State persons, e.g. state enterprises. The Chamber, has, however emphasized that the requirement of sponsorship also applies to the latter[3]. This is also confirmed by the wording of the regulations adopted by the International Seabed Authority for prospecting and exploration, which expressly impose such obligation on state enterprises[4].

The "sponsorship" is, therefore, a specific instrument to ensure compliance with obligations specified in the Convention. The nature of the Convention, which is an inter-State legal treaty, does not impose obligations directly on juridical and natural persons, but only on the subjects of public international law, i.e. mainly States and intergovernmental organizations (international organizations). Therefore, the effectiveness of the provisions of international law on carrying out activities in the Area requires not only the implementation of the relevant provisions of the Convention and regulations adopted by the International Seabed Authority, but also ensuring that the obligations are complied with by entities, which are subjects of domestic legal systems[5] and as such are not subjects of international law bound by the provisions of international treaties.

As a result, the sponsorship safeguards are intended to protect the interests of the international community[6] and to prevent a situation in which private entities engaging in activities in the Area would be exempted from regulatory requirements or liability or could select a State Party on the basis of its convenient jurisdiction where the legislation is less burdensome.

4. Activities in the Area

The Chamber has further analyzed the notion of "activities in the Area", which under article 1 par. 1 point 3 of the Convention is defined as all activities in the exploration for, and exploitation of, the resources of the Area.

One of the main points within the Advisory Opinion is the Chamber's analysis of what is or is not included in that term. Determination of that is necessary, because activities which are not "activities in the Area" are not regulated by the specific regime specified in Part XI of the Convention.

The Chamber considers that, generally, the recovery of minerals from the seabed and their lifting to the water surface are activities in the Area[7]. The Chamber also concludes that drilling, dredging, excavation, disposal of waste, construction and operation of installations, pipelines and other devices related to such activities are included in the notion of "activities in the Area"[8]. By analysing specific provisions of the Convention and Annex III thereto, the Chamber concludes that coring and excavation as well as disposal, dumping and discharge into the marine environment of sediment, wastes or other effluents are also activities in the Area.

Generally, the Chamber maintains that **processing** and **transporting** are **not the** activities in the Area. The exception is, however, shipboard processing immediately above a mine site of minerals derived from that mine site, which is considered to be an activity in the Area. This is because the Chamber considered that those are activities directly connected with exploration and exploitation. Moreover, such activities involve a specific (increased) risk, so it would be pointless excluding them from the legal regime applicable under Convention. Similarly, extraction of water from the minerals and an initial separation of materials of no commercial interest are also considered activities in the Area[9]. Conversely, transportation to points on shore and further processing on land cannot be included as they are not directly related to exploitation. The application of a deep sea mining regime to such activities would also interfere with other legal regulations (e.g. those applicable to shipping and freedoms of the seas).

In some instances, the Chamber admits that a case by case analysis could be necessary. That is specifically apparent with respect to polymetallic nodules. The Chamber is of the opinion that when transferred between the ship where the lifting process ends and another installation where the preliminary separation and disposal of material to be discarded takes place, these nodules would be included within the term “activities in the Area”, providing that that those actions are directly connected with extraction and lifting.

The sample interpretations should serve as a basis for assessment and classification of other activities related to deep sea mining. It can be assumed that further detailed analysis will be required with respect to each innovative technique that will be developed in the future. Currently, picking up the nodules from the ocean floor and bringing them up to the surface facility can be achieved by several collection techniques (picking up the nodules with dredge-type or bucket-type collector) and lifting techniques (lifting nodules through the pipe, dragging the bucket up with a rope or cable or having the collector ascend by the force of its own buoyancy)[10]. The interpretation given in the Advisory Opinion allows for the classification of the above activities as activities in the Area.

As already mentioned, the definition of “activities in the Area” includes all activities for exploration for, and exploitation of, the resources of the Area. The Convention does not define “exploration” or “exploitation”. Such definitions are included in the regulations adopted by the International Seabed Authority. For instance, Regulation 1 par. 3 (a) of the *Regulation on Prospecting and Exploration for Polymetallic Nodules in the Area*, exploitation is defined as also including “the construction and operation of mining, processing and transportation systems, for the production and marketing of metals”. Those actions seem to extend beyond the scope specified by the Chamber. Consequently, because regulations are subordinate to the Convention, the inconsistency could be eliminated by adjusting the wording of the above regulations to the interpretation of the Convention made in the Advisory Opinion[11].

5. Obligations of States Parties to the Convention

The obligations and responsibilities of States Parties arise under the Convention, the *1994 Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea* and in regulations adopted by the International Seabed Authority in accordance with the Convention.

The State Parties basic responsibility under the Convention and applicable to activities in the Area is to "ensure that activities in the Area, whether carried out by States Parties, or state enterprises or natural or juridical persons which possess the nationality of States Parties or are effectively controlled by them or their nationals, shall be carried out in conformity with this Part [Part XI of the Convention]" (art. 139 par. 1 UNCLOS). This is further explained by the wording of art. 153 par. 4 UNCLOS and Annex III, art. 4 par. 4 UNCLOS. The latter specifies that States Parties have the responsibility to ensure that a contractor that is sponsored carries out activities in the Area in compliance with the terms of its contract and its obligations under the Convention. All those obligations and responsibilities apply to activities in the Area, therefore, the above mentioned rules of interpretation of that term are indispensable for adequate and correct implementation of provisions of the Convention.

One of the most important features of the Chamber's Advisory Opinion was explaining the nature of that obligation – "responsibility to ensure". According to the Chamber, it is an obligation of conduct and not of result, which means that it is an obligation of due diligence. Due diligence means that the States Parties should "deploy adequate means, to exercise best possible efforts, to do the utmost, to obtain this result"[12]. Basically, the "responsibility to ensure" invokes not only the adoption of law within the domestic legal system, but also its enforcement and supervision. Further explanation is given in art. 4 par. 4 of Annex III to the Convention, which specifies that a sponsoring State is obliged to adopt laws and regulations and take administrative measures which are, within the framework of its legal system, reasonably appropriate for securing the compliance by persons under its jurisdiction.

The due diligence obligation should be more carefully observed when undertaking the activities which involve a higher risk of environmental harm (e.g. exploitation when compared to exploration which is considered less risky). In the Chamber's view, the due diligence obligation also includes taking preventive steps and applying a precautionary approach.

Because art. 148 of UNCLOS promotes the effective participation of developing States in activities in the Area, the Chamber considered whether the scope of the due diligence obligation under the Convention should be differentiated by adopting less stringent requirements for developing States. The Chamber's response is negative. Under the Convention, the developing States' participation should be promoted having regard to their special interests and needs, however, in the Chamber's view none of these provisions include the principle of a preferential treatment for the developing States with respect to their responsibilities to ensure compliance with the Convention. Consequently, the Chamber noted that "the general provisions concerning the responsibilities and liability of the sponsoring State apply equally to all sponsoring States, whether developing or developed"[13]. The Chamber maintains that the equality of treatment is essential, because it allows for the prevention of commercial businesses based in developed States from establishing their existence in developing States and being sponsored by such States to enjoy less burdensome requirements[14].

It is worth noting that in the written statements submitted in the course of proceedings, the United Nations Environment Programme (UNEP) concluded that under the Convention there is some degree of flexibility granted in relation to the amount of due diligence required from the States. Consequently, UNEP stated that developing countries' duty to prevent, reduce and control pollution of the marine environment is limited to using the best practicable means at their disposal and in accordance with their capabilities[15]. However, according to the Chamber, that does not exclude that rules setting out direct obligations of the sponsoring State could provide for different treatment for the developed and the developing sponsoring States[16]. That applies e.g. to the obligation to apply the precautionary approach which is to be applied by states according to their capabilities, which in this specific situation should be understood as "the level of scientific knowledge and technical capability available to a given State in the relevant scientific and technical fields."[17]. However, with respect to liability, as a rule, neither the Convention nor the implementation agreement allow for preferential treatment of developing States.

It seems that the regulation of the due diligence obligation could be considered to be rather flexible than absolute. Even though the Chamber did not focus on that aspect, it may be argued that with respect to protection of the marine environment the due diligence requirements are even higher. Such interpretation results from the wording of art. 192 and 194 par. 1 and 2 of the Convention. Those provisions specify that the States have the obligation to take **all** measures consistent with the Convention that **are necessary** to prevent, reduce and control pollution of the marine environment (such wording appears in art. 194 par. 1 UNCLOS). Similar obligations are specified in art. 194 par. 2 of UNCLOS, which provides for an obligation of the States to take **all** measures necessary to ensure that activities under their jurisdiction or control are so conducted as not to cause damage by pollution[18]. Use of such wording indicates the States obligations in that respect could be considered as more stringent when compared to obligations of States discussed in the Advisory Opinion, which are limited to adopting laws and regulations and taking administrative measures which are **reasonably appropriate** for the securing of compliance with the Convention.

Consequently, the relationship between obligations to take **all** measures to prevent pollution of the marine environment and obligations to take measures which are **reasonably appropriate** could need further clarification.

6. Liability of sponsoring States

The event which triggers liability is primarily the failure of the sponsoring State to carry out its own responsibilities. Under art. 139 par. 2 UNCLOS, damage caused by the failure of a State Party or international organization to carry out its responsibilities entails liability. Interestingly, the liability is *without prejudice to the rules of international law*, which means that the liability is dynamic. Further codification of international law or development of customary international law may result in introduction of new rules of liability which would extend or limit the liability of sponsoring States. Moreover, it is also worth noting that under art. 304 of UNCLOS, the provisions of the Convention regarding responsibility and liability for damage are without prejudice to the application of existing rules and the development of further rules regarding responsibility and liability under international law.

The Advisory Opinion does not provide much clarification on relationship between specific liability rules applicable to activities in the Area and other international law instruments (including general provisions on liability included in the Convention). A broad interpretation and applicability of the latter to activities in the Area was proposed in the *Memorial filed on behalf of Stichting Greenpeace Council (Greenpeace International) and the World Wide Fund for Nature* on 13 August 2010. The authors of the *Memorial* maintain that the taking of measures specified in Annex III art. 4 par. 4 by the sponsoring State to ensure that a contractor carry out activities in the Area in conformity with the terms of its contract and its obligations under the Convention could be insufficient to be exempted from liability. It is argued that those provisions must be interpreted to incorporate more specific language included in art. 194 par. 3 of UNCLOS[19]. It seems that the Advisory Opinion presents rather more narrow interpretation. Even though at first glance the interpretation suggested by the authors of the *Memorial* seems to be most appropriate, the relationship between Part XI specific obligations and general obligations under the Convention and general international law is not so straightforward. Consequently, it would need some additional and thorough analysis. In any case, one must agree with the opinion that obligations of States Parties related to activities in the Area must be interpreted in light of evolving international law, taking due regard of any further developed principles of States responsibility[20].

As already mentioned, the liability under the Convention is triggered by the sponsoring State failure to carry out its own obligations. Further, under UNCLOS, if States

Parties or international organizations act together, the liability would be joint and several. Under the Convention, the State Parties can be exempted from liability, if they have taken all necessary and appropriate measures to secure effective compliance (art. 139 par. 2, second sentence, UNCLOS).

It is worth noting that the rules discussed in this paper apply to state liability and not the liability of specific contractors which remains outside the scope of this paper. The basic rule of the latter is specified in art. 22 of Annex III to the Convention, which specifies that the "contractor shall have responsibility for any damage arising out of wrongful acts in the conduct of its operations, account being taken of contributory acts or omissions by the Authority. (...) Liability in every case shall be for the actual amount of damage".

In the Advisory Opinion, the Chamber added a few comments on essential components of such liability which do not stem directly from the Convention.

First, the sponsoring State does not act as a guarantor. Consequently, the sponsoring State's liability arises, only when there is a failure of the sponsoring State to meet its obligations. There is no sponsoring State's liability, when only a failure by the contractor to comply is a cause of damage.

Second, the condition of liability arising is the occurrence of damage. This means that the liability will not be triggered when the sponsoring State did not comply with the obligations it had under the Convention, but such non-compliance did not result in any damage. Similarly, no liability of the sponsoring State will arise in case damage occurred, but the sponsoring State complied with the obligations it has under the Convention. It is worth emphasizing that there is an exception to the customary international law rule on liability, under which the State may be liable even if there is no material damage – a failure to meet obligations under international law is sufficient for liability under customary international law.

A principle of international responsibility of a State is that a breach of international law by a State entails its international responsibility[21]. The principle was applied in many cases being milestones of international law, such as the *Corfu Channel* case[22], *Phosphates in Morocco* case[23] and in the *Military and Paramilitary Activities in and against Nicaragua* case[24].

It is worth noting that article 2 of the *Draft articles on Responsibility of States for Internationally Wrongful Acts* states that an internationally wrongful act of a State is when a State's conduct fulfils two conditions: first, it is attributable to the State under international law; and second, it constitutes a breach of an international obligation of the State. The mentioned regulation is silent on whether those two conditions are sufficient for the liability to arise. Specifically, it is unclear whether an additional element, being a further consequence of an action or omission, is necessary to trigger liability. In the International Law Commission's view this cannot be determined in the abstract[25] as there is no general rule in this respect. Consequently, an analysis on a case by case basis is necessary.

The Advisory Opinion which firmly specifies that occurrence of damage is necessary to invoke liability means that the above ambiguity will not arise.

7. Gaps in the legal framework

The Advisory Opinion of the Chamber is an invaluable contribution to understanding the responsibilities of various participants in deep sea mining and in implementing and enforcing the law on liability. But there are still many unanswered questions. The uncertainty could prevent implementation of the rules on liability; specifically, if ultimately there is harm to natural resources on the seabed.

Some of the gaps have already been highlighted by the Chamber.

First, the provisions of the Convention analysed by the Chamber do not apply when a sponsoring State fails to carry out its own obligations, but there has been no damage.

Second, the Convention does not apply when a sponsoring State has complied, but there has been no damage. The conclusion is that an undesirable situation could arise of there being harm for which no-one is liable (specifically, when the financial and technical capabilities of the contractor are limited). The Chamber suggested that a special fund can be established for such circumstances.

Third, an important gap is the lack of definition of compensable damage; specifically, advice is necessary on which harm to the environment is compensable. General liability in tort could be too limited because there must be an aggrieved part that has suffered loss because of the tort and the problem will be apparent when there is harm to the deep sea environment because, in most instances, there will be none who has suffered loss. Moreover, the Chamber observed that the Convention and regulations do not define compensable damage in prospecting for and exploration of the nodules or the sulphides. The Advisory Opinion of the Chamber is laconic and does not sufficiently analyse that aspect, simply stating that "...It may be envisaged that the damage in question would include damage to the Area and its resources constituting the common heritage of mankind, and damage to the marine environment"[26]. Damage means the obligation to compensate and there needs to be a coherent specification of a relationship between the two. Otherwise, there would be either a failure to fully compensate for a damage (because the scope of compensation would be too limited), or a clash because the obligation to compensate would extend the scope of compensable damage.

Fourth, it is unknown who can claim compensation for damage. The Chamber advised that "...subjects entitled to claim compensation may include the Authority, entities engaged in deep seabed mining, other users of the sea, and coastal States"[27]. In another point, the Chamber also argues that the International Seabed Authority could be entitled to do so, as well as the states that are parties to the Convention because of the *erga omnes* character of the obligations to preserve the environment in the Area. That, however, does not clarify all ambiguities.

In the future, a more thorough analysis of the matter would be necessary because, otherwise, there is the uncertainty, specifically in the following aspects:

- Harm to the marine environment and the Area would rarely result in harm to the property of a State. Why should that State be entitled to claim compensation, if it did not suffer harm?
- If none of the States suffers harm, but there is damage to the environment, who can claim compensation? That is a possible scenario because deep sea mining occurs in inaccessible seabeds.
- How can harm to natural resources be quantified in compensation?
- How is the harm to be redressed? What if the damage is non-compensable (e.g., restoration of destroyed fauna is impossible)?
- Is damage to be understood to be the difference between the state of environment before and after activity? How would it be possible to assess damage when there is no commencing (baseline) data?

Fifth, another problem could be a liability exceeding the financial capabilities of contractors. The Chamber suggests a fund to ensure that full compensation is paid.

Sixth, knowledge of the *status quo ante* is a further problem that requires thorough analysis; *restituto in integrum* applies to liability and compensation under the law on tort. That means full compensation and requires knowledge of pre-harm status because, otherwise, it is impossible to assess the scope of damage and scope of compensation. Even though the international law does not provide a ready solution, it seems that an environmental impact assessment which is to precede all deep sea mining needs to be extensive to meet those requirements. The purpose of an environmental impact assessment is, therefore, not only to assess the consequences of mining, but also to establish the state of the environment prior to any harm to it.

8. Endnotes

[1] *Responsibilities and obligations of States with respect to activities in the Area, Advisory Opinion*, 1 February 2011, ITLOS Reports 2011, p. 10.

[2] See decision ISBA/16/C/13 adopted by the Council of the International Seabed Authority on 6 May 2010 at its sixteenth session.

[3] Point 74 of the Advisory Opinion.

[4] See Regulation 11 par. 1 of *Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area* (ISBA/19/C/17), Regulation 11 par. 1 of *Regulations on Prospecting and Exploration for Cobalt-rich Ferromanganese Crusts in the Area* (ISBA/18/A/11), Regulation 11 par. 11 of *Regulations on prospecting and exploration for polymetallic sulphides in the Area* (ISBA/16/A/12/Rev. 1).

[5] See comments by the Chamber on the latter in point 75 of the Advisory Opinion.

[6] *Written Statement of the Kingdom of the Netherlands*, 11 August 2010, p. 6.

[7] Point 94 of the Advisory Opinion.

[8] Point 85 of the Advisory Opinion.

[9] Point 95 of the Advisory Opinion.

[10] *Summary information on the different phases involved in exploration and exploitation of polymetallic nodules and polymetallic sulphides in the Area. Information note prepared by the Secretariat of the International Seabed Authority in response to the request of the President of the Seabed Disputes Chamber*, p. 6.

[11] Such opinion was expressed e.g. by Tim Poisel, Poisel T, 2011, Deep Sea Mining: implications of Seabed Disputes Chamber's Advisory Opinion, *Australian International Law Journal*, **vol 3**, p. 218.

[12] Point 110 of the Advisory Opinion.

[13] Point 158 of the Advisory Opinion.

[14] Point 159 of the Advisory Opinion.

[15] UNEP makes here a clear reference to article 194 par. 1 UNCLOS, however the Chamber does not share the view to implement it here; see UNEP written statements, 1 September 2010, p. 2.

[16] See Point 160 of the Advisory Opinion.

[17] Point 162 of the Advisory Opinion.

[18] A similar opinion was presented in the *Memorial filed on behalf of Stichting Greenpeace Council (Greenpeace International) and the World Wide Fund for Nature, drafted by Van Dyke J M, Currie D E J and Simons D, 13 August 2010.*

[19] See p. 8 of the *Memorial*.

[20] *Ibidem*.

[21] See e.g. art. 1 of the *Draft articles on Responsibility of States for Internationally Wrongful Acts*, International Law Commission, 2008.

[22] *Corfu Channel, Merits, Judgment, I.C.J. Reports* 1949, p. 4, at p. 23.

[23] *Phosphates in Morocco, Judgment, 1938, P.C.I.J., Series A/B, No. 74,* p. 10, at p. 28.

[24] *Military and Paramilitary Activities in and against Nicaragua (Nicaragua v. United States of America), Merits, Judgment, I.C.J. Reports 1986,* p. 14, at p. 142, para. 283, and p. 149, para. 292.

[25] Commentary to article 2, point 9.

[26] Point 179 of the Advisory Opinion.

[27] *Ibidem*.

ENVIRONMENT AND EXPLORATION

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NUMERICAL SIMULATIONS OF SEDIMENT PLUME AND ITS DISPERSAL DURING DEEP SEA NODULES MINING OPERATIONS

Abstract. Numerical modeling was used to simulate the discharge of the tailings from nodule cleaning and separation from a mining system buffer. The modeling results can also be used for the preliminary description of behavior of the sediment plume generated by a nodule collector- and the temporal sequence of its dispersal and eventual disappearance. The process was modeled numerically using a multiphase (seawater-sediment slurry) approach involving Reynolds equations and mass conservation, complemented with corresponding volume-of-fluid multiphase models. Computations were performed for a 2D case. Results are presented as plots illustrating the formation and the dispersion of the sediment plume at the time of discharge. The results obtained allow to quantitatively estimate the size of a sediment plume which can be formed as a result of nodule collection from the bottom. The results will serve as a basis on which to assess the ecological impacts and their sequence, for commercial nodule mining in the Clarion-Clipperton zone as required by the International Seabed Authority.

1. Cases studied

Polymetallic nodules extraction is to be accomplished by stripping and collecting the sediment with nodules and subsequently transporting it from seabed to the mining vessel. Water pumped together with sediment and nodules is a multi-phase fluid-particle mixture and tailings from mining should be discharged near the sea bottom to protect the ocean surface environment. The technical solution for this process can be a double-pipe return flow riser including the use of a buffer for controlling the process of discharge. The buffer is located at a certain design depth- Fig. 1.

The polymetallic nodule collector buffer located above the bottom discharges sediment slurry including tailings from nodule cleaning. Data used in the numerical analysis presented in the paper was as follows:

1. Tailings discharge pipe diameter D = 0.3 m
2. Buffer location: 50 – 200 meters above the bottom (mab), Fig.1
3. Range of current speed change in the discharge area: 0- 1 m/s
4. Tailings discharge direction: horizontal, consistent with the direction of the current
5. Ocean depth at the discharge site: 5000 m
6. Tailings discharged (assumed for the analysis): clay
7. Maximum grain size: 0.004 mm
8. Discharge rate: about 20 tonnes pf clay/h
9. Clay density: $\rho = 1.1\ g/cm^3$ (lowest density recorded within the IOM exploration area)

The analysis was performed for four cases corresponding to combinations of pipe outlet depth above the bottom and current velocity. The analysed cases were:

1. Pipe outlet depth 50 mab; current speed 0 m/s
2. Pipe outlet depth 50 mab, current speed 1 m/s
3. Pipe outlet depth 200 mab, current speed 0 m/s
4. Pipe outlet depth 200 mab, current speed 1 m/s

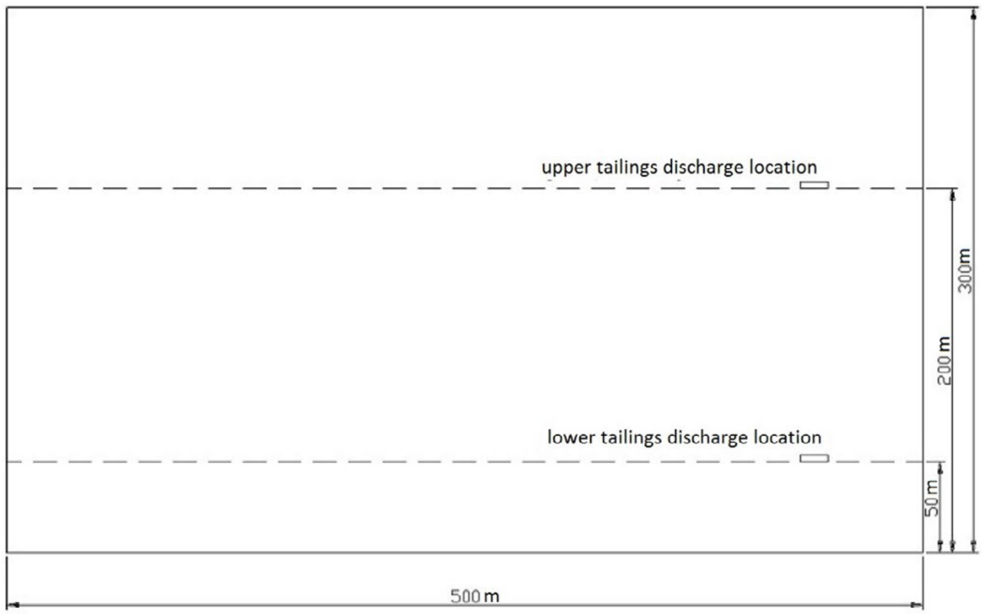


Fig. 1. Range of tailings discharge depths above the bottom

2. CFD Analysis – modelling procedures

Computational Fluid Dynamics (CFD) methods were used to analyze the cases described above. The analyses were carried out for two-dimensional (2D) space as a non-stationary problem, with a due consideration of liquid viscosity (based on the k-epsilon turbulence model), using the Euler multi-phase flow model which allows for the modeling of sediment-water slurry. The CFD analysis involves a numerical solution of the continuous flow equation:

$$\frac{\partial \rho}{\partial t}+\frac{\partial \rho v_x}{\partial x}+\frac{\partial \rho v_y}{\partial y}=0$$

and the Navier-Stokes equation:

$$\frac{\partial v}{\partial t}+(v\cdot\nabla)v=g-\frac{1}{\rho}\nabla\rho+v\nabla^2 v$$

in the Reynolds Averaged Navier-Stokes Equations (RANSE) format which, in the tensor symbols, takes the form of:

$$\rho U_j\frac{\partial U_i}{\partial x_j}=\rho F_i-\frac{\partial P}{\partial x_i}+\mu\left(\frac{\partial^2 U_i}{\partial x_i \partial x_j}\right)-\rho\left(\frac{\partial^2 \dot{u}_i\dot{u}_j}{\partial u^2}\right)$$

as well as the equations complementing the open equation system constituting a turbulence model. The κ-epsilon turbulence model used here consists of two equations associated with turbulent kinetic energy (κ):

$$\frac{\partial}{\partial_t}(\rho\kappa)+\frac{\partial}{\partial x_i}(\rho\kappa u_i)=\frac{\partial}{\partial x_j}\left[\left(\mu+\frac{\mu_t}{\sigma_\kappa}\right)\frac{\partial\kappa}{\partial x_j}\right]+P_\kappa+P_b-\rho\varepsilon-V_M+S_\kappa$$

and turbulent kinetic energy dissipation (epsilon):

$$\frac{\partial}{\partial t}(\rho\varepsilon)+\frac{\partial}{\partial x_i}(\rho\varepsilon u_i)=\left[\left(\mu+\frac{\mu_t}{\sigma_\varepsilon}\right)\frac{\partial\varepsilon}{\partial x_j}\right]+C_{1\varepsilon}\frac{\varepsilon}{\kappa}(P_\kappa+C_{3\varepsilon}P_b)-C_{2\varepsilon}\rho\frac{\varepsilon}{\kappa}+S_\varepsilon$$

Rotational viscosity is determined as:

$$\mu=\rho C_\mu\frac{\kappa^2}{\varepsilon}$$

Turbulent kinetic energy κ dissipation:

$$P_\kappa=-\rho\overline{\dot{u}_i\dot{u}_j}\,\partial\frac{u_j}{\partial x_j}$$

Buoyancy effect:

$$P_b = \beta g_1 \frac{\mu_t}{\mathrm{Pr}_t} \frac{\partial T}{\partial x_1}$$

Model constants:

$$C_{1\varepsilon}=1.44$$

$$C_{2\varepsilon}=1.92$$

$$C_{\mu}=0.09$$

$$\sigma_k=1.0$$

$$\sigma_{\varepsilon}=1.3$$

The Euler multiphase model. The Euler multiphase model allows to simulate the flow of numerous interacting phases including fluids, gases or solids in various combinations and relations. As opposed to the Euler-Lagrangian solution applicable in a discrete phase model, the Euler formula is applied to each phase. The actual number of phases in the Euler model is limited only by the computer's computational capability and the generation of convergences which may prove impossible for the multiphase flows assumed (e.g., when the number of phases is too high).

The Euler model does not discriminate between the fluid and the solid phase of the system (granular flow). A two-phase flow with a granular phase is described as a flow consisting of liquid phases, one of which, on account of parameters assumed, is specified as granular. The solution is based on the following assumptions:

- All phases are affected by identical pressure,
- Continuity and pulse equations are solved for both phases.

To compute pressure and velocity, the Phase Coupled SIMPLE (PC-SIMPLE) algorithm is used, the algorithm being an extension of the SIMPLE algorithm to multiphase flows. In the first stage, the vector equation of velocity is solved simultaneously for all the phases; subsequently, a corrective equation, derived from volume continuity (the volume may be continuous for both phases), is developed for pressure. Next, pressure and velocity are corrected to compensate for the limited flow continuity.

The corrective pressure equation for non-compressible multiphase flows is given as:

$$\sum_{\kappa=1}^{n} \frac{1}{\rho_{r\kappa}} \left\{ \frac{\partial}{\partial_t} \alpha_\kappa \rho_\kappa + \nabla \alpha_\kappa \rho_\kappa \vec{v}'_\kappa + \nabla \cdot \alpha_\kappa \rho_\kappa \vec{v}_{\dot{\kappa}} - \left(\sum_{l=1}^{n} \left(\dot{m}_{\kappa l} - \dot{m}_{l\kappa} \right) \right) \right\} = 0$$

where:

ρ_{rK} is reference density of phase *K* as determined by total volumetric density of phase *K*,

v_K is a velocity correction for phase K and v'_K is velocity of interacting flows. Velocity corrections are a function of pressure correction.

Volume fractions. The actual values of volume fractions result from the phase continuity equation. A volume fraction is a magnitude determined by the ratio between one phase in the mixture (slurry) and water, both at the point of discharge from the buffer and in subsequent computations extending to plume dispersion and mixing with clean seawater.

Determination of a volume fraction in individual points within the computation area at a given moment in time allows to arrive at the size of the plume and its "density" as well as the plume boundary. The latter is obtainable by using the minimal sediment volume fraction criterion for which the calculations are carried out. In its discrete form, volume fraction equation for the phase κ takes the form of:

$$v_\kappa = \int_v \alpha_\kappa dv$$

where the condition is that the sum of the volume fractions of all the phases in the flow equals 1:

$$\sum_{\kappa=1}^{n} \alpha_\kappa = 1$$

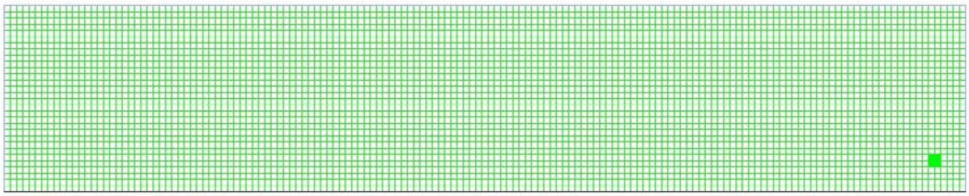
3. The area covered by the model

The computational area in the analysis described is a rectangular 1650 x 300 m area for situations with null current effect and a 3300 x 300 m area for situations when the current is present.

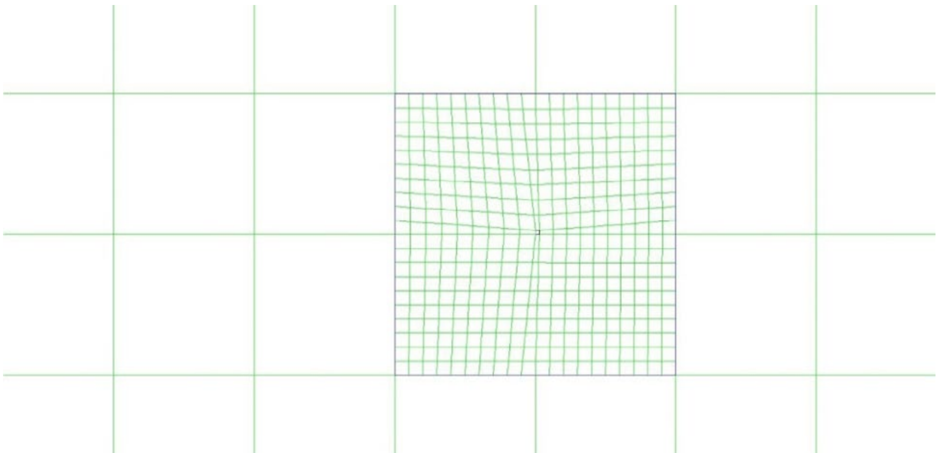
The rectangle depicted below reflects a fragment of space above the seafloor (the lower border of the rectangle models the seabed surface), positioned vertically and parallel to the current flow (and to the sediment-water slurry flow). Discretization of the area resulted in a numerical structure grid (grid cells being rectangles). Initially, the grid cells were 10 x 10 m in size (situations with null current) or 20 x 10 m (situations with current present). A separate, 20 x 20 m zone was created around the site of slurry discharge into the area (the site being the buffer discharge position). Initially, the zone was covered by a 1 x 1 m grid, tapering towards the discharge to take the size of 1 x 0.3 m.

Prior to calculation process, the grid around the slurry discharge to the area as well as in the zone of the presumed slurry flow and beneath it (solid particle re-sedimentation area) was preliminarily adjusted by a grid cell reduction where each cell was divided into four new cells.

Following preliminary calculations, an approximate area of slurry flow was determined and re-adjusted, except for the parts not affected by the slurry flow. The process was repeated several times to determine the entire area affected by the slurry flow. Subsequently, a preliminary grid (with 10 x 10 m or 20 x 10 m cells) served to adjust the area determined in the preliminary calculations (the smallest cells in this area having dimensions 0.11 x 0.037 m), and then model calculations were carried out.



The area with a preliminary grid (10 x 10 m)



The area of slurry discharge into the central part of the square covered by a denser grid.

4. Results

The results of the modeling process are presented in the form of plots below, which show contours at which the sediment volume fractions in the slurry are constant. Each case analyzed is illustrated by two plots differing in the sediment volume fraction range: 0.0001 - 0.0005 and 0.00001 - 0.0005. Plots are drawn in scale (in meters) to allow for comparisons between plumes differing in the minimal sediment volume fractions in the slurry.

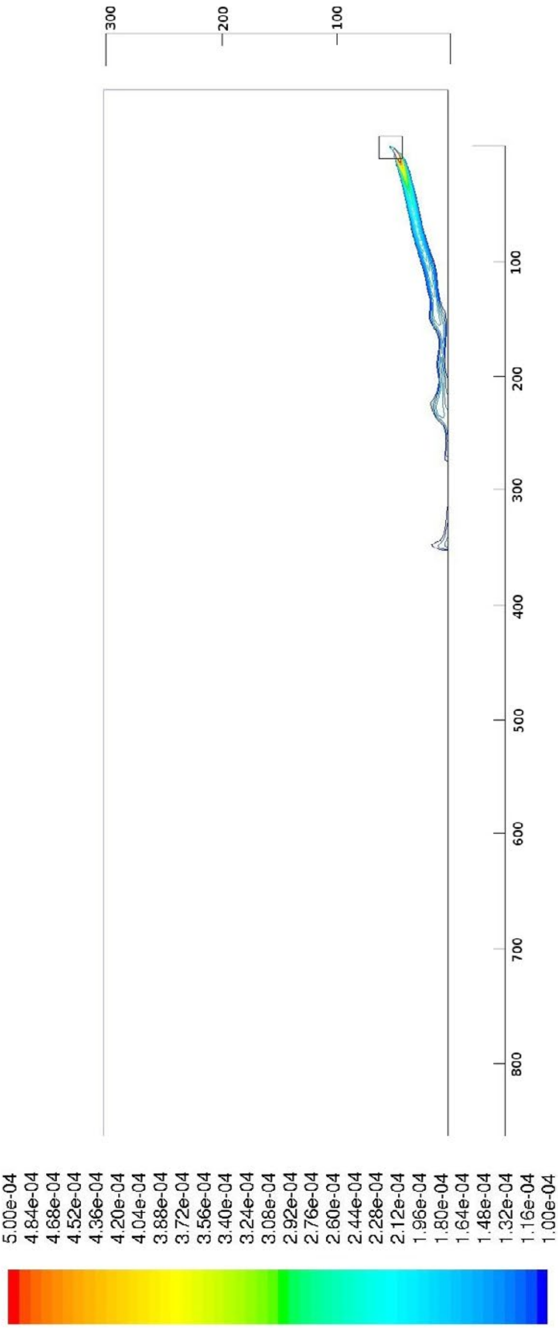
The horizontal dimension (fitted to the page size) in the plots corresponds to the true vertical dimension.

Case 1.
Slurry discharge: 50 mab
Current velocity: 0 m/s
Discharge duration: 30 min.
Slurry flow: horizontal.

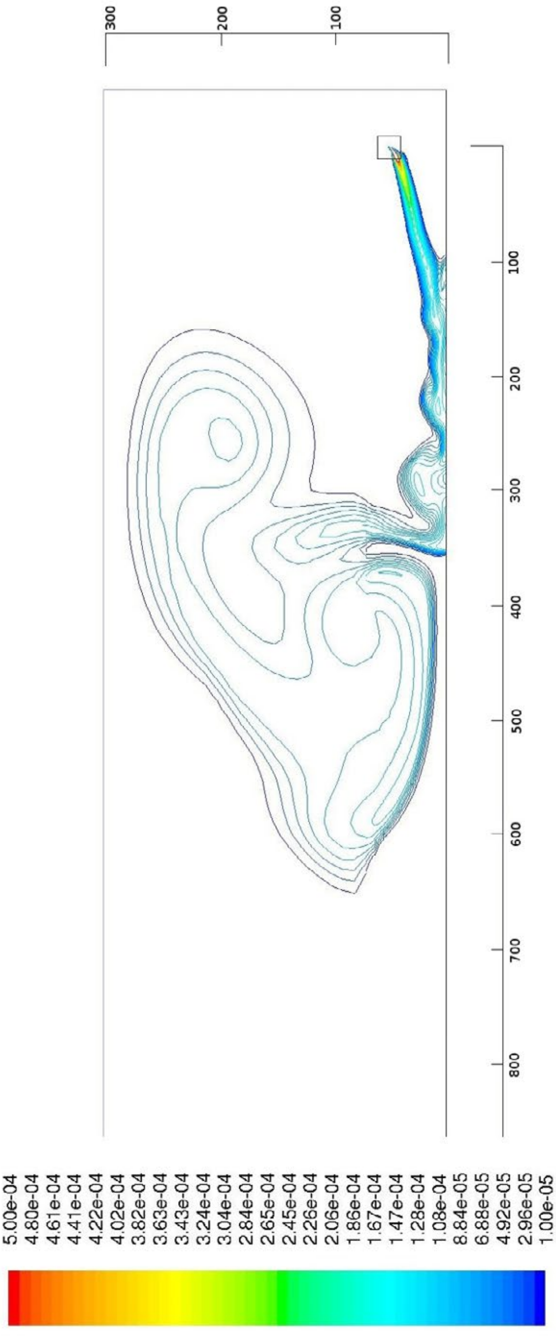
Case 2.
Slurry discharge: 50 mab
Current velocity: 1 m/s
Discharge duration: 30 min.
Slurry flow: horizontal.

Case 3.
Slurry discharge: 200 mab
Current velocity: 0 m/s
Discharge duration 30 min.
Slurry flow: horizontal.

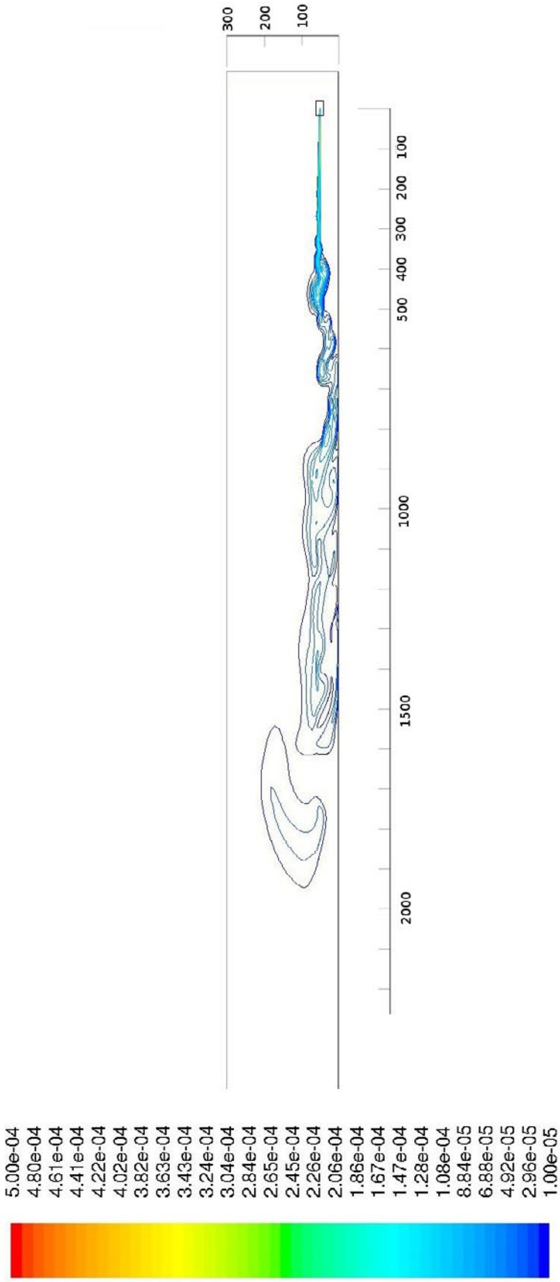
Case 4.
Slurry discharge: 200 mab
Current velocity: 1 m/s
Discharge duration: 30 min.
Slurry flow: horizontal



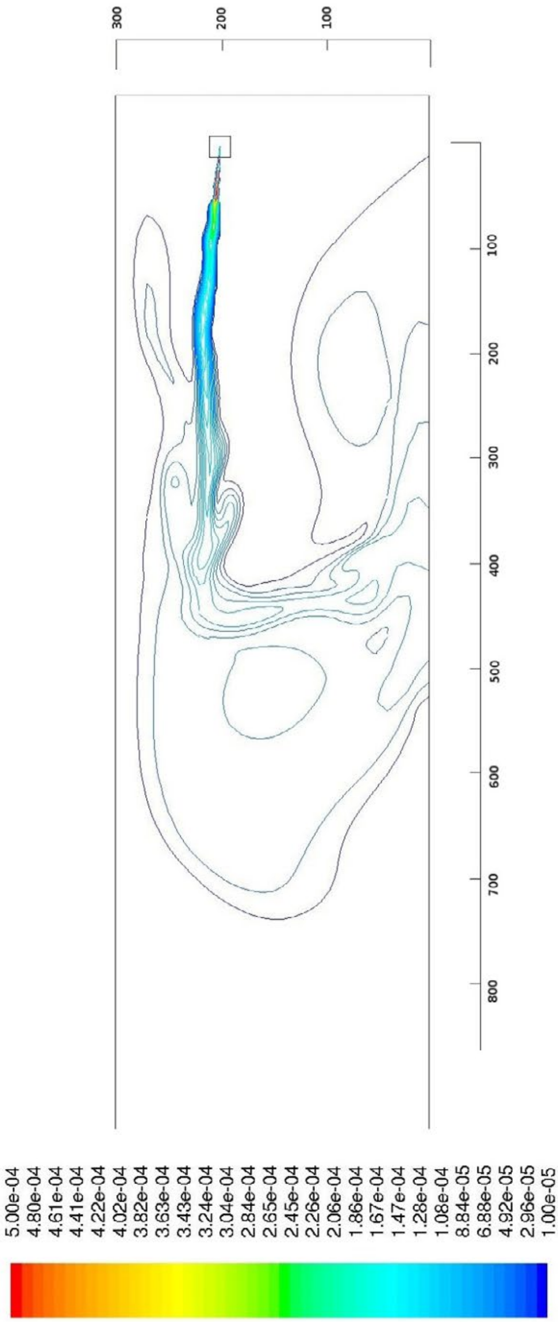
Case 1. The plume 30 min. after discharge. Plume contours correspond to the sediment volume fractions in the slurry fitting in range of 0.0001-0.0005.



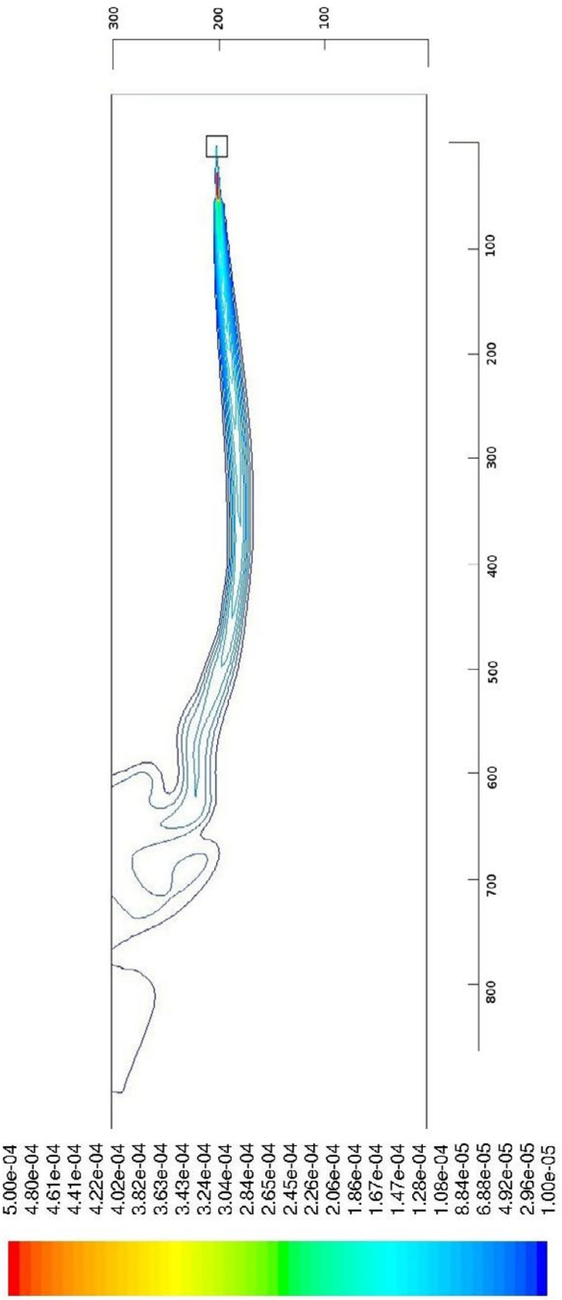
Case 1. The plume 30 min. after discharge. Plume contours correspond to the sediment volume fraction in the slurry of 0.00001-0.0005



Case 2. The plume 30 min. after discharge. Plume contours correspond to the sediment volume fractions in the slurry fitting in range of 0.0001-0.0005.



Case 3. The plume 30 min. after discharge. Plume contours correspond to the sediment volume fraction in the slurry fitting in range of 0.00001- 0.0005.



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Case 4. The plume 30 min. after discharge. Plume contours correspond to the sediment volume fractions in the slurry fitting in range of 0.00001- 0.0005.

The table below shows ranges of time during which the plume will disperse and disappear at individual sediment volume fractions in the slurry. The plume will disappear due to sediment particle resedimentation onto the bottom or dispersion in the water, or due to combination of both these processes.

As evident from the times shown in the table, there is no part of the computational area in which the volume ratio of sediment to water would remain within the ranges indicated.

Case	Time of dispersion [s] for volume fraction	
	0.0001-0.0005	0.00001-0.0005
1	2090-2100	110700-110750
2	2000-2010	15300-15350
3	1930-1940	>185000
4	2160-2170	2800-2810

5. Conclusions

In all the cases analyzed (two locations of slurry release in the water and two current velocities), the plume disappears from the near-bottom layer within a certain time after the cessation of the discharge. It is not possible to determine whether the disappearance is a result of total re-sedimentation. The disappearance is determined for the adopted boundary parameters (minimal values), i.e., sediment volume fraction in the seawater for which it is accepted that the water is still not free of the sediment. As the results of calculations can be obtained for any sediment volume fractions, there is a possibility of adopting values which are so low that, as the sediment particles will then remain in the water, it will become impossible to obtain absolutely clean (sediment-free) water. It is necessary for the evaluation of the results to develop such criteria of the sediment volume fraction in the water at which the water can be regarded as clean (sediment-free).

Besides, the disappearance of sediment from the near-bottom water layer may result from sediment particles dispersal, which leads to a reduction of their local volume fraction, hence meeting the "clean water" criterion. In that case it might be erroneously assumed that the water became sediment free only on account of dispersal. There is also a possibility of an increase in the local sediment-water volume fraction during resedimentation. The analysis has not shown any of such situations, but they, however, cannot be ruled out.

With a two-dimensional analysis it does not seem possible to determine the area covered by the resedimented particles originating from the discharge, which requires further calculations in a three-dimensional space. The model used deals with continuous phase only, which makes it possible to obtain the results for infinitely low sediment-water volume fraction (even if physically impossible to obtain due to sediment grain size). Calculation of both the time of complete resedimentation and plume size requires development of a 'clean water' criterion understood as the maximum sediment volume fraction at which the water can be regarded as 'clean' (sediment-free). Only by setting this criterion will it be possible to determine when the water is sediment-free ('clean') or alternatively sediment-laden. Such criteria could be based on reference concentrations of constant components carried by the water at the mining site; the actual sediment concentration would then be compared to the reference conditions. Under such circumstances it could be assumed that the sediment discharged to the water and carried by it will not lead to altered water properties. Such a criterion can be set for mass or volume of solids in water, mean density, viscosity, air solubility or any other parameter considered to be important.

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Units and nomenclature

mab	Meters above sea bottom
ρ	Specific weight [kg/m^3]
t	Time [s]
U_i, U_j, v_x, v_y	Velocity in direction of a coordinate system axis [m/s]
x_i, x_j, x, y	Direction vectors in the adopted coordinate system
V	Volume [m^3]
g	Earth acceleration 9.81 m/s
k	Turbulent kinetic energy
ε	Turbulent kinetic energy dissipation
F_i	Resultant of external forces
μ	Dynamic viscosity
μ_t	Rotational viscosity
P_k	Kinetic energy (k) dissipation
P_b	Buoyancy effect

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DEEP SEA EXPLORATION FOR METAL RESERVES – OBJECTIVES, METHODS AND LOOK INTO THE FUTURE

Abstract. Polymetallic nodules, as one type of deep sea mineral resources, are composed mainly of manganese and iron hydroxides. But they are economically attractive especially due to their high concentrations of trace metals such as Ni, Cu, Co and Mo and, lately also rare earth elements. The enrichment of metals in nodules is either hydrogenetical by the precipitation of metals from the seawater or through release from the interstitial spaces in the underlying sediments, or by a combination of both. Nodule fields can be explored by remote and contact methods. Interpretation of echosoundings helps to discover the topography of the seabed and what is hidden beneath it. Photo-profiling discovers the level of nodule coverage of the sea bottom and also reveals the obstacles for a nodule collector. Box corer sampling, as a contact method, provides full scale geological and geotechnical information about the site with nodule abundance. The IOM has delineated 5 preferential exploitation blocks for a detailed exploration. The detailed exploration will include swath mapping, hydro-acoustic and photo-profiling, bottom sampling and *in situ* geotechnical soundings.

Introduction

For Interoceanmetal Joint Organization (IOM) and its predecessor the history of prospecting of polymetallic nodule fields on the seabed of the eastern part of the Clarion-Clipperton zone started at the beginning of 1980s over the area of more than 500 000 km^2. In 1987, the year when the IOM was established, the prospecting and exploration was conducted ovr 300,000 km^2. In 1991 the IOM became so-called pioneer investor with the area for exploration equalling 150,000 km^2, one half of which it relinquished for the benefit of International Seabed Authority (ISA). In 2001 the IOM signed 15 years contract for exploration with ISA for the area of 75,000 km^2 (Fig.1).

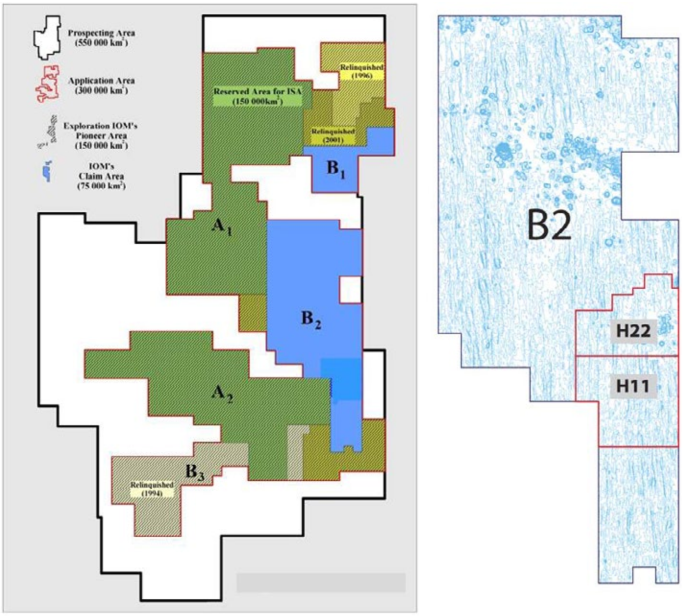


Fig.1. The prospecting and exploration areas of the IOM.

In a nutshell, polymetallic nodule looks much like a small potato except for being black, it is composed mainly of oxides and hydroxides of Mn, Fe, however, there are trace metal contents such as Ni, Cu, Co and Rare Earth Elements (REE) that make these deposits attractive to mine in order to meet the growing demand for these metals. The nodules vary in size from micro-nodules to about 20 cm, the common size being two to eight centimeters. They occur abundantly as a 2 D deposits at the unconsolidated sediment-water interface, and sometime buried in sediments at different layers. They occur in areas of extremely low sedimentation rate. As a rule, nodules require a nucleus to start forming. This nucleus could be old nodule piece, basalt debris or shark tooth. The enrichment of metals around the nucleus is either hydrogenetic by the precipitation of metals from the seawater, or through release from the interstitial spaces between the underlying sediments, by early diagenetic process, or by a combination of both.

1. Methods applied for deep sea exploration and examples of interpretations

Remote and contact methods are recognized as tools of the exploration. Sonars, using sound waves, belong to remote methods. There are two main types of sonars: multibeam sonars for mapping bathymetry, and sidescan sonars for mapping seafloor imagery. Multibeam sonar, attached directly onto the vessel, measures the time it takes for a pulse (120 kHz) to be reflected back and it is useful in determining the depths of the seafloor while sidescan sonar, mounted on a towfish device, measures the strength of pulse that is returned. The sidescan sonar works at 34 kHz frequency. It is usually coupled with a 3.5 kHz frequency profiler. Sound of such frequency is less attenuated when passing through the sediment.

With acoustic imagery swaths up to 16 km wide and a survey speed of 8.5 knots, multibeam sonar can image up to 250 km^2 per hour. From multibeam echosounding a bathymetric image and a backscatterred signal image can be derived. As for the IOM exploration area, the topography of the sea bed is represented by raised and immersed blocks, deep troughs, horsts and grabens, strictly north-south oriented (Fig.2).

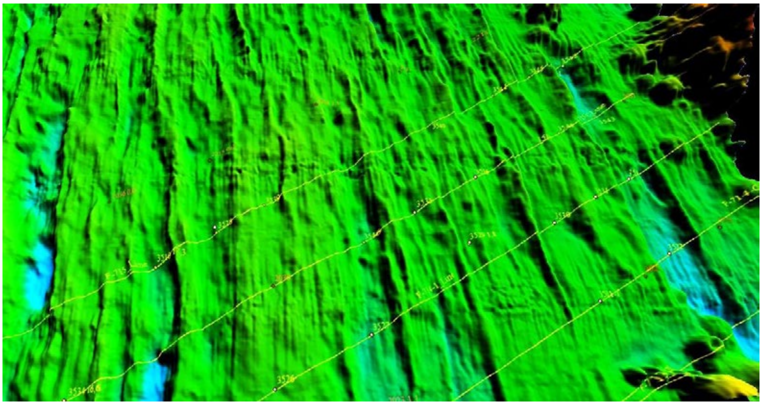


Fig.2. Topography of the fragment of the IOM exploration area.

Back-scatterred signal helps to determine basement outcrops, volcanoes, soft nodule-free areas and nodule rich fields (Fig.3).

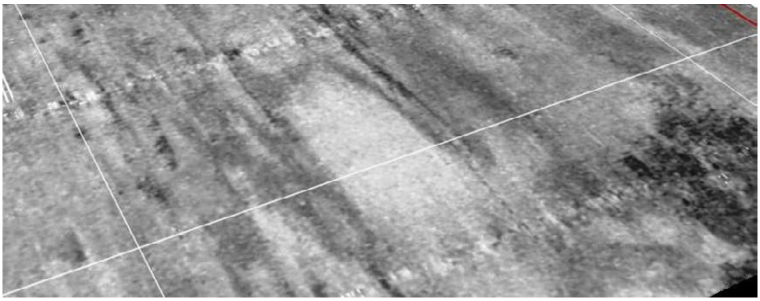


Fig.3. Basement outcrops (dark color at right) and a nodule free area (light in the centre).

The hydro-acoustic system employed by the IOM is capable of covering about 1000 m of seafloor area on either side of the towfish, while the profiler has a capacity to penetrate the sedimentary cover down to 150 m which is sufficient for the IOM area where no more than 100 m thickness of the sediments is expected. There are subsurface interfaces reflecting a part of the acoustic waves penetrating beneath the seafloor. Interpretation of hydro-acoustic profiles helps to see the topography of the seabed and what is hidden beneath it. Four hydro-acoustic facies can be distinguished: transparent A and C, stratified B and massive basement F. The A facie can somewhere further be divided into A1 and A2 with a border constituted probably by zeolitic or argillaceous crust (fig.4).

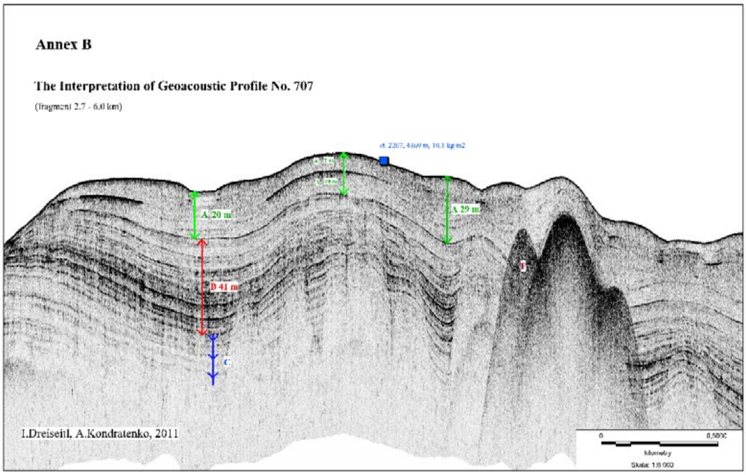


Fig.4. Interpretation of standard hydro-acoustic profile.

The knowledge of the sea bed surface (topography and nodule occurrence) is enriched with results of photo- video profiling. The device (Neptun C-M1, Russia) is towed on a coaxial cable 8 km long. The speed of the vessel during operation is 1-1.2 knots. The intervals between snapshots are 30-40 seconds. Any particular photograph is taken only when the device is 4 m above the seafloor which ensures uniform picture area equalling 5 m^2. Parameter "nodule coverage" for any photograph is calculated using special software. For comparison, two examples of nodule coverage are included (fig.5).

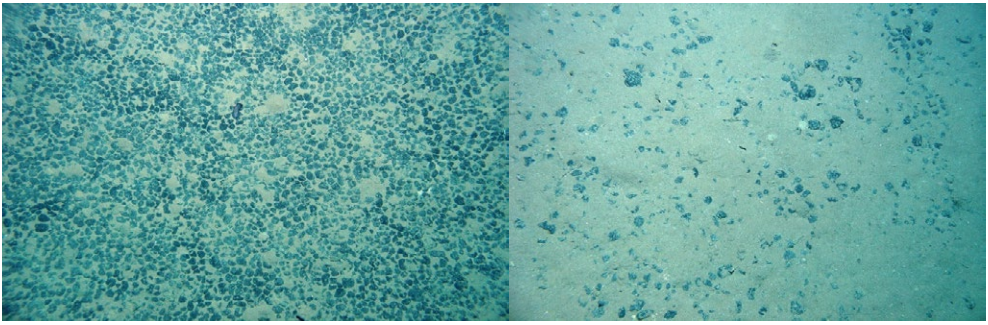
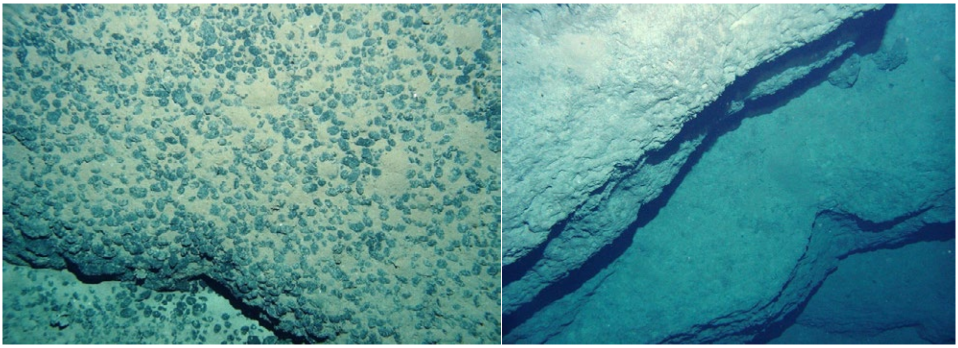


Fig.5. Calculated nodule coverage: left – 68 %, right – 13 %.

Photo-video profiling reveals also the areas unfavorable for mining. They are formed by solid rock (nanofossil carbonates or basalts) with multi steps in meters (fig.6a). Another example of unfavorable area is the following: although abundant with nodules, lava outcrops make things complicated (Fig.6b). Lava outcrops are poorly recognizable in sonograms and a method of photo-video profiling is the only way to detect them.



a) b)

Fig.6. Examples of areas unfavourable for mining.

The combination of sidescan sonar surveys and photo-video profiling data and their simultaneous analysis makes it possible to reveal the true appearance of the seafloor and its underlying structure (Fig.7). At the point no.1 (left) the light-shaded elongated patch on the sonogram represents a soft sediment and a nodule-free area. Seabed photo left proves the area to be nodule-free. The acoustic profile crossing point 1 indicates the occurrence of an erosion canal 256 m wide and about 15 m deep. The absence of nodules can be explained by the fact that near-bottom currents possibly eroded the canal and prevented nodule formation.

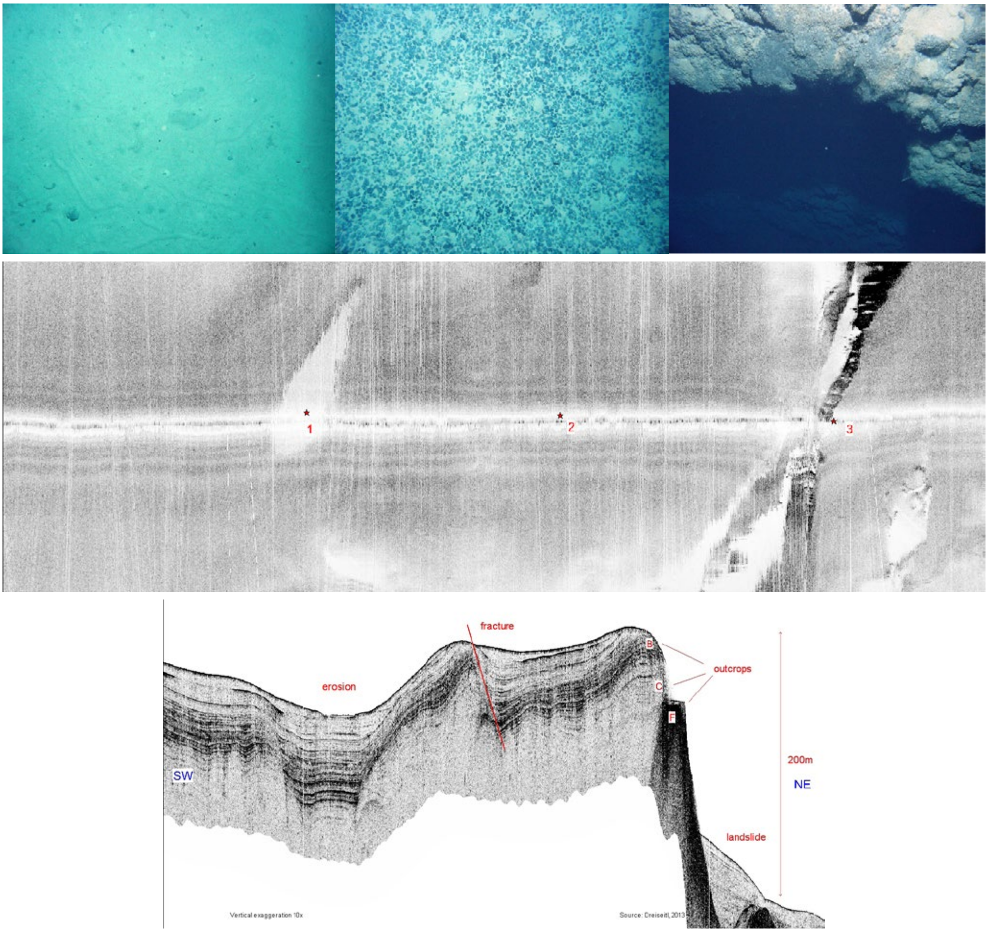


Fig.7. Simultaneous analysis of the seafloor photo, sonogram and profiler.

Point no.2 (centre) features an undulating plain with rich nodule occurrence, i.e. the area favourable for mining. Point no. 3 unmistakably reveals a dangerous zone of solid rock outcrop, forming a steep cliff (about 200 m high) in all three images.

The most important contact method is box corer sampling with which a lot of knowledge can be obtained, both on nodules and sediments. In the IOM exploration area all three genetic types of nodules occur. Hydrogenetic type (Fig.8) is characterized by its small size and smooth surface. These properties are seen in corresponding seabed photo, inside the box corer and also on the grid. But the main indicator for hydrogenetic nodules is their chemical composition: low manganese x high iron, low ratio Mn/Fe. Different morphological types can be seen on the gridded sheets: ellipsoidal E, discoidal D, accreted (multi-nuclear) P and the fragments f of all.

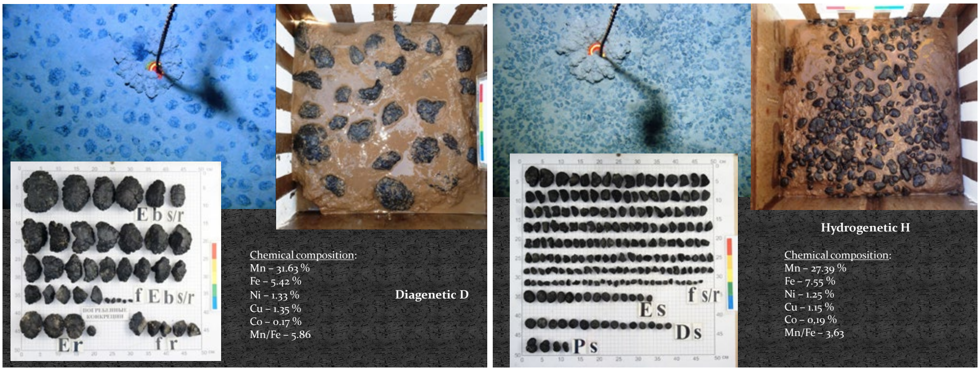
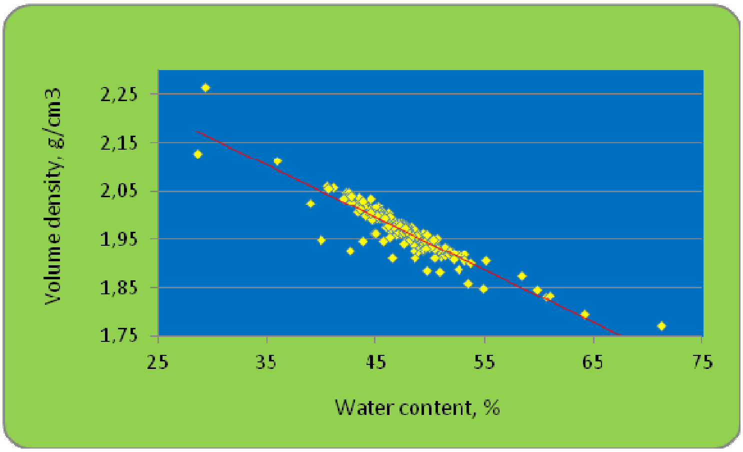


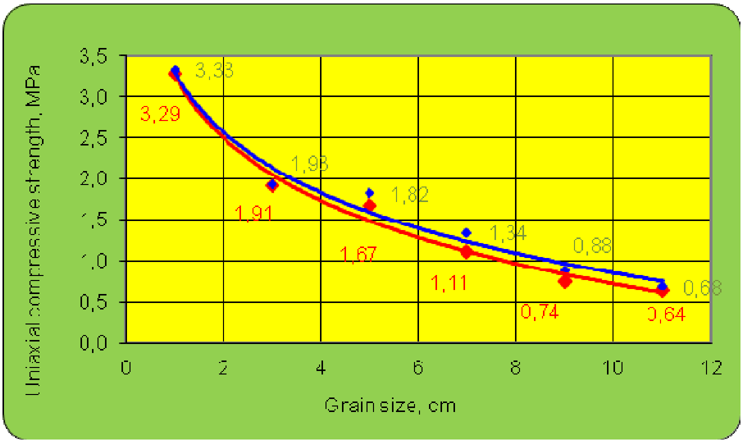
Fig.8. Box corer sampling with hydrogenetic (left) and diagenetic (right) nodules.

Diagenetic nodules (Fig.8) are bigger in size, often more than 10 cm in diameter, smooth on upper side, rough on the contact with sediment. They have different chemical composition, high manganese x low iron and high ratio Mn/Fe. Buried nodules, if any, (Fig.9) are deployed on the grid with a label of morphological type and character of surface (Fig.8). Nodules can be buried as a result of e.g. landslides. At a couple of box corer stations in the IOM area up to 3 depth levels of buried nodules were found.

Fig.9. Buried nodules in a box corer, found at the depths 20-25 cm.

Box corer sampling provides also the geotechnical data of nodules and sediments. Volume density and water content of nodules are the main physical properties (Fig.10) which can be determined outright in a vessel laboratory. There exists a relationship between these two parameters: the more the density, the less the water content. For nodules the density varies from 1.85 to 2.05 g/cm^3 and water content from 40 to 55 %.





Kondratenko, 2011

Fig.10. Geotechnical properties of the nodules, physical (up), mechanical (below).

Uniaxial compressive strength, expressed in MPa, is a single mechanical (strength) property that is routinely determined in a vessel laboratory. The property expresses the amount of stress that has to be applied to break a nodule. The property is not dependent on nodule genetic type or nodule morphotype. The grain size is what plays the main role. Some regularities can be observed: the smaller the nodule, the higher the compressive strength value (Fig.10) and, the spheroidal nodules are harder than the discoidal and/or the ellipsoidal ones.

IOM also conducts gravity corer sampling. This technique allows for obtaining geological knowledge about sediment layers below the sea bottom, including physical and strength properties of the sediment, down to 3- 4 m. Based on the results of the analysis conducted on 8 gravity corers, the cross section was built (fig.11).

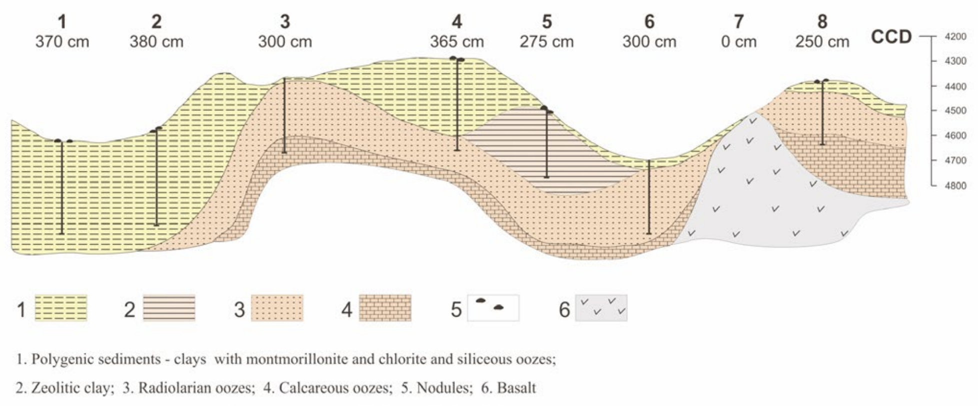


Fig.11. The cross-section through the uppermost part of the sedimentary cover, compiled on the basis of gravity corer data (Zadornov, 2001).

Up to 7 stations provided full scale information about sediments near the sea bottom from depths of 0- 380 cm, except for station No.7 where the corer encountered a lava outcrop (Fig.11).

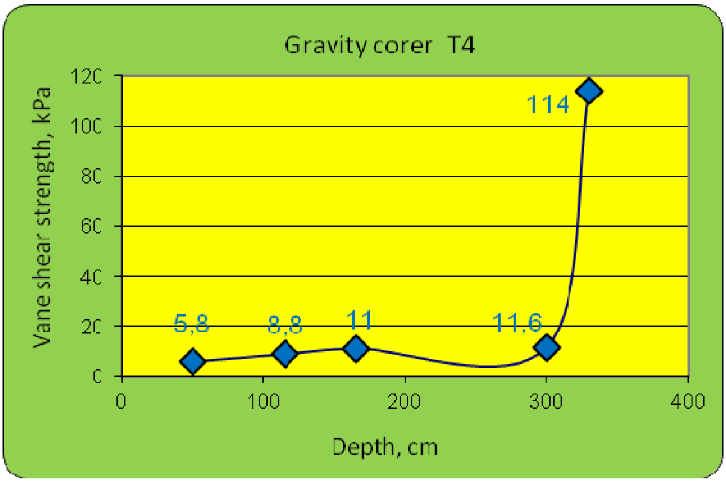


Fig.12. Development of vane shear strength in station T2.

The replacement of siliceous clays with substantially solid radiolarian oozes at the depth of 330 cm at station T4 represents the curve at Fig.12 where the values of vane shear strength increased more than 10 times. The effect of the change of sediment type is documented in the cross-section at the point 4 (fig.11).

Another contact method, trawling (dredging), is applied to obtain a large sample of nodules for a metallurgical experiment. During the IOM-2014 cruise more than 2300 kg of wet nodules were extracted from 4 trawling operations.

2. Delineation of preferential exploitation blocks and ore bodies

Having used the above mentioned methods and having processed all the data obtained during 15 years and more, the IOM drew up the map of preferential exploitation blocks (PEB), Fig. 13 (red hatched areas).

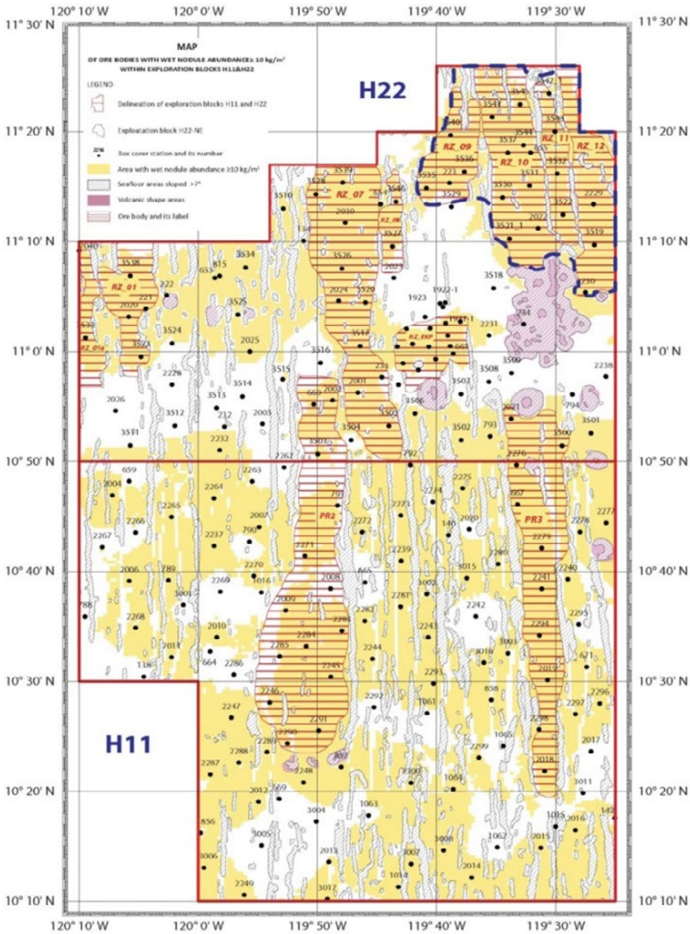


Fig.13. Map of preferential exploitation blocks.

The characteristics of particular exploitation blocks are shown in Table 1. The main column in the table is the one quoting the resources. The resources were estimated using geostatistics, namely the Kriging method.

Table 1. Main characteristics of PEBs.

	Area, km^2	Number of stations	1 station per __km^2	Wet nodule abundance, kg/m^2	Resources wet, mln tonnes	St. error ε_R, %
H22_NE	627.6	20	31	15.7	9.9	10
H22_MID	537.3	23	23	15.5	5.7	11-28
H11_PR2	564.9	12	47	13.0	6.2	13
H11_ PR3	358.8	9	40	15.5	4.2	12
H22_NW	179.2	5	35	14.2	2.4	20-28
∑PEB	**2267.8**	**69**	**35.2**	**14.8**	**28.4**	

In accordance with CRIRSCO classification about 28 mln metric tons of indicated wet nodules is prepared for detailed exploration and, afterwards, for commencing of mining operations.

The most promising PEB is believed to be the H22-NE (fig.14). That block consists of 4 ore bodies: RZ_09, 10, 11 and 12. Its total area of 628 km2 was fully covered by swath mapping (bathymetry), 100 km of photo-profiling in 5 profiles (bold lines) was carried out and 20 box corer samples were taken from depths from 4249 to 4501 meters. From RZ_10 and RZ_12 more than 2 metric tons of nodules were extracted. Diagenetic type of nodules prevails in the block.

Ore body RZ_10 itself (Fig.14) represents an undulating area marked by a north-south oriented mini-ridge in its central part which disappears in its southernmost part. It has an area of 255 km2, it is further crossed by 4 photo-profiles having a total length of 32 km. Nine box corer sample stations have been deployed within the ore body since 2001, with their depths ranging from 4272 to 4386 m. Mean nodule abundance was 16.5 kg/m2, wet resources are 3.9 mln tonnes of mostly diagenetic type. In the northernmost part of the ore body a hydrogenetic-diagenetic type occurs. Coefficient of blanketing varies from 1.0 (no blanketing) to 1.6.

The profile 714 crossing the RZ_10 at an angle is provided as an example (fig.15). The green outline confirmed the undulating plain landscape marked by a mini-ridge in the central part. Red curve in Fig.15 above shows the nodule coverage obtained from photo-profiling. It is evident that the surface of mini-ridge is practically nodule free. On the other hand, the flat passages of the profile are nodule abundant with nodule coverage 50-70%. Two box corer stations on this profile are located, having promising nodule abundances of 16 and 17 kg/m2, which corresponds to 50-60 % of nodule coverage in the images of photo-profile. Taking into account the angled orientation of the profile, the width of swathes rich with nodules at this profile extends to 2- 3 km (with 20 and more km in length) which is suitable for effective exploitation of nodule fields.

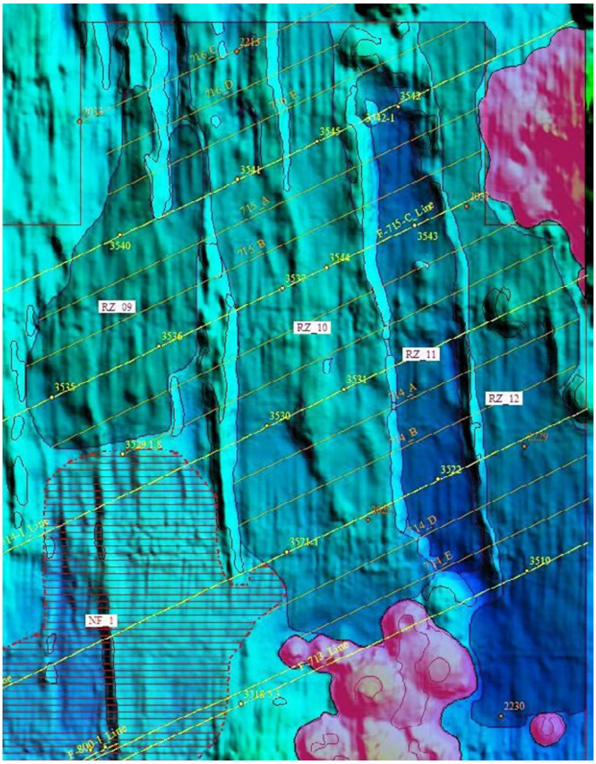


Fig.14. Four ore bodies of H22_NE.

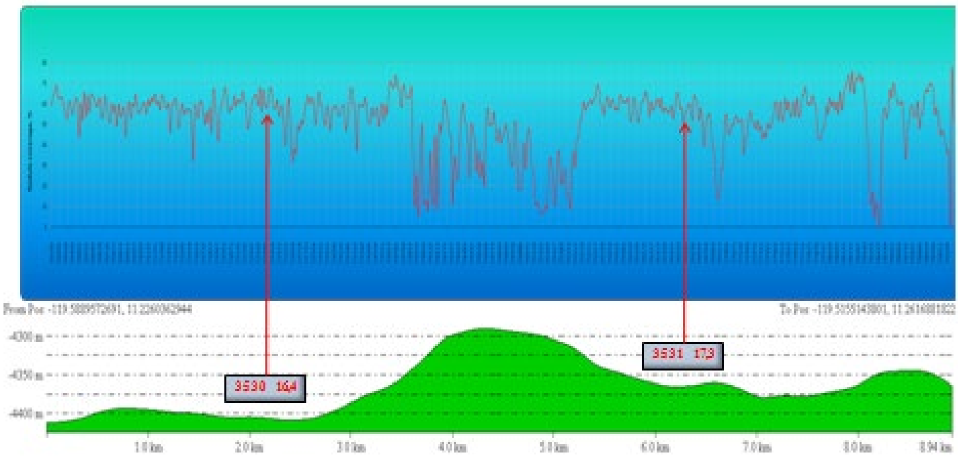


Fig.15. Topography (green) of profile 714 crossing the RZ_10 with nodule coverage (red curve).

3. Conclusions

1. The remote and contact methods used by the IOM for prospecting and exploration of polymetallic nodule fields are presented.
2. Only a simultaneous interpretation of both can give satisfactory results.
3. The appropriate graphic software should be applied to display all the results in the set of well-arranged maps (e.g. MapInfo and Global Mapper in case of IOM).
4. To complete the phase of exploration in the IOM exploration area new additional hydro-acoustic and photo-profiles have already been drafted (thin lines at Fig.14). Afterwards, new box corer stations will confirm the assumptions obtained from hydro and photo-profiling. Gravity corer sampling allows for building a geological cross-section crossing at least two ore bodies of H22_NE. Geotechnical sounding *in situ* will test the bearing capacity of the sediments essential for effective work of nodule collector.

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CONCENTRATIONS AND METAL POTENTIALS OF REES IN MARINE POLYMETALLIC NODULE AND CO-RICH CRUST DEPOSITS

Abstract. The rare earth elements (REEs) are transition metals and include 15 lanthanides plus scandium and yttrium. Most of the REEs are not as uncommon in nature as the name implies. Deep-sea oxidic deposits such as polymetallic manganese nodules and Co-rich ferromanganese crusts take up their metal content predominantly from the seawater and the pore water of the uppermost sediment layers. They contain distinctly higher concentrations in REEs than seawater and typically show a distinctly positive Ce-anomaly. The main carrier phase of the REEs in nodules and crusts is the hydrogenetic substance which contains in crusts up to about 3000 ppm ΣREEs (for dried matter); in contrast the diagenetic material is in general strongly depleted in REEs. In the world's oceans, REE resources in polymetallic nodules of about 15.0 x 10^6 t are considered to be recoverable. This amount corresponds to 15.7 % of the tonnages of ΣREEs in land-based reserves (95.7 x 10^6 t). The ΣREE potential of hydrogenetic Co-rich ferromanganese crusts in the world oceans adds up to at least 69.48 x 10^6 t, which corresponds to 72.6 % of the ΣREE reserves of land-based deposits. Not all of this amount will be recoverable. Since the marine oxidic deposits are economically interesting, in particular, because of their main and minor metals, the REEs might be considered as significant byproducts. A great advantage of the marine oxidic deposits is the virtual absence of radioactive waste elements (Th and U), which are very common in the land-based deposits.

1. Introduction

The rare earth elements (REEs) are transition metals and include 15 lanthanides plus scandium and yttrium. Most of the REEs are not as uncommon in nature as the name implies (Table 1). During the past 25 years there has been a real explosion in demand for many technical products that require REEs. Metals and alloys containing them are needed in many devices that people use every day and which are very important for future high- and green-technologies. However, significant amounts of REEs are produced only in a few countries: China is the dominant producer of REEs at present and is responsible for about 90-95% of the world mine production. Because of the presently stagnating economic market situation the demand for REEs has significantly decreased and the market prices dropped down by 40 to 50%.

2. How do REEs reach the Ocean?

During differentiation of the magmatic rocks, the REEs are successively accumulated in the upper Earth's crust rocks (Table 1). General weathering and erosion delivers the REEs to the oceans; but only a few percent of the total REE amount entering the oceans are dissolved. The bulk of the REEs in eroded material is contained in the clay fraction. The absolute and relative concentrations of the REEs in ocean waters reflect their input from rivers, eolian transport and hydrothermal venting as well as the influence of sedimentation and precipitation. Due to their high particle surface reactivity, the REEs have short marine residence times of only about 400 years. The REE concentrations in the oceans display a non-random vertical distribution, concentrations of all REEs increase towards the seafloor (Fig. 1).

	Element	**Symbol**	**Atomic number**	**Upper Crust Abundance [ppm]**	**Chondrite Abundance [ppm]**
	Scandium	Sc	21	22	9
	Yttrium	Y	39	22	na
LREEs	**Lanthanum**	La	57	30	0.34
	Cerium	Ce	58	**64**	0.91
	Praseodymium	Pr	59	7.1	0.121
	Neodymium	Nd	60	26	0.64
	Promethium	Pm	61	na	na
	Samarium	Sm	62	4.5	0.195
	Europium	Eu	63	0.88	0.073

HREEs	**Gadolinium**	Gd	64	3.8	0.26
	Terbium	Tb	65	0.64	0.047
	Dysprosium	Dy	66	3.5	0.3
	Holmium	Ho	67	0.8	0.078
	Erbium	Er	68	2.3	0.2
	Thulium	Tm	69	0.33	0.032
	Ytterbium	Yb	70	2.2	0.22
	Lutetium	Lu	71	0.32	0.034
	ΣREE			**146.37**	**3.45**

Table 1: Names and chemical symbols of REEs ordered in ascending atomic number; in addition the absolute abundances in continental crust and chondrite are given; na: not available. The Table demonstrates the relative enrichment of REEs in the upper crust rocks compared to primitive rocks (Taylor, 1964).

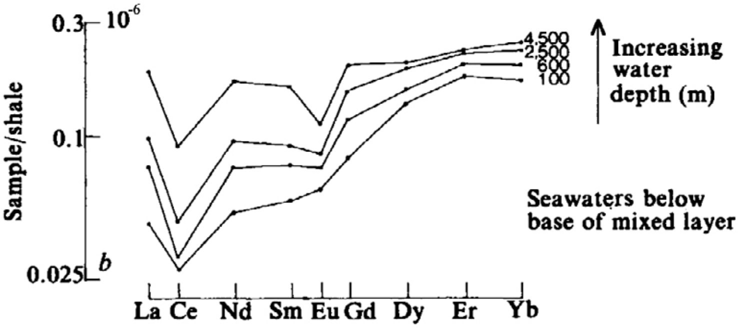

Figure 1: Typical REE patterns (normalized to shale composition) from seawater below the mixed layer, the considered depth range is 100-4,500m; example North Atlantic Ocean. The distribution graphs show the typical enrichment of REEs with increasing water depth (Elderfield and Greaves, 1982). A pronounced negative Cerium anomaly exists in all water depths; i.e. Cerium is distinctly depleted in comparison to shale composition, the heavy REEs are slightly enriched in seawater. This enrichment increases with water depth.

3. Deep-sea oxidic mineral deposits

Two kinds of oxidic precipitates exist in the oceans: (1) polymetallic nodules (Figure 2) in the deep oceans (e.g. CCZ; 4000 to 5000m) and (2) Co-rich ferromanganese crusts (Figure 3) as cm-thick layers on seamounts and guyots, regarding the Co- and Ni- composition, the best depth range is 1000 to 3000m (Halbach and Manheim, 1984). Deep-sea oxidic deposits such as polymetallic manganese nodules and Co-rich ferromanganese crusts take up their metal content predominantly from the seawater and the pore water of the uppermost sediment layers. These oxidic deposits contain distinctly higher concentrations of REEs than seawater and typically show a positive Ce-anomaly (Halbach and Marbler, 2009).

The metal composition of (1) polymetallic nodules is controlled by two formation processes (Halbach, 1986). The diagenetic process delivers solved metal-ions from pore water of the underlying pelagic sediments. The main Mn-phases in the diagenetic nodules are buserite and birnessite which both carry little or no REEs. The second process causing nodule and crust growth is the hydrogenetic precipitation which delivers colloidal particles and dissolved metal compounds from the water column. The two competing metal-bearing mineral phases in this type of nodule and crust substance are Fe-oxyhydroxide and δ-MnO_2, which are intimately intergrown; both phases take up REEs from the water column by particle surface adsorption, i.e. the main carrier phase of the REEs in nodules and crusts is a hydrogenetic substance (Halbach, 1986). Typical mixed-type nodules from the CCZ contain therefore only 600-900 ppm REEs (dried matter; Halbach et al, 2013).

(2) Co-rich ferromanganese crusts, which, in general, form by hydrogenetic precipitation are characterized by distinctly higher REE content: the **Σ**REE amounts up to 3300 ppm, Ce is the main REE and amounts up to 2000 ppm (dried matter) and displays a positive anomaly in the shale-normalized diagrams (Halbach et al, 2013).

These different growth processes and varying mixtures of diagenetic and hydrogenetic ferromanganese substances lead to the result that we can distinguish between several types of nodules and hydrogenetic crusts, but also regional influences can be observed. Geochemically, the REEs are basically inversely related to the Mn/Fe – ratio, but display a positive relationship to the Co-concentrations. A comprehensive summary of the averaged data differentiated by regions and type of deposition are presented in Table 3.

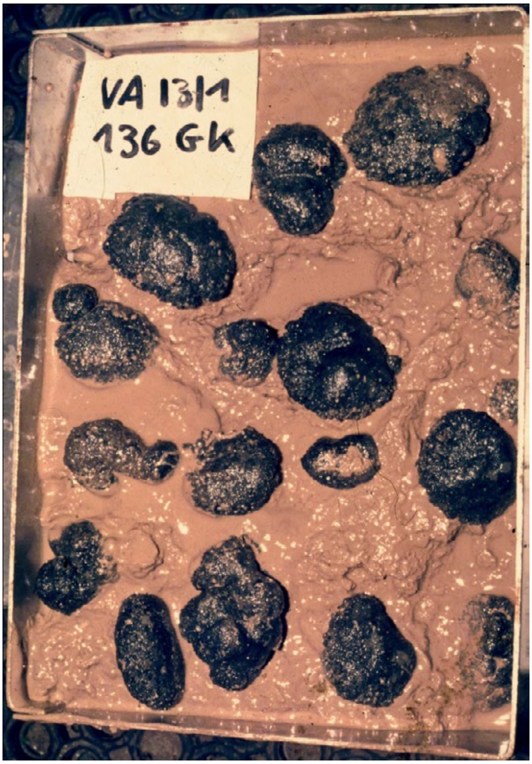

Figure 2: Nodule samples from the CCZ (typical mixed-type nodules; Halbach et al, 1988).

Figure 3: 8-cm thick Co- rich crust sample from the Central Pacific; the crusts, in general, consist of several growth generations, whereby the older layers are impregnated with phosphorite (Halbach and Marbler, 2009).

Oxidic deposit	Ocean	Region	Deposit type	Mn/Fe	Ni + Cu [%]	Co [%]	**ΣREE [ppm]**	**ΣHREE [ppm]**
Polymetallic nodules	Pacific	CCZ	A-Type nodules	5.3 - 9.0	2.12 - 3.16	0.15 - 0.16	315 - 345	61 - 65
			AB-Type nodules	3.0 - 5.1	2.10 - 2.80	0.16 - 0.28	685 - 902	118 - 146
			B-Type nodules	1.4 - 2.2	1.32 - 1.33	0.26 - 0.31	1157 - 1462	107 - 171
		Peru Basin	A_c-Type nodules	8 - 49	0.69 - 1.34	≤ 0.02	68 - 198	14 - 40
		Penrhyn Basin	B-Type nodules	1.0 - 1.1	~ 0.37	~ 0.6	1629 - 1792	130 - 148
	Indic	IONF	AB-Type nodules	2.0 - 3.4	1.06 - 2.16	0.13 - 0.18	532 - 1381	63 - 209
	Atlantic	SS, NAP	B-Type nodules	0.7 - 1.4	0.36 - 0.58	0.25 - 0.47	1934 - 2594	-
Ferro-manganese Co-rich crusts	Pacific	MWS, MS, LI, MI, MPM, CP, MP, HI	hydrogenetic crusts	0.4 - 2.1	0.37 - 1.34	0.37 - 1.53	1364 - 2132	95 - 189
	Indic	CIB, MR, ANS	hydrogenetic crusts	0.6 - 1.9	0.26 - 0.54	0.30 - 0.86	1234 - 3054	109 - 220
	Atlantic	TS, SLR, CS	hydrogenetic crusts	0.5 - 2.0	0.26 - 0.70	0.19 - 0.64	1636 - 3280	87 - 218

Table 2: Ranges of typical metal compositions of different types of nodules and of Co-rich crusts from different regions. A-Type: diagenetic nodules, Ac-Type: cauliflower-shaped diagenetic nodules, AB-Type: mixed-type nodules and B-type: hydrogenetic nodules. CCZ (Clarion-Clipperton Fracture Zone, n=206), Peru Basin n=5, Penrhyn Basin n=4, IONF (Indian Ocean Nodule Field, n=12), SS (Sargasso Sea, n=5), NAP (Nares Abyssal Plain, n=5), MWS (Marcus Wake Seamounts, n=7), MS (Magellan Seamounts, n=4), LI (Line Islands, n=10), MI (Marshall Islands, n=40), MPM (Mid-Pacific Mountains, n=25), CP (Central Pacific, n=7), MP (Manihiki Plateau, n=3), HI (Hawaii Islands, n=30), CIB (Central Indian Basin, n=3), MR (Mozambique Ridge,

n=10), ANS (Afanasiy-Nikitin Seamount, n=8), TS (Tropic Seamount, n=6), SLR (Sierra Leone Rise, n=13) and CS (Canarias Sea, n=2). Hydrogenetic crusts: only younger growth generation. All data refer to dried substance (Halbach et al., 2013).

4. REE - behaviour

In seawater REEs occur mainly as carbonate complexes (Ohta and Kawabe, 2000); in the most cases light Rare Earth Elements (LREEs) form monocarbonate complexes ($REECO_3^+$(aq)) and heavy Rare Earth Elements (HREEs) form bicarbonate complexes ($REE(CO3)_2^-$). The fact that REEs in seawater form cationic and anionic carbonate complexes is used by the two main hydrogenetic constituents-hydrous δ-MnO_2 and Fe-oxyhydroxide to fractionate the group of REEs by surface absorption: the Mn-phase prefers to collect LREE –complexes, while the Fe-phase (in contrast) HREE – complexes. Because of the transitional configuration, this fractionation is not complete.

In marine geochemistry the REE concentrations are normalized to shale composition in order to show the relative distribution between each other. Doing this with our data, the obtained comparative patterns (Figure 4), which also demonstrate regional differences: very high REE-concentrations, for example, are found in Atlantic ferromanganese crusts. The content of REEs in Indian Ocean ferromanganese crusts is in the same range (2436 ppm, Table 3), since the distribution of the individual Lanthanides in the Indian Ocean pattern is very similar to the Atlantic Ocean. This curve was not included in Figure 4.

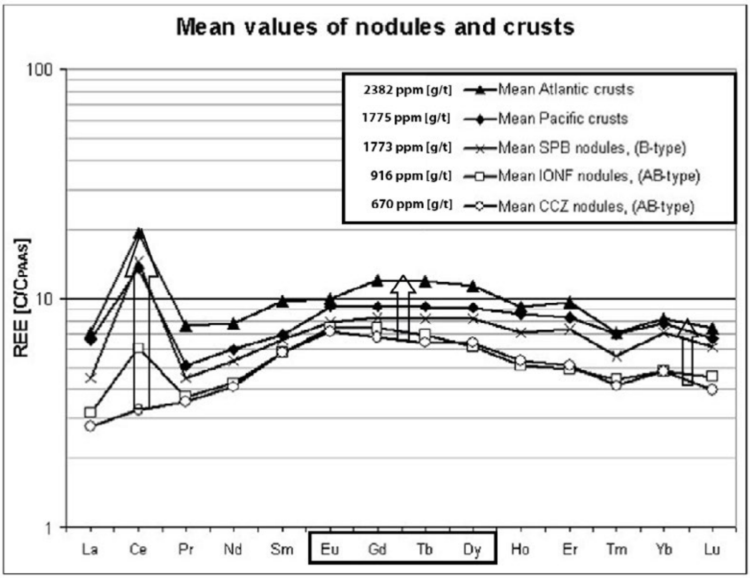

Figure 4: Shale-normalized average REE patterns of five nodules and crust groups from different marine regions. The Atlantic crusts are richest in REE and show the largest positive Ce anomaly; the CCZ nodules are relatively poor in REEs and show no distinct Ce anomaly. With increasing hydrogenetic influence the positive Ce-anomaly as well as the concentration in MREE (Eu to Dy) rises. SPB=South Penrhyn Basin; IONF=Indian Ocean Nodule Field; CCZ=Clarion-Clipperton Fracture Zone of the Pacific Ocean. The CCZ nodules show any clearly positive Ce-anomaly. The SPB nodules are very similar to the mean Pacific crusts.

5. Resource assessment model for ferromanganese crusts

Co-rich ferromanganese crust deposits exist on slopes, summits and platforms of seamounts and guyot structures in the oceans. A complete exploration of these deposits like the nodule deposits in the CCZ does not exist. Nevertheless, in the Pacific Ocean more areas were investigated than in the Indian and the Atlantic Ocean. Therefore, we developed a linear resource assessment method which is based on the assumption that all seamounts and guyots in all three oceans in a defined water depth contain Co-rich crust deposits. The assessment model (Halbach et al., 2013) considers two types of seamounts, the classical cone-shaped seamounts and the guyots. In addition, the roughness of the seafloor, possible thick sediment coverage, and surface obstacles like boulders were regarded as non-mineable areas.

Seamounts and guyots were distinguished by their slope angle. Most of the submarine mountains are volcanic structures. Variations of the slope angles of submarine mountains are also controlled by erosion and subsidence. While seamounts form slopes with more than 12° from the base to the top, guyots have erosional plateaus which reduce their overall height/radius ratio and, therefore, their mean slope angle. The respective slope angles were calculated for all known seamounts which are included in the seamount catalogue of Wessel (2001; revised Wessel et al., 2009), who compiled the global seamount population measured by satellite surveys.

The cumulative curve (Figure 4) for all of the more than 11,000 entries shows two distinct groups of submarine structures: (1) mountains with angles of up to 12° which are interpreted as guyots and (2) mountains with more than 12° which represent normal conical seamounts. This method to distinguish the two types of seafloor structures by their overall slope angle has been checked on several real examples; its correctness was confirmed.

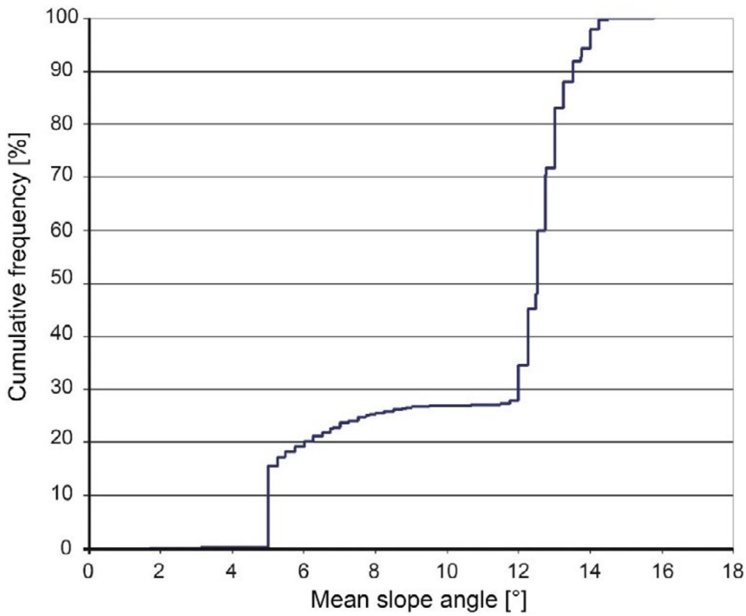

Figure 5: Cumulative curve depicting the mean slope angle of seamounts and guyots versus their cumulative frequency. The diagram shows a bimodal distribution. The first group comprises the slope angles (mean angles from the foot to the top of structure) from 5 to 10° that corresponds to about 28 % of the population. The second group starts with 12° and ends with 16°. Group 1 represents guyots, which have a summit plateau that reduces the height/radius ratio. Group 2 stands for seamounts with no or only small summit plateaus. Note: The steep rise of the curve at a mean slope angle of 5° is a result of the stepwise increase of radius and height information in the original data set which masks the onset of the curve

Assuming a mean water depth of 4500 m, the surface areas of all seamounts were calculated by equations that describe the seamounts as simple cones using the given data for the height and the basis radius. For guyots it was assumed that the mountains can be characterized as truncated cones with slope angles like seamounts (12°) and corresponding plateaus. Thus, also the surface areas for the slopes and the plateaus of guyots were determined.

For the estimation of the ore potential the seamounts and guyots of interest were selected by certain criteria: (1) Geographic position between 50°N and 50°S, (2) Minimum age is Early Cenozoic (55 Ma) and (3) the top of the respective mountain structure must be in a depth range between 800m and 2500m below sea level.

For this selection the surface areas of the seamounts and guyots were summed from 3000m water depth to the top, while the platform areas of guyots were taken into consideration only with 30%. With a given in-situ crust density (2.0g/cm³) and an abundance of manganese crusts determined by thickness (3.5 cm), the potential ore quantity was calculated. First these numbers were reduced by the water content and then by an empirically derived mineability factor of 50% because of seafloor roughness, sediment coverage and obstacles.

The total amount for all the oceans assessed by this model provides 35.1×10^9t of ore material (dried matter), whereas this value splits into:

3.7×10^9t (Indian Ocean; 10.6%),
7.8×10^9t (Atlantic Ocean; 22.2%),
23.6×10^9t (Pacific Ocean; 67.2%).

6. Resource estimates and comparison to land-based deposits

The REE amount of polymetallic nodules in the Pacific and Indian Ocean is 22.5×10^6t, of which a minimum of 15.0×10^6t might be recoverable (Halbach et al., 2012). This amount corresponds to 15.7% of the tonnages of ΣREEs in land-based reserves (95.7×10^6t; USGS, 2012). With regard to the comparison of inferred marine resources to land-based reserves it has to be noted as a caution that the land-based deposits correspond to the category "reserves" (high probability of confidence) whereas the marine deposits only fulfil the category "inferred resources" (lower probability of confidence).

The ΣREE potential of Co-rich ferromanganese crusts which might be recoverable in the world's oceans adds up to at least 69.5×10^6t, which corresponds to 72.6% of the ΣREE reserves of land-based deposits. In the case of the ferromanganese crusts it has to be stated that this estimation is only based on the occurrence of the young crust generation, thus, the quantity shown represents a minimum assessment. Huge deposits of buried crusts underneath non-consolidated calcareous sediments may also exist, but a quantitative estimation of such occurrences is not possible at present. Summarizing, the total REE potential in marine oxidic deposits amounts to 84.5×10^6t ΣREEs (classified as "inferred resources") which corresponds to 88.3% of the REE reserves from land-based deposits (Table 3). The REEs of marine oxidic deposits are significantly less fractionated than REEs in most of the land-based deposits. This becomes obvious from the tonnages of ΣHREE in polymetallic nodules (1.8×10^6t) and in ferromanganese crusts (5.6×10^6t). Therefore, the sum of the quantity of ΣHREE of 7.4×10^6t is relatively high (Table 3). Current estimations of the BGR/Hannover (in ADAC Motorwelt, 2012) specify a total continental resource for the REEs of 285×10^6 t; thus, the total amount of 84.5×10^6 t (dried matter) in marine oxidic mineral deposits (nodules and crusts) yields only 29.5% of the continental resources. The total Y quantity in oxidic seafloor deposits amounts to 7.1×10^6 t which is about thirteen times the continental reserves (USGS, 2012). Interestingly, marine Y resources are in the same range as marine heavy REEs resources (Table 3).

Deposit type / Region	ΣREE (ppm)	ΣHREE (ppm)	Y (ppm)	Tonnage of dried ore material (10^9 t)	ΣREE (10^6 t)	ΣHREE (10^6 t)	Y (10^6 t)	REE (marine) as % of continental reserves	Y (marine) as % of continental reserves
Polymetallic nodules									
CCZ	670	103	101	18.9	12.66	1.95	1.91	13.23	354
Penrhyn Basin	1733	135	144	5.2	9.01	0.70	0.75	9.42	139
IONF	916	104	105	0.9	0.86	0.10	0.10	0.89	18
Atlantic	2258	-	-	-	-	-	-	-	
Total Nodules				25.0	22.53	2.75	2.76	23.54	510
possibly recoverable resource (2/3 model)				16.7	15.02	1.83	1.84	15.70	340
Ferromanganese crusts									
Pacific	1775	152	167	23.6	41.89	3.59	3.94	43.77	730
Indian	2436	151	-	3.7	9.01	0.56	-	9.42	-
Atlantic	2382	183	167	7.8	18.58	1.43	1.30	19.41	-
Total crusts				35.1	69.48	5.57	5.24	72.60	971
Total marine oxidic deposits				51.8	84.50	7.40	7.08	88.30	1311

Table 3: (after Halbach et al, 2013) REE potential resource estimation for oxidic deep-sea deposits in the world's oceans (Halbach et al., 2012). The amount of the nodule and crust deposits refers to dried matter. The REE potential for the polymetallic nodules is reduced by a factor of 2/3 which considers that the nodule resources should refer to a model where a minimum nodule abundance is necessary. The total of the marine oxidic REE resources amounts to 81.22 x 10^6 t ("inferred resources") which corresponds to 84.87% of the land-based "reserves" with 95.7 x 10^6 t of REEs (113.8 x 10^6 t REO; USGS, 2012).

7. Conclusions

Huge REE resources exist in the nodule and Co-rich crust deposits of the three oceans. The most important reasons to make economic use of this potential are:

1. In the case of future deep-sea nodule and crust mining REEs will be recovered anyway. Thus, REEs could be produced as by-products if suitable and reasonable methods of extraction and enrichment did exist.
2. The relative amount of HREEs in the marine oxidic deposits is quite high compared to land-based deposits, whereby the economic importance of HREEs is much higher than that of light REEs.
3. In contrast to many land-based resources the marine oxidic deposits are practically free of contaminating radioactive elements (Th and U).
4. Due to the dominant type of absorptive chemical bonding of REEs it can be expected that the REE extraction and enrichment could be made possible by comparatively gentle and thus environment-friendly hydrometallurgical methods.
5. Our geochemical analyses have shown that REEs in the marine oxidic deposits are fractionated: the δ-MnO_2 – phase preferentially carries light REEs whereas the Fe-oxihydroxide-phase contains more HREEs (Halbach et al., 2014). This observation provides the chance to use this natural fractionation for a technical extraction step which would separate light and heavy REEs.

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PROTECTION OF MARINE AND MONITORING SYSTEMS FOR DEEP-SEA MINING

Abstract. Current international regime that governs all resource-related activities in the international seabed area imposes comprehensive environmental protection obligations on the contractors and sponsoring States involved in the prospecting and exploration for mineral resources. However, the existing environmental regime is only applicable to exploration activities and there is a need for the International Seabed Authority (ISA) to develop a separate set of environmental regulations governing deep-sea mining in the context of its exploitation phases. Considering that the scope and severity of impacts depend on the design and operational mode of the mining systems actually utilized, research on the environmentally sound mining projects carried out by the entities will support their efforts to find an acceptable compromise in minimizing environmental concerns. This paper is a general overview of the legal framework established by the ISA for the monitoring and protection of the marine environment in the Area, particularly with emphasis put on the environmental practices of the Interoceanmetal Joint Organization (IOM) as a contractor conducting the exploration for polymetallic nodules and its other future activities in such a way as to prevent harmful effects to the marine environment.

1. Introduction

The deep seabed mineral resources have a potential to become an alternative source of Cu, Ni, Co, Mn, Pb, Mo, Zn, Pt, Li, Au, Ag, Y, REE, etc., as the land base resources of these metals are being depleted at increasing rates during the last decades. The recent extensive research in the deep-sea areas identified that deposits of polymetallic nodules, cobalt-rich ferromanganese crusts and polymetallic massive sulphides may be economically feasible for mining in the presence of favorable metal prices on the world market (Herrouin et al., 1989; Lenoble, 2000; Kotlinski, 2001; Yamazaki et al., 2002; Rona, 2003; Rona and Lenoble, 2004; Hein et al., 2010).

Polymetallic nodules as the primary mineral resource found in the deep seabed area promise to make an enormous contribution to the world's resource base. In particular, deposits of polymetallic nodules in the eastern equatorial Pacific (within the Clarion-Clipperton Zone, CCZ) have 1.1 times more Mn, 1.4 times more Te, 1.85 times more Ni, 3.2 times more Co, and 4 times more Y than the entire global land-based reserves for those metals. Otherwise, metals in CCZ nodules as a percent of the total global land-based reserves are Cu 22%, Mo 63%, W 21%, Li 19%, Nb 13%, and REEs 11% (Rona, 2008; Hein at al, 2010; Morgan, 2000). As a potential resource, polymetallic nodules contain 7.5 billion tonnes of Mn, 340 million tonnes of Ni, 285 million tonnes of Cu and 75 million tonnes of Co with at least 2.5 % combined content for Ni+Cu, 0.2% Co, 30% Mn, 0.15% Zn, 0.07% Mo, etc.(Morgan, 2000).

As these deposits are spread out over large seabed regions beyond any national jurisdictions (termed as the "Area"), their development falls under the administration of the International Seabed Authority (ISA) in accordance with the 1982 UN Convention on the Law of the Sea (UNCLOS) and the Agreement relating to the implementation of Part XI of the Convention. Thus far, on behalf of the States parties to the Convention, the ISA is responsible for administering the mineral resources of the Area, including prospecting, exploration and exploitation activities related to those resources.

In 2000, the ISA has adopted the Regulations to govern prospecting and exploration for polymetallic nodules in the Area (Mining Code) (https://www.isa.org.jm/mining-code/Regulations) which cleared the legal way for ISA to enter into the first seven contracts for exploration of polymetallic nodules with the following national and multinational entities registered as „pioneer investors": Interoceanmetal Joint Organization, Yuzhmorgeologiya (Russian Federation), KORDI (Republic of Korea), COMRA (China), DORD (Japan), IFREMER (France), and Government of India.

Increased accessibility and the potential for new opportunities have led a number of entities and industries to move into this area. To date, ISA has granted contracts for exploration for polymetallic nodules, polymetallic sulphides and cobalt crusts in the deep seabed to twenty-three entities (https://www.isa.org.jm/deep-seabed-mineral s-contractors). Fourteen of these contracts are for the exploration of polymetallic nodules in the CCZ (13) and Central Indian Ocean Basin (1). There are five contracts for exploration for polymetallic sulphides in the South West Indian Ridge, Central Indian Ridge and the Mid-Atlantic Ridge and four contracts for exploration for cobalt-rich crusts in the Western Pacific Ocean. The conclusion of contracts allows these contractors to explore the specified parts of deep oceans lying outside national jurisdiction.

The Interoceanmetal Joint Organization (IOM), an intergovernmental consortium certified by the governments of Bulgaria, Cuba, Czech Republic, Poland, Russian Federation, and Slovakia, signed a contract with the ISA for the exploration of polymetallic nodule deposits in the area (75,000 km^2) situated in the eastern part of the CCZ, NE

Pacific (Fig. 1, *right)* on 29 March 2001. In the implementation of its 15-years plan of work for exploration, IOM is carrying out comprehensive research and development studies in geology, marine environment, mining technology and processing of polymetallic nodules, and reports annually to the Authority in accordance with the established legal regime in the Area (Kotlinski and Zadornov, 2002; Radziejewska at al., 2003; Kotlinski and Stoyanova 2007; Dreiseitl, 2010; Abramowski and Stoyanova, 2012).

2. Current environmental regime in the Area

The increasing interest in deep-sea exploration and research into mining in the Area obviously raises serious concerns regarding environmental issues. Although three different ore types- polymetallic nodules, cobalt rich crusts and polymetallic massif sulfates were discovered on deep seabed, they have much in common in respect of potential environmental impact, environmental risk assessment, and the need for precautionary research. When mining of deep-sea resources ultimately begins, it is expected to be the largest scale human activity to directly and indirectly impact the marine environment (Thiel, 2001; Morgan et al., 1999; Glover and Smith, 2003).

The responsibilities to protect marine environment in the Area have to be shared between all States parties to the UNCLOS as the Area while its resources are a common heritage of mankind. Under the Convention (Article 192) State parties have a general obligation to protect and preserve the marine environment. This obligation encompasses responsibilities to prevent, reduce and control pollution of the marine environment coming from any source, to monitor the risks or effects of pollution and to assess the potential effects of activities that may cause significant and harmful changes to the marine environment. As noted previously, the ISA, on behalf of the State parties to the Convention, is responsible for administering the mineral resources of the Area, including the creation of rules, regulations and procedures to ensure effective protection of the marine environment from the harmful effects that may arise from prospecting and exploration of such mineral resources. Within the framework of the Mining Code, prospectors and contractors have substantial responsibilities to assess and monitor the effects of their operations on the marine environment in exploration area and annually to report to the Authority on the results of their environmental activities.

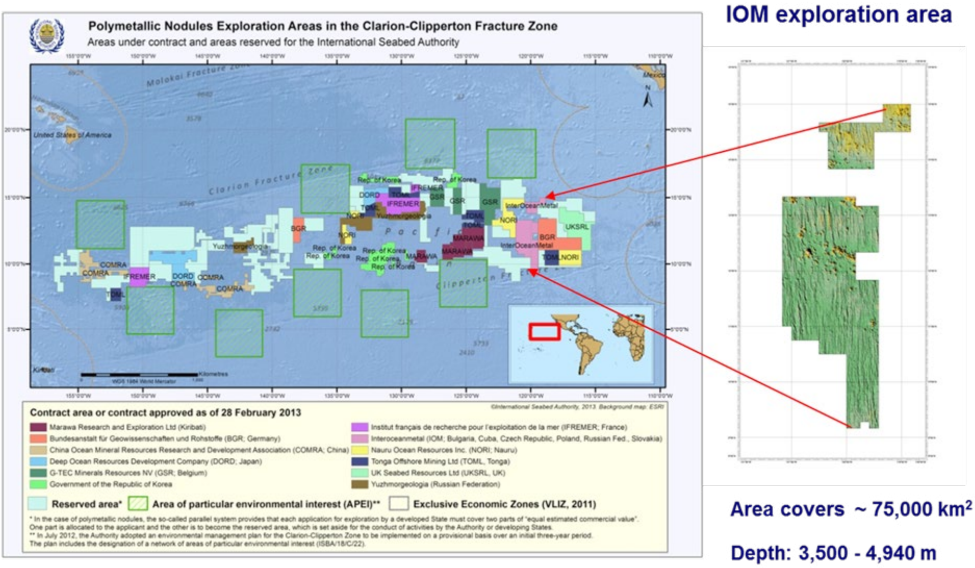

Fig 1. Location of areas granted by the International Seabed Authority for the exploration of polymetallic nodules (contract areas), and areas assigned to particular environmental interest (APEIs, in green) in the Clarion-Clipperton Fracture Zone, NE Pacific

In order to assist the contractors, the Legal and Technical Commission of ISA has issued Recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for marine minerals in the Area (ISBA/19/LTC/8). These Recommendations describe the procedures to be followed in the acquisition of baseline data, and the monitoring to be performed during and after any activities in the exploration area having a potential to cause serious harm to the environment. Environmental guidelines defined biological, chemical, geological and physical components to be measured and identifying those activities during the exploration requiring impact assessment and those do not. It should be also mentioned that Regulations and Recommendations issued by the ISA are only for the exploration of mineral resources, not for exploitation.

Nevertheless, the provisions under the UNCLOS and the Mining Code are encouraging but the deep-sea environment still remains the least understood region of the planet. To avoid any unintended consequences from deep-sea mining that may significantly destroy biodiversity as well as ecosystem structure and function, the precautionary principles are applied within the framework of the Environmental management plan for the Clarion-Clipperton Zone approved by the Council of the ISA in 2012 (ISBA/18/C/22). In order to protect and conserve the natural resources in the CCZ, preventing damage to the flora and fauna of the marine environment, nine areas of particular environmental interest (APEI) were delineated (Fig. 1). Each APEI covers

400x400 km^2, with a total area of 1.44 x 10^6 km^2, will place around 25% of the entire CCZ management area of under protection. This approaches the general conservation guidelines of protecting 30-50% of available habitat to prevent losses of biodiversity and ocean reserves. The main strategic aims of the Environmental management plan are to ensure environmentally responsible and sustainable seabed mining within CCZ as a whole and to protect and conserve the natural resources of the Area.

3. Anticipated impacts of deep-sea mining of polymetallic nodules

Abyssal nodule mining will include picking up the polymetallic nodules and separating them from the surrounding fine-grained sediments, lifting nodules to the ocean surface, separating them from the seawater and sediment entrained in the lift operation, and transporting them to the onshore metallurgical facility (Fig. 2). Each of those operations poses environmental risks for seafloor, water column and sea surface that needs to be assessed, minimized and mitigated in any future mining project.

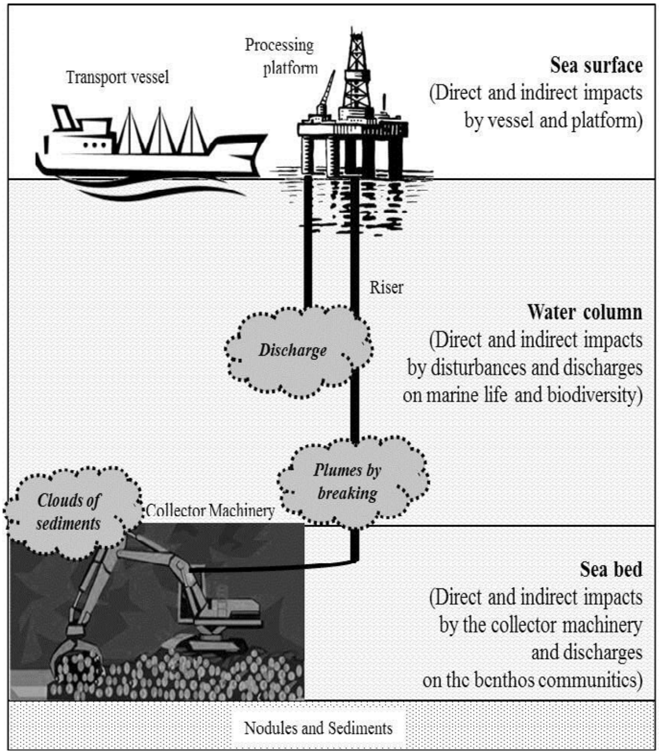

Fig 2. A schematic diagram of a nodule mining system with anticipated categories of potential environmental impacts (from Liu and Yang, 1999)

Picking up the nodules and removing the associated fine-grained sediments fundamentally will disturb the benthic habitat in the mining area and will generate sediment plumes near the seafloor which be transported by the bottom currents at some distance away from the mining tracks. Nodule-lifting operations will include the entrainment of significant volumes of deep-ocean seawater, associated biota and sediments that require their discharge after the separation of nodules on board of mining ship. The essentially permanent removal of nodules within the mining collector track will directly destroy the hard substrate upon which the nodule epi- and infauna depend, thus a large portion of bottom dwelling animals will be killed immediately and compacted (Oebius et al., 2001; Thiel et al., 2001, Morgan et al., 1999). Because abyssal nodule habitats normally are very stable (possibly the most physically stable habitats on Earth) and are dominated by very small and/or fragile animals, the direct effects of commercial-scale nodule collection are predicted to be devastating to the benthos. In addition, the sediment dwelling organisms inhabiting the upper few centimeters of bottom sediments between and beneath the nodules will be also damaged by re-deposition and penetration deeper into the sediments.

The potential impact of nodule mining on the benthic environment was investigated during a number of experiments as DOMES, DISCOL, BIEs, JET, and INDEX and more essential environmental issues were identified (Lavelle et al., 1981; Ozturgut et al., 1981; Tkatchenko at al., 1996; Trueblood at al., 1997; Yamada and Yamazaki, 1998; Thiel, 2001; Radziejewska et al., 2001; Sharma, 2011). Although these experiments produced disturbances much lower in intensity and many orders of magnitude smaller in spatial scale than would result from commercial mining operations, they provide some insights into the sensitivity and recovery times of abyssal nodule communities subjected to mining disturbance. Some of these studies have been shown not to have any deleterious effects or have been demonstrated to have minor or otherwise acceptable impacts without the danger of producing serious long-term, wide-ranging, and undesirable consequences.

Nevertheless, the commercialization of deep-sea nodule resources requires large-scale mining tests with subsequent monitoring programs that will yield results to allow the establishment of a reliable environmental impact assessment. The scale and subsequent impacts of mining operations on the environment are dependent on the mining technology used. At present, the exact technology to be used for the mining of polymetallic sulfides is not known. However, it is highly important to define the optimal technological pattern and environmentally friendly mining system in relation to the local geological, geotechnical and environmental conditions of the mineable area, already at the phase of early design guidelines (Morgan at al., 1999; Oebius at al., 2001; Chung, at al., 2002; Chung, 2003).

4. IOM environmental practice: results and future efforts to minimize the anticipated impact on the marine environment

The main objective of the IOM activity as a contractor with the ISA is to delineate nodule blocks and identify nodule resources/reserves within prime areas that could be mined in the future. In order to minimize the anticipated environmental impact from deep-sea mining of polymetallic nodules, the current efforts of IOM are also focused on a research of an optimal technology pattern in relation to the local geological, geotechnical and environmental baseline conditions of the area identified as the IOM's first generation mineable exploration block H11 (Stoyanova, 2013). For the development of such site-specific mining design, the following factors and criteria were considered: size of a mineable site, nodule grade and abundance, annual recovery rate for a single mining unit, duration of mining operations, dredge and sweep efficiency of the collector, seafloor disturbance etc.

Mining site determination

The factors influencing the mining site determination include:

- production factors (annual recovery rate and duration of mining operations), which determine the cumulative nodule recovery required from a mine-site;
- site factors (nodule abundance and mineable ratio), which combine to indicate the tonnage of nodules available for recovery from mine-site;
- system and other factors (dredge and sweep efficiency, net nodule recovery, net mining efficiency etc.), which will determine the percentage of the available nodules that might actually be recovered.

Based on the available published information, a mining site was defined as a portion of the seabed, where a commercial operation could be maintained during 20-25 years with a production of 1.5 to 4 million tonnes per years of nodules with an average containing of 1.25-1.5% nickel, 1-1.4% copper, 27-30% manganese, and 0.2-0.25% cobalt (Herrouin at al., 1989; Sharma, 2011).

The IOM's site most perspective for future mining and having about 5370 km^2 was selected on the base of comprehensive exploration research carried out within 2001- 2009. Polymetallic nodules in the studied area are partially embedded in the semi-liquid layer (Fig. 3, *middle*) covering the seafloor up to 61% (Fig. 3, *left*), and the abundances amounted from 3.9 to 19.1 kg/m^2, averaging 13.4 kg/m^2 (wet nodules). At most studied stations (78.4%), the nodule abundance is higher than 10 kg/m^2, thus the local heterogeneity of habitat within the studied area comprises patchiness of nodule-bearing and nodule-free sites. Nodule size distribution can be summarised as follows: nodules < 2 cm: 4.0%; 2-4 cm: 25.6%; 4-6 cm: 30.3%; 6-8 cm: 20.9%; > 8 cm: 19.2%.

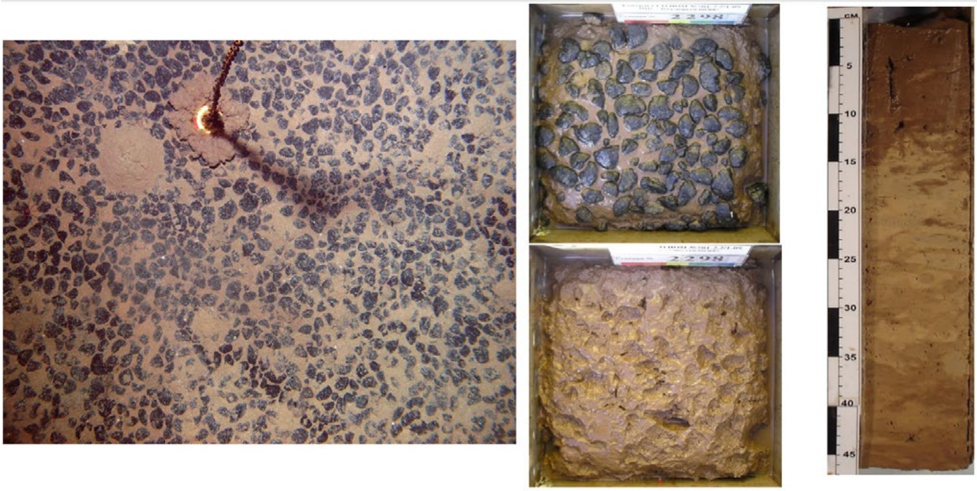

Fig. 3. Photograph of the seafloor (*left*) taken at station ID 2298 shows patchily distributed nodules with 59 % estimated coverage; on board box corer content photograph (*middle, upper*) with 16.6 kg/m^2 nodule abundance; on board box corer after collecting the nodules (*middle, lower*), and sediment core (*right*)

Sediments of the boundary semi-liquid layer (up to 15 cm thick) consist of siliceous ooze and siliceous-clayed ooze, the clay fraction accounting for 55.9 - 93.6% (85% on the average) of the bulk weight. Sediment in the layers deeper than 15 cm was denser and more compact, clayey, and mottled due to the presence of remains of in faunal burrows filled with diagenetically transformed, darker material derived from the overlying sediment (Fig 3, *right*).

For the purpose of this study, taking into account current mining, geological and economic criteria and practices of nodule deposit contouring, a significant portion of about 1570 km^2 (29%) was excluded from the previously recognized mineable site of 5370 km^2 due to the occurrence of topographic obstacles for the movement of nodule collector, metal-poor deposits with a total value of Co+Ni+Cu < 2%, and nodule deposits with less than 700 m in width. It was estimated that the size of the IOM's first generation minable site/block is about 3800 km^2, virtually uniformly covered by nodules with their average abundance of 12.6 kg/m^2. A total resource of 48.1 million tonnes of wet nodules (or 33.9 million tonnes dry nodules) based on the kriging geostatistical method were estimated within the H11 mineable block (IOM, fund data).

Seafloor covered during mining operations

At the rate of 3 million tonnes per annum (dry nodules), with an annual operation time of 300 days/year for average nodule abundance of 12.6 kg/m^2, the relevant area of 0.79 km^2 will be mined daily. Taking into account the mining system factors, i.e. both dredge and sweep efficiencies of 0.65, it is assumed that an area of 0.52 km^2 will be contacted daily by the nodule collector. Similar data were reported from Ozturgut (1981a) and Sharma (2011) where for commercial production of 10,000 and 5,000 t/day for an optimum nodule abundance of 10 kg/m^2, the actual area mined will be 1 and 0.5 km^2/ day, respectively. In consequence, over 10 years' life of mining in the IOM's prime mineable block the seafloor area of 1548 km^2 would be directly impacted by the mining operation.

Sediment disturbance

The amount of mobilized sediment thickness during mining operations depends from the penetration depth of collector and ration between nodules and surrounding sediments. Because the size of nodules the in studied area was identified as up to 8 cm for about 80% of all data, it is assumed that the depth of collector penetration into the sediment for the initial removal of nodules would be limited to 10 cm, but 5 – 6 cm depth of penetration is more appropriate. Nodule coverage in the H11 block calculated on the base of photo-profiling data ranging from 0 to 60 % (in average of 38 %), i.e. about 62 % of the upper 6 cm layer consists of sediments. Hence, the amount of sediment disturbed by the collector as a result of sweeping an area of 0.52 km^2 could be about 19,190 m^3/day. As the bulk density of siliceous ooze in the studied area averaged to 1.18 g/cm^3, thus the weight of sediment to be re-suspended would be approximately 22,645 t/day. About 90 % of re-suspended sediments, aggregated in knobs of various sizes will resettle immediately and in general will remain near the seafloor (Jankowski et al., 1996; Rolinski et al., 2001; Oebius, 2001). The remaining particulates consisting of sediments, nodule fragments, dissolved nutrients, trace metals, and benthic biota will be sent to the surface through the lift pipe.

Impacts on the biological communities

The IOM environmental baseline survey of benthic fauna showed that the average abundance of macrofaunal organisms within 0- 10 cm sediment layer (based on data from 10 random box-corer stations studied in 2009) was 301 inds/m^2, ranging from 168 to 460 inds/m^2. Besides macrofauna, a total of 461 nodule faunal individuals were collected from 50 box-corer stations, belonging to four taxa: bryozoan (bryozoans' colony-forms), polychaets, stephanoscyphus, and sponges, comprising about 80% of all the identified individuals. Meiofauna was studied during the IOM's BIE and the results showed that meiobenthic abundance within the non-impacted control area changed over 1995 – 2000 within a fairly wide range of 86 – 394,000 inds/m^2 with a corresponding biomass of 3 – 28 mg/m^2 at the top 3 cm of sediment. Analyses of 11,758 bottom photographs taken along 7 transects in 2009 identified 8675 mega-faunal individuals, which could be converted to about 1640 inds/10,000 m^2.

On average, total benthic biomass including the weight of the larger epifauna was estimated at 0.65 g/m^2 (wet weight), which corresponded with the data obtained from other studies in the CCZ. Thus, the value of benthic biomass intercepted by the collector would be about 335 kg daily in case the collector comes in contact with an area of 0.52 km^2. The destruction of benthic organisms during mining operations is expected to produce a major portion of environmental issues for the polymetallic nodules production.

Environmental approaches to the development of mining system components

As already mentioned, the anticipated environmental impact mainly depends on the mining technology to be used. The recent concepts of mining system models are principally based on the Lockheed/OMCO mining system tested in the Pacific Ocean in 1976 and 1978 (Chung, 1985; Welling, 1981; Chung, 2003). In general, the integrated mining system includes the seafloor nodule collector, the buffer, pipe system for vertical transport, and the mining ship/platform (Fig. 2). At present, the IOM carries out the research and design works focused on a so-called hydraulic mining method. There are several proposals for the technical approach to be used in order to achieve satisfactory results in the operation of picking up the polymetallic nodules and transporting them vertically to the mining ship or platform.

To avoid the generation of a surface plume, the second discharge pipe supported by on-board pumps should be used to return the bottom water and remains of sediment particulates as well as dissolved nutrients and trace metals to the buffer subsystem after on-board separation of nodule fragments. The aim is to ensure that no mining impact should occur not only at surface water layer but also in the entire water column. The only impact to surface water will be the presence of the mining ship, the specialized bulk cargo carrier, and the riser and discharge pipes. Therefore, the bulk of seafloor re-suspended sediment, cut-off nodule fragments and the remains of benthic biota will be stored up in the buffer subsystem and periodically discharged in the path of the collector. It is assumed that the sediment blanketing will occur mostly within the already mining affected habitats and thus will ensure the survival of animals living outside the mining tracks.

5. Conclusions

The current international environmental regime established under the UNCLOS and administrated by the ISA requires effective protection for the marine environment from harmful effects, which may arise from the activities of contractors in the Area.

Basing on the accepted precautionary principles, the Environmental management plan was set up for the CCZ. Also, the areas selected for particular environmental interest were delineated to safeguard biodiversity and ecosystem function in the abyssal Pacific region targeted for nodule mining.

Deep-sea mining of polymetallic nodules is foreseeable and a reduction of environmental effects remains an important objective for the development of nodule mining systems. The categories of impacts discussed all involve a level of uncertainty due to the mining technologies not having been tested *in-situ* so far.

In order to minimize the adverse effect on the benthic community, IOM recognized some technical approach in developing the system components and ultimate reliance on the environmentally sound strategy became more vital and sustainable.

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TECHNOLOGY DEVELOPMENT

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NICKEL, COPPER AND COBALT CONCENTRATE PRODUCTION FROM POLYMETALLIC NODULES

Abstract. The geological mining research and experimental pilot exploitation of polymetallic nodule (PN), requires a simple and viable processing technology variant, with a low capital cost investment which would allow for a commencement of commercial concentrate production in scope of Ni, Cu and Co, in order to refinance the costs of mining and experimental development of commercial technology in the medium term. Until now, the most perspective technology is still pressure acid leaching of nodules with laterite mixed or not, with a potential use of pyrite as a reducer agent. In this paper two short technological flow diagrams are proposed for the processing of polymetallic nodules which will be extracted during the experimental test pilot mining. Its implementation and economic benefit to be gained from being applied in the plants currently in operation are discussed. Such a variant will allow for the pilot study of mining while providing financing for the industrial pilot test to be executed in the near future.

1. Introduction

The production of nickel and cobalt may be based on a laterite process involving pressure acid leaching (HPAL), the ammonium carbonate process known as Caron process (Punta Gorda plant, Cuba and Yabulu refinery, Australia) as well as ferronickel production from serpentine (Cerro Matoso, Colombia and other plants in several countries).

The HPAL process is recognized as technology with lower operating costs and higher recovery rates, with plants operating in Cuba, Australia and Ambatovy, among others. It is considered so far the most perspective technology from the economic point of view for the processing of polymetallic nodules (Aja, R, Castellanos, J. and Hernandez AN 2014) and is a pressure leaching technology with the use of a reducing preferably by pyrite (Castellanos, J., 2014), with the variant using a bank of pachuchas

(RIP) resin in pulp used for copper separation and another bank of RIP for the separation of Ni and Co.

The manganese solution precipitates to pressure and temperature as manganese sulfate. This product is calcined to MnO2, and SO2 is recycled for the production of acid. This technology is still in development on a laboratory scale and is planned to run on a pilot scale in the next 3- 5 years. Recent studies (Zeljko, Kamberovič, AMES, 2004, Her P. Agarwal, 2003, Liu Wan-rong, 2010, Kristen, B. 2010, Kwatara, M., 2011, Kvstov, B. and lligallic, 2013, Biswanditakav and Tapan Kumar Panda, 2013) have focused on finding a simple technology for the production of a Ni and Co concentrate, nickel pig iron or a commercial product, with low power consumption and cost. Many studies of the segregation process were carried out in New Caledonia, Cuba, Russia and other countries (Symposium of the Serpentine, 1980, Cuba, Castillo, CR and Titova, Z. P, 1980), concluding that it was feasible to use the process of segregation, but the efficiency of this process is dependent on maintaining the system pressure to control the chlorides concentration in the oven.

Studies in the last 3-5 years have shown that the segregation process can be improved and constitutes an alternative for launching the production of Ni and Co in a short timeframe with low operating costs, as has been reported in publications mentioned earlier in this paper.

2. Background

The Cuban nickel industry has over 70 years of experience in the exploration and exploitation of laterite deposits in the north-eastern province of Holguin, Cuba. More than 800 million tons of developed reserves of nickel and cobalt and over two thousand million tons of total laterite resources are concentrated in this region.

The Republic of Cuba is a member of the Joint Organization Interoceanmetal since its foundation in 1987, and is represented by Business Group Cubaniquel (Cubaniquel) from the Ministry of Energy and Mining (MEM). Cubaniquel is the member of IOM nearest to the area in the Clarion-Clipperton zone. In the Fig 1 the route of transportation is shown).

Fig. 1 PN transportation route from the IOM exploration area in the Clarion – Clipperton.

CUBANIQUEL has published more than 50 research papers on the technology of polymetallic nodules processing. In 2010 the research centers of the Cuban nickel industry and CIPIMM CEDINIQ were involved in the optimization study of the existing methods for the recovery of base metals from the polymetallic nodules (M. Pelegrin, Aja R. and R. Causse). A new approach to the application of the existing methods for the extraction of base metals from the polymetallic nodules was developed by the CEDINIQ and CIPIMM. Fig. 2 shows the block flow chart of the optimized technology. The research was carried out along two lines:

- Various processes involved in polymetallic nodules leaching with sulfuric acid under pressure in the presence of sugar cane molasses were studied in the Research Center Nickel, at CEDINIQ.
- Several processes involved in the leaching of nodules with sulfuric acid under pressure in the presence of pyrite were investigated in the Research Center for the Mining and Metallurgical Industry, CIPIMM.

Experts from CIPIMM, CEDINIQ and IOM evaluated the results and selected the best aspects of the technologies studied in both lines of research, concluding that the studied technologies allowed for achieving a high recovery efficiency for base metals (Ni, Cu, Co, Zn and Mn) and the possibility of using the installation for nickel pressure acid leaching plant infrastructure existing in Moa, Cuba.

Even though the technology studied is more efficient and has lower operating cost, the expert opinion was that additional studies are required to find a technology enabling continuous processing of marine nodules recovered in pilot mining tests, with lower CAPEX and rapid recovery of the costs of deposit extraction. This paper describes a new approach to methods and results of preliminary economic evaluation of the simple block flow chart technologies to be used for the processing of all polymetallic nodule from the pilot mining experiment.

3. Investigation works and development

Recent studies (CIPIMM, 2015-16, US Patent 4402735A) yielded good results. CIPIMM studied one sample of polymetallic nodules (1.2% Ni, 0.15% Co, 1.3% Cu and 32% Mn). The work has shown that separation technology can produce concentrate by flotation or magnetic separation or combination of both techniques. In this case, a concentrate of Ni, Cu and Co can be produced, with a content equal or higher in Ni and Cu (6-12%) and Co (1.0-1.2%). Under these conditions, metal recovery depending on the separation conditions and the controlled magnetic field will be between 70 and 80%, allowing for the production of a commercial concentrate.

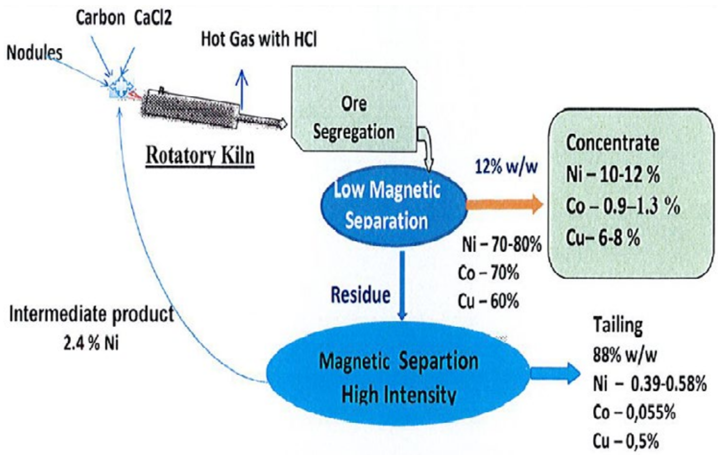

Fig. 2 Conceptual flow chart of separation process to be used for the production of concentrate including Ni, Co and Cu.

In Figure No. 2 the segregation process flow chart is shown for the production a concentrate including Ni,Co and Cu while the table N°1 shows the economic evaluation of this technology option. The simple separation scheme for the processing of 500,000 tons of polymetallic nodules reports an economic benefit of $ 12.4 million, so after the rent for the facility is discounted, a profit of $ 7.0 million to the supplier of the nodules which could for example be “Interoceanmetal (IOM) Joint Organization”, Poland, is obtained.

Table 1. Economic evaluation of Ni, Co and Cu production by Separation Process

OPEX				**Cost**	
			Amount	**USD/t**	**MUSD**
Raw Materiał, t Polymetallic Nodule			500 000	80	**40 000**
Commodity					**11 428**
Power, maintenance, salary and others expen.					
Contingency @ 10%					**6 455**
Total Operating Cost					**71 002**
Cost/lb Ni	**Cu**	**Co**	**Ni**	**6.71**	
Metals Production, t	**3900**	**525**	**4800**		
Price LME, Ni USD/lb			***7.50***		
Price LME, Co USD/lb		***10.00***			
Price LME, Cu USD/t	***6 500***				
REVENUE, MUSD	**19 266**	**8 244**	**56 548**		**84 058**
EARNING					**13 056**
CAPEX. Payment for the leasing of the facility					**4 441**
NET EARNING FOR IOM					**8 615**

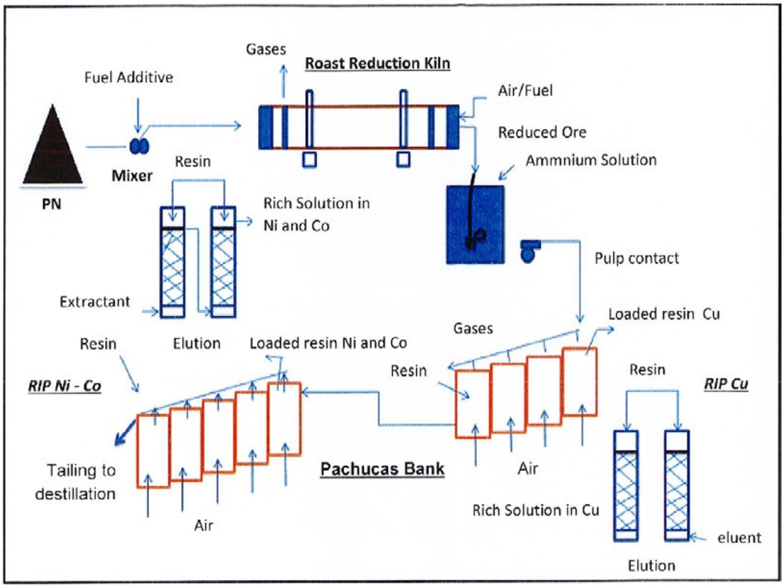

Fig.3 Improved Technology Reduction Roast- Ammonium Carbonate for the Processing of Polymetallic Nodules.

Table 2 Economic evaluation of Ni, Co and Cu production by Modify Caron Process

OPEX				**Cost**	
			Amount	**USD/t**	**MUSD**
Raw Materiał, t Polymetallic Nodule			500 000	80	**40 000**
Commodity					**16 419**
Power, maintenance, salary and others					**17 620**
Contingency @ 10%					**7404**
Total Operating Cost					**81 443**
Cost USD/lb Ni	**Cu**	**Co**	**Ni**	**7.24**	
Metals Production, t	**3900**	**675**	**5100**		
Price LME, Ni USD/lb			***7.50***		
Price LME, Co USD/lb		***10.00***			
Price LME, Cu USD/t	***6 500***				
REVENUE, MUSD	**20 470**	**12 017**	**61 348**		**93 834**
EARNING					**12 392**
CAPEX. Payment for the leasing of the facility					**5 327**
NET EARNING FOR IOM					**7 065**

The variant uses a simple ammonia carbonate process (selective reduction and resin in pulp into contact tank), it was evaluated in laboratory scale and the proposed diagram is shown in Figure 3.

Technological results indicated that we achieved a high recovery of metals, operating with a simple technology setup (elimination of 66 turbo aerators and 12-15 thickeners) can be achieved. The developed technology (Figure 3) consists of selective reduction of polymetallic nodules in the ovens of flats type Herrshoff, with the reduced ore being sent to the tank's contact with an ammonia solution, containing 50% of the current process (Yabulu, Refinery, Australia and Punta Gorda Nickel Plant, Cuba).

Contact tank pulp is processed in a bank of pachucas (8-10) by the process of resin in pulp (RIP) to separate the copper and the last Pachuca pumped another bank of pachuca with resins, similarly as in the previous one, where Ni and Co of is separated from the pulp.

The resin undergoes the elution with H2SO4 and the final product can be metals, sulfur, or pure metal salt. Recovery of Ni, Co and Cu, based on the experiments will be 80-85% for Ni, 60-65% for Co and 60-80% for Cu. The commercial product will depend on the market. Economic evaluation reported that profit will be 19.7 millions of dollars, so after a rent for the industrial facility is paid, 14.5 million dollars per year remains for the company conducting nodule ore mining.

4. Conclusions

The studied simple technologies can be implemented in industrial plants in operation and under construction in Cuba (FeNi), with little changes needed in a relatively short time and with little investment, allowing for the processing of the volume of polymetallic nodules mined during pilot marine mining as planned by Interoceanmetal Joint Organization (IOM), Poland.

For the final selection of the technology to be used in the processing of polymetallic nodules extracted as a result of pilot mining experiment, further study is required to minimize the investment, adaptation of equipment and the current technology scheme of plant process, the final commercial product to be adapted to the most attractive market.

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PROCESSING TECHNOLOGIES FOR MN-FE NODULES VERSUS THE METHODS CURRENTLY USED FOR PRODUCTION OF BASE METALS

Abstract. The key properties of manganese nodules and selected aspects of their exploitation were shortly reviewed. Special attention was paid to their chemical and phase composition and some other properties, important from the engineering point of view. The land and deep-sea reserves of Ni, Co, Cu and Mn as well as methods and technologies used or proposed for their processing have been identified and analyzed. The potential suitability of currently used technologies for Mn-Fe nodule processing, especially for nodules from Clarion-Clipperton zone, has been evaluated. The proposals for further research and engineering works in order to develop a processing technology for Clarion-Clipperton nodules have been presented as well.

1. Introduction

Development of modern society requires availability of higher and higher quantity of various metals. Many of them- as for example the rare earth metals (REEs) – not so long as several dozen years ago had no use or were used only in a negligible degree (Graedel T. E., Harper E. M. et al, 2015). Currently, the demand for such metals as Ni, Cu, Co and Mn increased so dramatically that opinions concerning a threatof a quick depletion of metal reserves are commonly presented. During the last 10- 15 years, as the demand for rare earth metals increased dramatically and simultaneously, their availability becomes more and more limited. (E.g. Zepf V., 2013). This situation was a reason for a qualification of many such elements, among others Co and REE, by the European Commission as so called “critical elements” (Anonym, 2014a). Exploitation of Fe-Mn nodules can be one of ways for meeting the continuously growing demand for metals.

Manganese-iron or manganese or polymetallic nodules are underwater accumulations of Mn and Fe oxides, hydrated oxides, oxide-hydroxide and hydroxides containing significant contents of Ni, Co and Cu and a number of other metals at lower concentrations, including REEs. The mentioned metals occur in such minerals as δ-MnO2, todorokite, buserite and asbolan, less frequently birnessite, and amorphous ferric oxide (Hein J., R. Mizel K., et al., 2012). Manganese occurs in those minerals mainly as Mn^{+4}, less frequently as Mn^{+2}.

Nodules are mineral formations and their shapes and sizes are similar to potatoes (See Fig. 1). They can be found (see Fig. 1) in many places around oceans and seas, at different depths, however, the most frequently at a depth of several thousand meters (Secretariat of the Pacific Community, 2013). In last years, more and more importance is attached to REEs, also those which occur in nodules (See Chapter 2).

Although nodules were discovered as early as in 19th century, during famous, oceanographic expedition of HMS Challenger (a British corvette), interest in them as a potencial source of metals, began to grow not before end of the 1950s. Since the 1960s ans 1970s one can again see increase of interest in all aspects concerning the exploitation of these nodules, i.e. their properties, resources, mining, processing, environment, economy, law and politics.

Rys. 1. Konkrecja Mn-Fe i jej przekrój.
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Usefulness of the nodules and also other underwater metal resources, such as crusts and massive sulfides (*Hein J. R., Mizeli, 2013*), as the source of Ni, Co, Cu, and also other metals, cannot be considered without taking into account the existing land resources, the technologies used for their mining and processing, the current and future metal demand and supply trends, the social and environmental protection issues etc. Techniques used for the exploitation must be accomodated to the specific features of a given deposit. A failure to develop a method for mining and processing with adequately high effectiveness and sufficiently low operating costs leads to inability to exploit such deposits and the same applies to the deposits of nodules.

The most important conditions which determine the opportunities for the exploitation of Ni, Co Cu and Mn in land deposits and nodules have been overviewed in the present paper. The comparision concerns first of all the currently used methods for the exploitation of the existing land reserves of Ni, Co, Cu and Mn and- being currently under research – the processing methods for the nodules.

2. The nodules as a future metal deposit

The average composition of nodules from Clarion-Clipperton area, calculated basing on the results of analysis of 66 samples, is displayed in Table no. 1 (Hein R., J., Mizell K., et al. 2012).

Table 1 The average chemical composition of nodules from Clarion-Clipperton area on Pacifik Ocean (Hein R., J., Mizell K., et al. 2012)

Element	Fe	Mn	Si	Al	Mg	Ca	Ti	Cu	Ni	Co	REE*
Unit	%	%	%	%	%	%	%	%	%	%	ppm
Content	6.16	28.4	6.55	2.36	1.89	1.7	0.32	1.07	1.3	0.21	813
Clark	5.0	0.1	27.7	8.3	0.1	3.6	0.63	0.0028	0.0047	0.00021	23.8
Conc. ratio	1.2	28.4	0.2	0.3	18.9	0.5	0.5	382.1	276.6	1000.0	34.1

*REE without Pm

A concentration ratio for a given element which has been calculated as a ratio of its content in nodules and average content in earth crust (a so called Clark) is also given in the Table.

The question of rare earth elements (REEs) content in nodules needs a separate discussion. The REE group contains all lanthanides, and additionally itrium and scandium, which formally do not belong to lanthanides, but because of similarity of their chemical properties and co-occurence together with lanthanides, are included in them. As a result, REE group includes 17 metals: 9 in the group of Light Rare Earth Elements- LREE (Sc, La, Ce, Pr, Nd, Pm, Sm, Eu i Gd) and 8 in the group of heavy REE, so called HREE (Y, Tb, Dy, Ho, Er, Tm, Yb i Lu). The collective content of REEs in nodules from Clarion-Clipperton area amounts to 0.081 %, and it is much smaller than their contents in the currently exploited deposits of REEs, such as e.g. Boyan Obo, Lemki Pass, Thor Lake, Olympic Dams or even in alluvial deposit (Vonncken H. T. L., 2016). The concentration ratio of all REEs in nodules equals to 34.1 but ratios for individual elements range from 0.8 for scandium to 291 for itrium. For the rest of REE the concentration ratios range from 3.7 to 8.2. They are not too high but in case a technology of nodules leaching with sulfuric acid was used, REEs would pass to solution with a total efficiency of approx. 50 % and could be recovered (Kuyng H., Pankaj Ku et al.:

2013). In case a pyrometallurgical technology was used, REEs would pass to slag and their recovery would be very difficult.

The question whether the production of Ni, Co, Cu and Mn from the nodules is profitable is a more complex one. Basing on the prices of metals, according to Investment Mine for the day of 28.01.2015, the values of the most important metals contained in 1 tonne of nodules and corrected for their recovery, have been calculated and are given in Table 2.

Table 2. Value of metals, which can be recovered from 1 ton of nodules (dry mass)

Metal	Price USD/t	Content, %	Recovery, %	Value USD	Share, % NiCuCoMn	Share, % NiCuCo
Ni	8544.90	1.30	90	99.98	25.3	54.1
Cu	4500.96	1.07	90	43.34	11.0	23.4
Co	22010.07	0.21	90	41.60	10.5	22.5
Mn	1480.00	28.4	50	210.16	53.2	-

For manganese, one assumed that only 50 % of Mn which is contained in nodules can be recovered. Even in such a case, its value makes more than 50 % value of income from sale of all metals. Hovever, justification for Ni, Co and Cu recovery is obvious, whereas the questions concerning the recovery of manganese are more complex.

Manganese can be produced both from slags of nodule smelting, likewise tailings of ammoniacal leaching (Randhawa N. S., Jana R. K., et al. 2012). Because Mn content in leaching tailings amounts to 26 % only (and 10 %- Fe and 8- % Si) to make production of Fe-Si-Mn alloy possible, addition of rich manganese ore with content of Mn bigger than 40 % is necessary. Such a solution is very disadvantegous, because would diminishes mass of processed nodule in significant degree. Furthemore, such enrichement would be probable impossible in longer period of time, considering systematical lowering grades of manganese deposit (Machamer J. F., 2002).

Hovever, the most important question which is bound up with manganese production is maintaining a proper balance between demand and supply. The current annual world production of manganese (See Chapter 3) corresponds to its mass contained in 6.6 mln ton nodules. Such level of nodule processing could be achieved without any difficulties in one year because a number of countries interested in underwater exploitation of nodules is significant (ISA, 2010). For nodule exploitation amounting to 6.6 mln Mg per a year, tonnage of produced manganese will constitute more than 15 % current world production, what would have unprofitable influence on Mn prices. Therefore, for the existing level of land Mn reserves, considering influence this metal on future incomes must be done very carefully and with regard to the economy of not only a specific country but also global market.

At this stage of consideration, REEs and other metals, first of all Zn, Mo, V, were not taken into account also because they occur in the nodules in small amounts and a justification for their recovery will be dependent on the choice of a proper technology tailored for the processing of thenodules, and especially, on the availability of other sources of those metals. Furthemore, because the value of above mentioned metals is marginal in comparison with Ni, Co, Cu and (Mn), this question will not have decisive significance for income level and for making a decision about prospective recovery of those additional metals.

Nickel content in the nodules is at a level close to currently mined deposits of limonitic latherites, Cu content is slightly higher than in average ores exploited all over the world (USGS, 2014), whereas Co content is even significantly higher (USGS, 2015). The presence of many metals in the nodules and their quite high contents suggests high attractiveness of this raw material comparing to land reserves. Recovery of Ni, Co, Cu and possibly other metals as well as their subsequent separation in order to produce market products, will need the application of a complex technological flow-sheet and a number of specialized equipment pieces. As a result, nodule processing will need high capital level. An adaptation of the available production capacities of the existing smelters- if possible, and especially for the HPAL (High Pressure Acid Leach) plants currently closed or planned for closure, such as e.g. Cawse, Bulong, Murin Murin, (Anonim, 2015a, Dreisinger D., 2013), could allow for lowering the level of capital costs and a general improvement of investment effectiveness. For those reasons, the existing technologies for processing the nickel, cobal and copper ores have been overviewed and analysed in order to evaluate the possibility of their application for nodule processing.

3. Land reserves of selected base metals vs reserves in Fe-Mn nodules

The potential attractiveness of nodules as a source of base metals (Co, Ni i Cu), and possibly also other metals, especially Mn and REE, is unquestionable, hovewer the open question is when their exploitation will become profitable. It is a multi-aspect issue and such factors as demand and supply, prices, other raw materials availability, political issues as well as social and environmental conditions belong to the most important ones. The attempt at an evaluation when land reserves of Ni, Co, Cu and Mn will be depleted has been presented below. Despite the approximate character of the attempt, caused by a number of limitations, it allows for determining general trends explicitly.

The land cobalt reserves are estimated at the level of approx. 7.2 mln Mg of Co, and annual production amounts to approx. 112 thousand ton Co (USGS, 2015). Basing on those data, the time when Co deposits will be depleted amounts to approx. 64 years. In the case of nickel, the total reserves of this metal are evaluated at level of approx. 81 mln ton. At the annual production amounting to approx. 2.4 mln ton Ni (USGS, 2015), it gives the time when reserves will be depleted as amounting to 34 years. In 2012 the production of manganese amounted to 18.0 mln t, at mineable resources equal to approx. 570 mln t Mn, what should be enough for approx. 32 years of exploitation (USGS, 2014). As far as copper is concerned, mining production of this metal in year 2015 amounted to approx. 18.7 mln Mg Cu (USGS, 2015). Because the existing Cu reserves are estimated as amounting to approx. 700 mln t, this means that they will be exhausted after 37 years. If one takes into account also the known probable land reserves, the period when Cu deposits will be depleted would increase several times. Furthemore, systematically executed exploration works lead to continuous discovery of new reserves, which as the existing practice confirms, causes further extension of the period of reserve depletion.

The underwater nodule reserves in the area of Clarion-Clipperton zone are only estimated as amounting to approx. 21 bilion tonnes (ISA, 2010), what for the composition given in Table 1 gives approx. 5964 mln t of Mn, 273 mln t of Ni, 224,7 mln t of Cu i 44,1 mln t of Co. Comparing to the land reserves (see above), those numbers are very promising but taking into account the difficulties and risks connected with nodule mining, the reserves of Ni, Co, Cu (and Mn) in the nodules are not competitive with the land reserves of those metals.

Currently, the world is in the period of low and very low prices of base metals. This forces the producers with the highest operating costs and/or the lowest profitability into temporary closures of their mines. This can be seen especially clearly for the market of nickel (and partially cobalt) where the majority of plants processing the latherites (nickel ores with the lowest Ni content) by pressure leaching with sulfuric acid have been closed, e.g. Cawse, Bulong (Dreisinger D., 2013), or their closing is considered, e.g. Murin Murin (Anonim, 2015a).

4. Methods of nickel and cobalt production from land reserves

Cobalt is produced almost exclusively during production of other metals and this applies to both oxide and sulfide ores. Nickel production delivers approx. 57 % of world cobalt production and copper production- approx. 37 % of cobalt (Gecamine, Kongo). The rest of cobalt comes from low-grade Co ores, Bou Azer arsenic ore (Marocco) and the processing of smelting and mining tailings.

Copper is produced mainly from sulfide ores of this metal**.** The most important three types of Cu deposits are: porfiric, stratoidal, and volcanous-sedimentary. Only a small part of the production (approx 21 %) cames from oxide and oxide-sulfide deposits. The biggest, primary copper producer is positively Chile, with its mining production amounting to 5.78 mln Mg Cu per a year. The next places are occupied by China (1.56 mln), Peru (1.38 mln), USA (1.28 mln, Australia (0.99 mln), Congo (0.84 mln) and the rest of 48 remaining countries (USGS, 2015). The biggest producers are Codelco (Chile), Freeport –McMoRoan (USA), Glencore Xstrata (Switzerland), BHP Billiton (Australia), Southern Corporation (Grupo Mexico) and Rio Tinto (United Kingdom). Production of copper from sulfide ores is accomplished in the majority of cases by flotation, flash furnace (electric furnace), converting and electrorafination. Oxide and oxide-sulfide ores are usually processed by hydrometallurgical method, most frequently by heap leaching.

Nickel is produced from two main types of ores: sulfide and oxides (laterites). As early as1970s, more than 60 % of nickel production came from sulfide ore while a share of latherite surpassed 50 % and this trend is going to only strengthen.

The conventional sources of laterite nickel ore are: New Caledonia – with laterite deposits in Nepoci, Thio, Kouaouna, Tebaghi; Cuba – with four mines and processing plants like Empresa Niquelfero Ernesto Che Guevara w Punta Gorda, Moa Nickel S.A (Sherrit International Corp. – 50 % and government 50 %) in Moa, Empresa Niquelfero Comandante Rene Ramus Latour in Nicaro and Empresa Mixta Ferroniquel S.A. (government of Venezuela- 50 % and Cubaniquel- 50 %) (Wacaster S., Baker S. M., et al., 2015); Cupey and Bonao – Dominikana; Cerro Matoso – Colombia; and HPAL plants e.g. Murrin Murrin, Bulong and Cawse – Western Australia. Cobalt is also produced in the majority of those plants.

Sulfide copper ores are typically polymetallic and apart from Ni they can also contain Cu, Co and metals of Platinium Metal Group (PGM). Nickel sulfide ores are mined by e.g. Anglo American Platinum and Impala Platinum Holdings Ltd. in South Africa, Voisey`s Bay in Canada, Forrestania (one of the richest nickel deposits all over the world), Agnew, Kambalda and Mount Keith in Australia, Norilsk and Pechenga in Russian Federation and others. The extraordinarily rich and unique stratoidal, sulfide copper deposit, containing also cobalt and situated at the border between Congo (Katanga province) and Zambia needs a separate mention. Thanks to those deposits, The Democratic Republic of Congo provides approx. 55 % of cobalt and owns the biggest reserves of this metal in the world. Sulfide ore processing is usually accomplished according to the process path comprising: a) production of collective concentrate, and next, its converting in order to remove iron and to increase nickel content; b) refining of rich nickel matte. The refining can be accomplished by a pyrometallurgical-hydrometallurgical method, using oxidizing roasting and pressure leaching, or by hydrometallurgy only, using various leaching methods. If copper is present in ore, it is separated at the proper stage of technological process.

Laterites can be processed through: a) direct smelting in order to significantly diminish Fe content and to produce ferro-nickel which is the marketable product. This method is used for saprolitic type of ore and only Larco smelter in Greece produces FeNi alloy from limonitic laterites (Anonim, 2016 a); b) smelting with sulfidization, and next, converting in order to produce rich sulfide matte with lower Fe content (saprolitic ore); c) Caron process (consisting in laterite reduction at a higher temperature in furnace, and next, ammoniacal leaching of roast), e.g. Nicaro and Punta Gorda- Cuba, Yabulu- Australia, Tocantis- Brazil (Raid. J. G., Fittock J. E., 2004; Taylor A., 2013). Caron process is used for limonitic type of laterite with higher content of Mg); d) various types of pressure leaching with sulfuric acid (HPAL- High Pressure Acid Leach, PAL- Pressure Acid Leach and LPAL- Low Pressure Acid Leach), e.g. Bulong, Murin-Australia (Anonim, 2015c), Goro- New Caledonia (Home A., 2014), Ambatovy- Madagascar (Anonim, 2016a), Moa Bay- Cuba; d) various types of atmospheric leaching with sulfuric acid, such as AL- Atmospheric Leach, ATL- Atmospheric Tank Leach) or combinations of pressure leaching and atmospheric leaching, e.g. ATL + HPAL- Agata Project, (Anonim, 2014b), or EPAL process (Enhanced Pressure Acid Leach), which is a combination of PAL and AL- e.g. Acoje (Anonim, 2011) and ATL + LPAL process, used for limonitic and transition ores – e.g. Raventshorpe (Anonim, 2016b).

In the last years, the description of a new, interesting process: Direct Nickel Process has been published in the literature (See. Fig. 2).

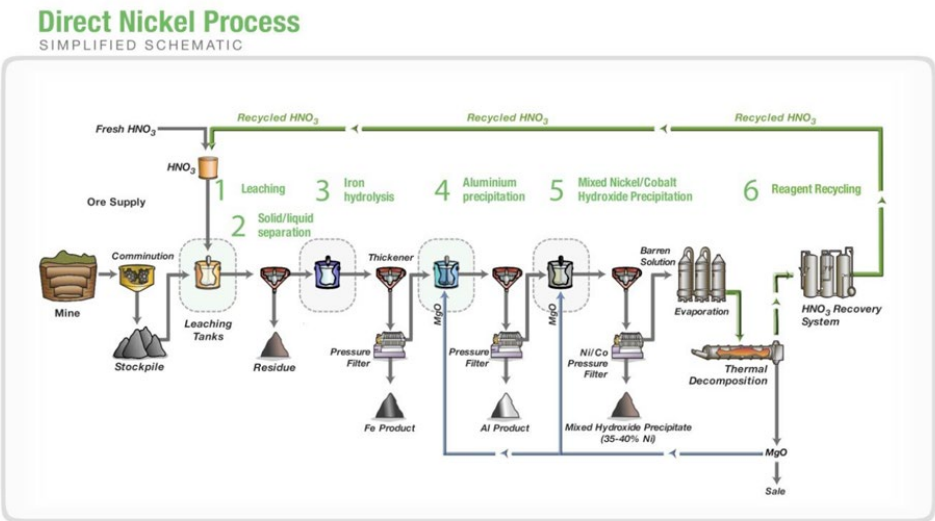

Fig. 2. Flow-sheet of Direct Nickel Process (McCarthy F., Brock G., 2015).

The process consists in laterite leaching with nitric acid and the final product is MHP (45.4 % Ni) or MOP (68.1 % Ni), with recovery higher than 90 % (McCarthy F., Brock G., 2015). In order to reduce the cost of nitric acid, it is recovered using a thermal method and acid is returned to leaching stage. Additionally, Al and Fe precipitates are produced, which can be market products as well.

The final products of hydrometallurgical plants processing the laterite ores can be highly varied: a precipitate of mixed sulfides, so called MSP – Mixed Sulfide Precipitate, e.g... Coral Bay and Acoje – the Philippines, Moa Bay- Cuba, Yabulu Rafinery – Australia; nickel hydroxide (so called NHP- Nickel Hydroxide Product); Ni and Co carbonate or oxide, e.g. Goro – New Caledonia; sometimes Ni and Co hydroxide, so called MHP – Mixed Hydroxide Precipitates, e.g. Raventshorpe – Australia. Furthemore, various combinations are also possible: for example, in Bulong plant, nickel was produced by electrowinning of solution, which was received as a result of direct extraction, whereas cobalt was produced after its prior precipitation as sulfide and then its dissolution under pressure, with the presence of oxygen.

In order to produce pure Ni and Co, or their compounds, hydroxide, carbonate, oxide or sulfide precipitates are processed in a separate circuit, as a general rule. In some cases, it is accomplished in the same plant where leaching is being conducted (e.g. Murin Murin- Australia, Yabulu Rafinery- Australia, Ambatovy- Madagascar (Anonim, 2016c), etc.), and in other, in separate rafneries (e.g. Nickelverk SA Company in Norway, Niihama and Harima rafineries in Japan, which produce nickel sulfate (Anonim, 2013). Various processes can be used for refining: for example, hydrochloric leaching in the presence of chlorine (e.g. Niihama refinery- Japan, NikielVerke SA- Norway (Anonym, 2016d); pressure leaching in the presence of oxygen (e.g. Harima refinery- Japan (Anonym, 2013); ammoniacal leaching; and others.

5. Nodule processing technologies

Information about nodule processing technologies given in the underlying chapter, concerns only the results of laboratory tests and- in the best case – pilot tests, because there are no running plants.

Thanks to similar ion radius, Ni, Co and Cu can substitute Mn^{+4}, Mn^{+2} and Fe^{+3} ions in manganese and iron oxide lattices which constitute the nodules. Fine size of Mn and Fe oxide phases, which are lower than 100 Å, makes the usage of conventional processing methods impossible, which includes: magnetic separation; flotation; gravity concentration; or screening, which is used with success for laterites, sometimes (Anonim, 2016e; Baozhong Ma, Wang, et. al., 2013). In order to liberate nickel, cobalt and copper, it is necessary to destroy thelattice of Mn and Fe oxides by reduction roasting or by leaching. Favourable forms of Ni, Co and Cu (and also Mn and Fe) occurrence in nodules (See Chapter 1) cause them to be easily amenable for processing with various hydrometallurgical techniques. Thanks to that, metal recovery values usually achieve a level higher than 90 %, and even recoveries at level of 98 % are quoted in the literature (Premchand, Jana R. K, 1999).

The majority of methods for processing the nodules, which have been proposed up till now, involve an adaptation of currently used technologies for the processing of laterites, and- in some cases- also sulfide ores of Ni and Co. It is caused by some similarities existing between the nodules and currently mined laterites. As a result of research work which started at the end of the 1960s, three groups of nodule processing methods have been elaborated: 1) hydrometallurgical (ammoniacal leaching, leaching with various acids (H_zSO_4, HNO_3, HCl, citronic acid), acid leaching in the presence of various reductors (e.g. Mn^{+2}, Fe^{+2}, Cu^{+1}, CO, SO_2, Cl_2, coal, coke, alcohols, hydrazine, pyrite, sodium sulfite, etc.); 2) pyrometallurgical; and 3) hybrid- pyrometallurgica l-hydrometallurgical (Nicaro process, smelting to produce NiCoCu alloy and its futher processing by various hydrometallurgical metods, sulfatization roasting, chlorination roasting, segregation process).

The exemplary flowcharts, representing two of the mentioned groups of technologies: pyrometallurgical- on the left; and hydrometallurgical- on the right, have been presented in Fig. 3 (ISA, 2010). In reality, pyrometallurgical technologies are limited to the production of a semiproduct- NiCoCu alloy. Its mass amounts to only 6-8 % of a primary mass of nodules. Pyrometallurgical processing can be treated, to some degree, as a concentration process which removes manganese and iron to slag. Next, NiCoCu alloy is oxidized, sulfidized and converted, in order to produce rich sulfide matte. It is a feed for the production of pure metals by oxidative leaching, e.g. INCO technology (ISA, 2010). Manganese can be recovered both from slag or tailings after ammoniacal leaching (Ranhava N. S., Jana R. K. et al., 2013), if justifiable.

Technologies for the processing of nodules, which have been developed up till now, include mainly hydrometallurgical and hybrid methods. Several types of bioleaching processes have been proposed also (e.g. Mukherjee A., Raichur A. M., et al., 2004), however, they did not achieve such a level of maturity which would enable them to be treatedas a serious alternative to the above mentioned technologies.

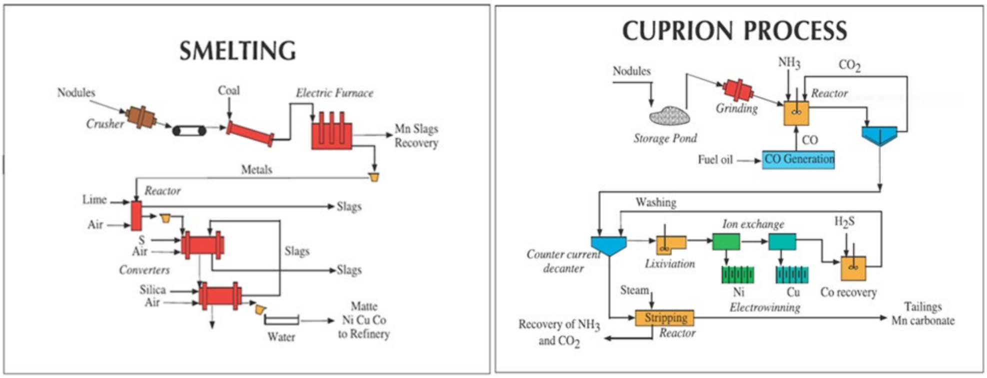

Fig. 3. The example of pyrometallurgical (left) and hydrometallurgical (right) technologies which could be used for the processing of manganese nodules (ISA, 2010).

Among the considerable number of the technologies for nodule processing which have been developed up till now, the ones most promising for practical application are:

1. INCO technology and its variations, consisting in a reduction in rotary kiln, NiCoCu alloy smelting in electric furnace, production of matte and its further processing by hydrometallurgy, with production of FeMn or FeSiMn from slag or without it.
2. Pressure leaching with sulphuric acid (HPAL), leaving Fe and Mn in leaching wastes.
3. Caron process and its modifications, consisting in a reduction in temperature of approx. 740 – 750 °C and the following ammoniacal leaching using NH_3 and $(NH_4)_2CO_3$.
4. Cuprion process elaborated by Kennecott Copper Corporation (leaching in ammoniacal solution in the presence of Cu^+ ions and gaseous CO).
5. Metallurgie Hoboken-Overpelt process (MHO), consisting in leaching using hydrochloric acid, Fe removal by extraction and selective precipitation of Cu sulfides and then Ni-Co sulfides using hydrosulfide. Mn^{+2} is precipitated as mixed oxide Mn(IV) after its oxidizing with gaseous Cl_2. Evolving HCl is returned to leaching operation.
6. Two versions of Deep Sea Ventures process: chloride and sulphate ones. Chloride technology is similar to MHO process, and in sulfate version, nodules are first sulfated with SO_2 in fluidization bed, and then water leached. Manganese is recovered from the solution by electrowinning. Solids are leached once again, with the presence of SO_2 and air. Ni, Co and Cu go to solution as sulfates and iron remains in wastes.

The technologies which were proposed for nodule processing yield similar technological parameters, with small exceptions only, significant differences arise only for cobalt. Teleki P. G., Dobson M. R. et al. (1985) inform that Caron process provides for 90 % recovery being achieved for Cu and Ni and 50 % for Co. Other sources inform that cobalt recovery can be even as low as 20 % (Dreisinger D., 2013). The advantage of Caron process is the removal of a majority of Fe and Mn to leaching wastes, which can be used as a raw material for the production of Si16Mn63 (Randhawa N. S., Jana R., K et al., 2013). HPAL process enables a recovery as high as 92 % for Ni, Co and Cu, removing a majority of Fe and Mn to wastes. Smelting gives the highest recovery values for the three above mentioned metals amounting to 95 %, whileat the same time up to 98 % manganese is rejected to wastes, whereas in the case of chloride leaching, the majority of Mn and Fe goes to solution (Premchand, Jana R. K., 1999).

6. Summary

Selection of a technology for any raw material is determined, first of all, by its specific properties. In the case of the nodules, an important driver is also a possibility to reduce the relatively high CAPEX and OPEX of the investment and a possibility to limit the risks and hazards, connected with an introduction of not only new processing technologies but also new deep sea mining technologies. Those conditions significantly favor the methods using the currently existing technologies and infrastructure.

The most important features of the nodules are: occurence of metals in the form of easy-to-leach oxides, oxide-hydroxides and hydroxides; very high content of water - both physically (25-30 %) and chemically (10-15 %) bound, relatively low content of acid consuming components (with the exception of Mn, Fe, Ni, Co and Cu) and a possibility of simultaneous recovery of REE. This seems to favor the application of hydrometallurgical methods only for nodule processing. Furthemore, there is a possibility to use HPAL installations (e.g. Cawse, Bulong, Murin Murin) in Australia, which are currently closed or planned to close. The opposite arguments are technical difficulties brought by HPAL technology and, typically for all hydrometallurgical installations, additional costs connected with water circuit closing and waste management.

The selection of pyrometallurgical-hydrometallurgical methods for nodule processing is supported by a possibility for a reduction of a mass of feed into the hydrometallurgical circuit to as low as 6-8 %, which means adequate reduction of capital and operating costs of a hydrometallurgical installation. An additional advantage of this group of technologies is that marketable NiCoCu alloy can be produced just after one technological operation. In the case of Caron process, its main advantage is good management of Mn and Fe and a lower temperature of the process, comparing to smelting. Hovever, quite obvious disadvantage are quite low recovery values of metals, especially Co. The weak points of all pyrometallurgical-hydrometallurgical technologies are high energy consumption, especially in case of Caron process, and a lack of possibility for the recovery of REE, because those elements go to oxide slag during smelting.

The ultimate selection of a technology basing only on its technological parameters is, as it was shown above, impossible. The only base for such a decision can be a pre-feasibility study of available methods for the processing of the nodules.

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HYDROMETALLURGICAL METALS RECOVERY FROM NODULES

Abstract. Mineral resources in the form of polymetallic oceanic nodules represent a broad range of many different metals. Global trends as well as necessity of valuable metals recovery from a low quality raw or recycled materials raise the interest in deep-oceanic nodules, which are mainly composed of iron and manganese but also include critical and strategy metals such as nickel, copper and cobalt. Numerous processes of metals recovery from oceanic nodules by hydrometallurgical methods have been described in the literature. "Hybrid methods", which are the combination of pyro- and hydrometallurgical techniques are also known. In the late 1980s, the Institute of Non-Ferrous Metals developed complex hydrometallurgical technologies for metals recovery from the nodules in particular references to nickel, copper and cobalt. This paper presents the examples of the above-mentioned metals recovery using various leaching solutions. Selective hydrometallurgical separation of copper, nickel and cobalt using various methods has been proposed (eg. solvent extraction, electrochemical techniques and precipitation). Technology diagrams for nickel, cobalt and copper recovery in the form of concentrates and /or their compounds or in metallic form have been presented. Selection of the appropriate technology of metal recovery from nodules on an industrial scale will be strongly dependent on the environmental and economic aspects (CAPEX/OPEX costs). The use of polymetallic nodules as a source of nickel, cobalt or copper may result in significant changes in the global market of the non-ferrous metals. Their exploitation will be possible when the right economic conditions are met (very high world prices of nodules metals).

1. Introduction

Sediments accumulated at the bottom of oceans and seas are a very interesting and still unexploited source of various elements, including non-ferrous metals.

Decreasing amounts of natural resources excavated on the mainland will force, in the near future, a start of mining operations in the seas and oceans. The most interesting and prospective resources, apart from crude oil and natural gas, located on the ocean seabed, are polymetallic nodules (ocean concretions). This type of sediment was discovered at the bottom of the oceans in the nineteenth century. Ocean nodules are natural clusters composed mainly of iron and manganese oxides. There are also non-ferrous metals including rare, precious or critical metals [1,2,4]. The nodules occurring in the ocean with contents of Ni, Co, Cu, Zn and Mo are considered as a source of metals with high economic potential [1-3,6]. The composition ranges of polymetallic nodule samples, taken from the Clarion-Clipperton Zone (CCZ) on the bottom of the Pacific Ocean, are presented in the table 1 [1-5].

Tab. 1. Composition ranges of polymetallic nodules (Clarion-Clipperton Zone).

Ingredient	Content, %
Manganese	28.0-29.0
Iron	4.9-6.5
Nickel	1.3-1.4
Copper	1.2-1.3
Cobalt	0.15-0.25
Zinc	0.13-0.15
Molybdenum	0.05-0.06
Cerium	0.05
Zirconium	0.04
Lanthanum	0.02
Tungsten	0.01
Lithium	0.01

Various technologies of valuable elements recovery from the ocean nodules have been described in the literature. Technology Readiness Levels (TRL) for each proposed technology are heavily differentiated. Most of these studies are carried out in pilot scale allowing results transfer to an industrial scale (target process conditions). Processes used for the recovery of non-ferrous metals from the ocean nodules can be divided into three types (fig.1):

- pyrometallurgical,
- hydrometallurgical,
- hybrid (combining elements of pyro- and hydrometallurgical processes).

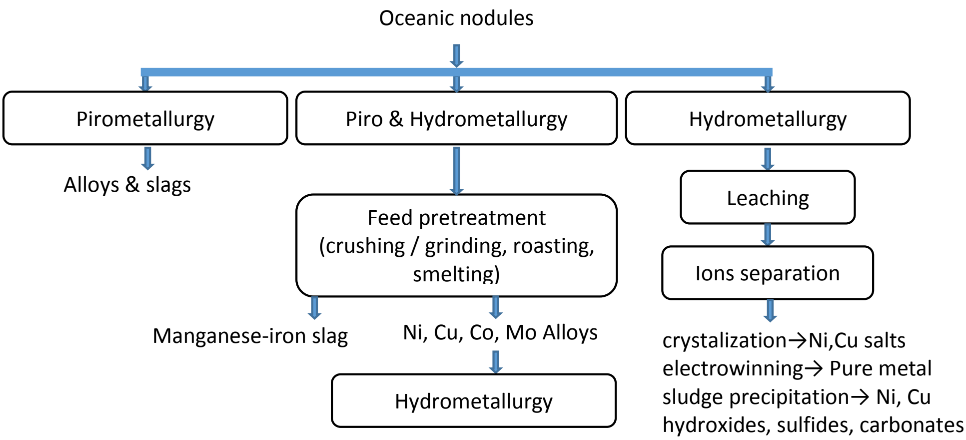

Fig. 1. General division of ocean concretions processing.

Coexistence of large amounts of iron and manganese, which are essential components of concretions, is a major obstacle in the separation of precious metals (Ni, Co, Cu, Zn and Mo). Fire processes (pyrometallurgical) usually yield a metal alloy and polymetallic slag, including Mn-Fe slag.

Hybrid processes usually involves pyrometallurgical pre-treatment, yielding Mn-Fe slag by manganese reduction as well as a polymetallic alloy. The obtained polymetallic alloy is treated by hydrometallurgical processing to separate individual metals.

There are several hydrometallurgical concepts for Mn and Fe separation. In the first method, metals are leached by H_2SO_4 solutions under reducing conditions while the rest of metals are leached in the second stage under oxidizing conditions. Another concept assumes complete metal extraction in a HCl solution followed by individual metals precipitation in the form of insoluble compounds. There are also methodologies using selective leaching solutions for particular metals.

2. Hydrometallurgical metals recovery

Hydrometallurgy is a method of metals recovery from primary and secondary raw materials, through their solubilisation, purification of the obtained solutions and separation of metal in the elemental or compound form (Fig. 2) [7].

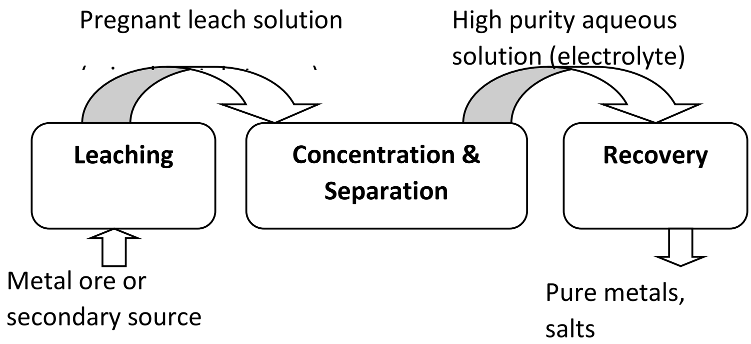

Fig. 2. The main process units in the hydrometallurgical metals recovery.

Hydrometallurgical process of metals recovery from ocean nodules can be classed by the pressure used in the leaching reactor (high- and low pressure) or with regard to the process temperature. Reaction environment of the leaching step is the most commonly used classification criterion for the hydrometallurgical treatment processes used on ocean nodules. In accordance with the mentioned classification, processes can be acidic or alkaline. The four selected methods of hydrometallurgical ocean nodules processing are presented below.

Kennecott Copper Corporation Process (KCC)

In the KCC process, crushing and grinding of ocean nodules are followed by leaching them in an ammonia solution in the presence of copper. A solution of ammonia and ammonium carbonate with addition of metallic copper and carbon oxide(II) is the reducing agent for manganese oxide (IV). This kind of medium creates the perfect environment for leaching of selected metals, i.e. copper, nickel and cobalt. Under these conditions, manganese and iron are separated from the main process stream in the form of carbonates (Mn) and hydroxides (Fe). The key step of this proposed method is separation of nickel, copper and cobalt by solvent extraction. Consecutively, each metal (Ni, Cu) is stripped by depleted electrolyte from the stage of electrowinning. Figure 3 illustrates the general flow chart of a KCC process [4,8].

Hindustan Zinc Limited process (HZL)

HZL process (Fig. 4) is based on a two-stage countercurrent leaching of crushed and ground ocean nodules. The first stage of leaching (pre-leaching) is carried out at atmospheric pressure and the leaching agent from the second stage is used as lixivant.

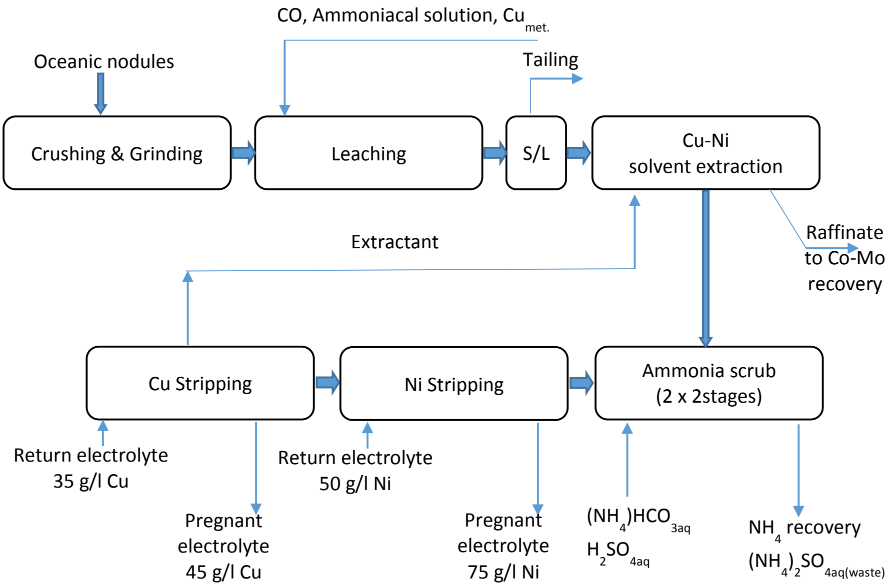

Fig. 3. General flow chart of a Kennecott Copper Corporation process.

The second stage leaching is carried out with sulfuric acid(VI) solution under conditions of elevated pressure in the presence of gaseous oxygen. The first stage leaching solutions are firstly purified and then copper and nickel are sequentially extracted. Cobalt is maintained in the raffinate [3,4,8].

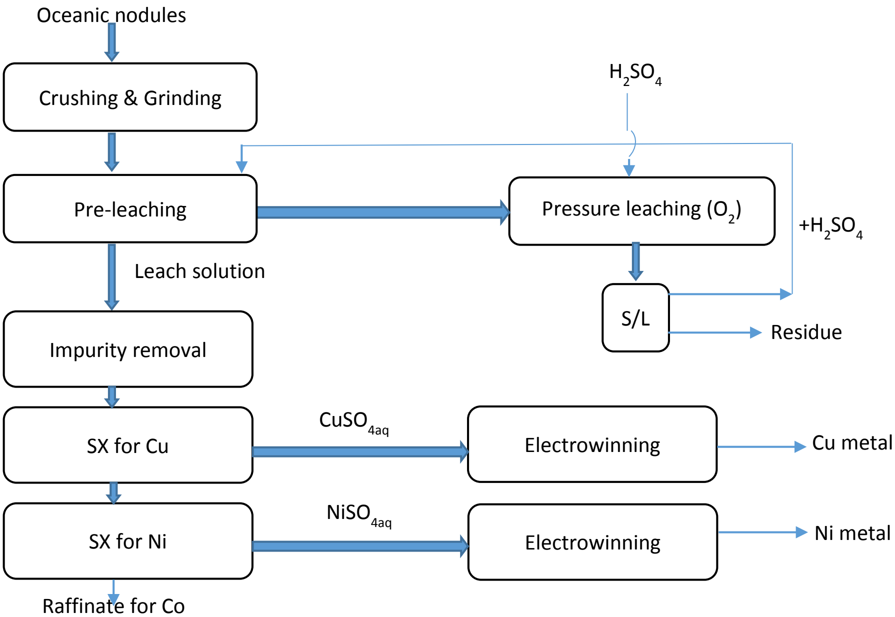

Fig. 4. General flow diagram of a Hindustan Zinc Limited process.

Metallurgie Hoboken – Overpelt process (MHO)

MHO general flow diagram is shown in Figure 5. In this process, crushing and grinding of ocean concretions are followed by leaching them in hydrochloric acid solution. This acid is recovered at the end of the process in hydropyrolysis step, after precipitation of manganese oxide. The solvent extraction technique is used for solution purification from iron ions in the MHO process, while other metals (Ni, Co, Cu, Al) are recovered by precipitation in the form of hydroxide or sulphide concentrates [8,9].

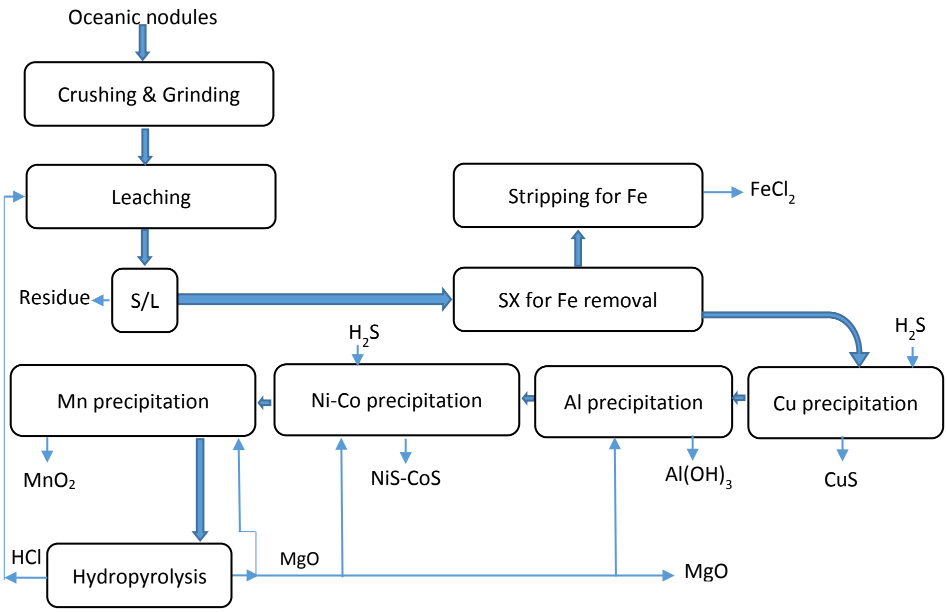

Fig. 5. General flow diagram of a Metallurgie Hoboken – Overpelt process.

The process by the Institute of Non-Ferrous Metals (Instytut Metali Nieżelaznych, IMN)

In the 1990s the processing method was developed for ocean concretions in laboratory scale (Fig. 6) [2] at the Institute of Non-Ferrous Metals. The proposed method is based on leaching the previously crushed and ground material in a solution of sulfuric acid (VI). The ion exchanger Amberlite IRC- 718 is added to the reaction mixture and the reactor is saturated with gaseous SO_2. At the end of leaching process, the ion exchanger was first separated from the reaction mixture on sieves and then filtration and the manganese oxides precipitation were conducted. Nickel and cobalt were eluted from the separated ion exchanger.

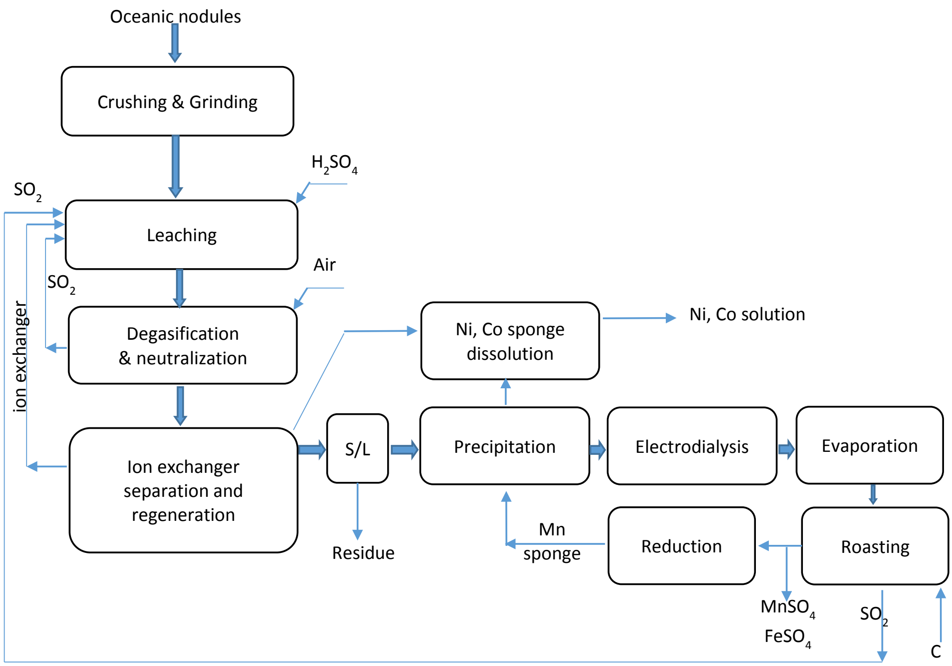

Fig. 6. General flow chart of an IMN lab scale process.

3. Summary

Technology diagrams for the selected hydrometallurgical methods for the recovery of precious metals from the ocean nodules were presented. Each of the presented methods has its advantages and disadvantages. Choice of a particular processing technology for the ocean nodules should depend not only on technological factors but also on the environmental and economic factors (market metal prices). The stages of material mining and transport from the bottom of the ocean as well as formal and legal restrictions are an important factor contributing to the selection of a particular technology. By analysing the collected data, it can be concluded that the most prospective concept is pyrometallurgical pre-treatment, which will effect iron and manganese removal into slag and production of polymetallic alloy containing other valuable metals. Further processing of this polymetallic alloy should be conducted using hydrometallurgical methods (Fig. 7)

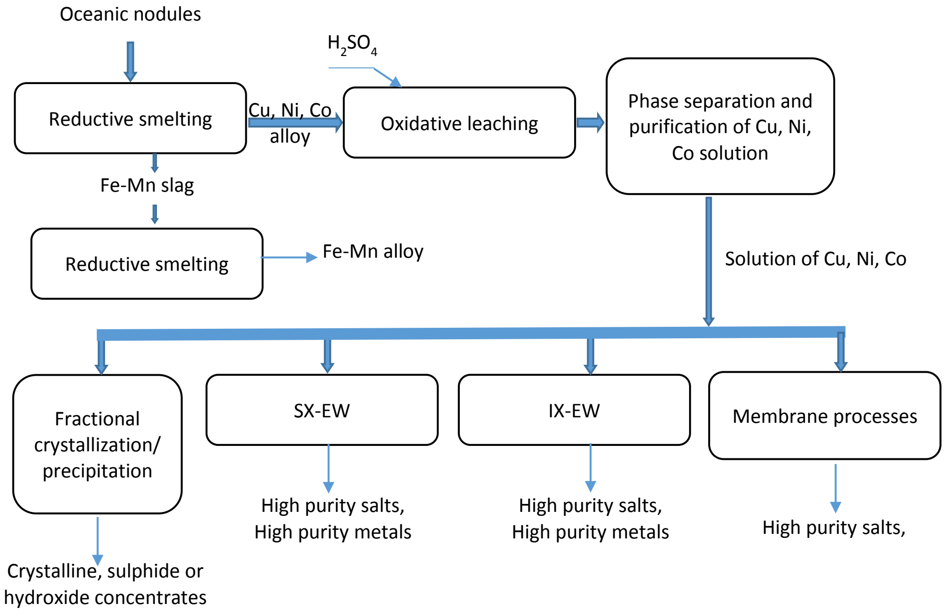

Fig. 7. The general diagram of the research proposed by the Institute of Non-Ferrous Metals.

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TECHNICAL PLANNING OF PILOT MINING TEST ON POLYMETALLIC NODULE DEPOSIT PART I: RESEARCH AND DESIGN OF A MINING SYSTEM

Abstract. The article presents main results of the works, ie. a conceptual design of a mining ship, a conceptual design of a nodule collector and exemplary results of computer simulations of mining system dynamics, as used in the development of a mining system concept.

1. Introduction

Joint Organization Interoceanmetal (IOM) was established in 1987 with headquarters in Szczecin (Poland). Since 1988 IOM has launched geological prospecting of polymetallic nodule ores located at the Pacific Ocean bottom in the Clarion-Clipperton Fracture Zone. After a relevant plan for works for exploration was submitted by the organization, a contract with the International Seabed Authority (ISA) was signed in 2001 for the exploration of nodules over the area of 75,000 km^2.

In 2002 IOM established an international group of experts in nodule mining technology. The group's task was to analyze various mining methods and a design of the mining system. This research project was completed in 2013.

2. A research project carried out by IOM in scope of the mining system

The nodule mining technology group performed the analysis of various mining methods:

- hydraulic lift pipe (riser) methods (Fig. 1),
- continuous line bucket methods (Fig. 2),
- autonomous undersea shuttle methods (Fig. 3).

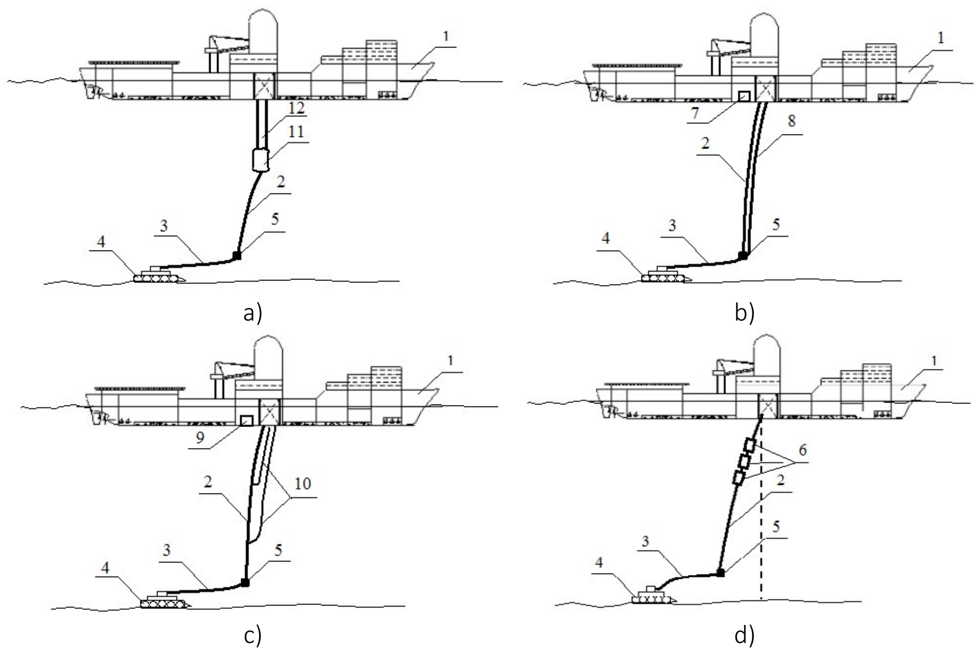


Fig. 1. Hydraulic lift pipe (riser) methods [3]
a – with a separate underwater chamber, b – double pipeline system with pumps on board the mining ship, c – airlift system, d – single pipeline system,
1 – mining ship, 2 – riser, 3 – horizontal elastic hose, 4 – a seafloor ore collector, 5 – buffer, 6 – deep sea pumps, 7 –ship onboard pumps, 8 – pipeline pumping clean water, 9 – compressors, 10 – compressed air pipe, 11 – underwater separation chamber with pumps, 12 – mechanical system for vertical transport of nodules

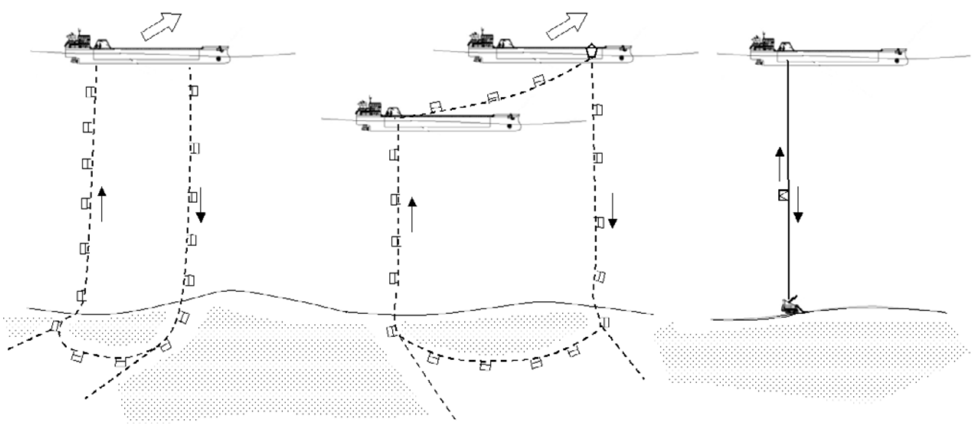


Fig. 2. Continuous line bucket methods [3]
a) continuous line bucket with one ship (Japanese version), b) continuous line bucket with two ships (French version), c) line bucket with nodule collector

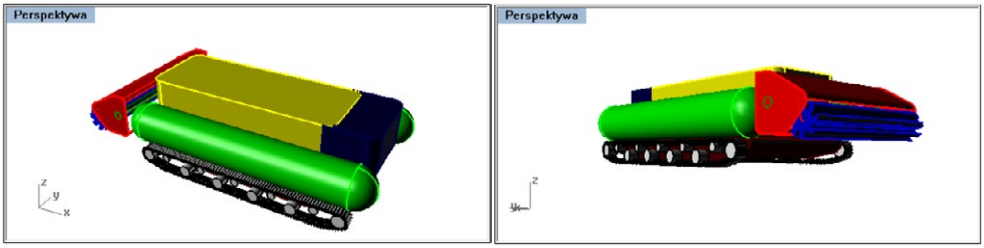


Fig. 3. Virtual concept of an undersea mining barge [3]

Eventually a hydraulic pipe technology (Fig. 1d) was selected for further works, with an alternative being a hydraulic pipe with pumps placed onboard the ship (Fig. 1b). The following works were completed for the selected hydraulic methods:

- conceptual design of the mining ship, e.g. [1],
- conceptual design of the nodule collector,
- experimental test stand system for the vertical transport of nodules,
- studies and computer simulations of the movement of the system mining ship – hydraulic lift pipe – nodule collector, computer simulations of hydraulic lift pipe deformations, computer simulations (CFD) of water flow around the hydraulic lift pipe.

2.1. Conceptual design of mining ship with hydraulic lift pipe

The concept of a mining ship has been developed for the following design parameters:

- annual mining system production,
- duration of nodules' temporary storage in the holds of the ship (the time and performance of mining system depending on capacity of the ship),
- maximum values of weather parameters (mainly wind speed and wave height), weather operational limits,
- the average abundance of nodules on seabed,
- the average depth of mining.

The exact values of some of these parameters are not known, eg. the annual production of mining system and the time of temporary storage in the holds of the ship. Their value will be determined after the optimization of the whole mining system complex. The concept of the ship has been developed as a module including such parameters as its dimensions, weight, and hydraulic lift system power demand depending on variable design parameters. Planned overall concept of the mining ship is shown in Fig. 4, and some of the design solutions are shown in Fig. 5, [4].

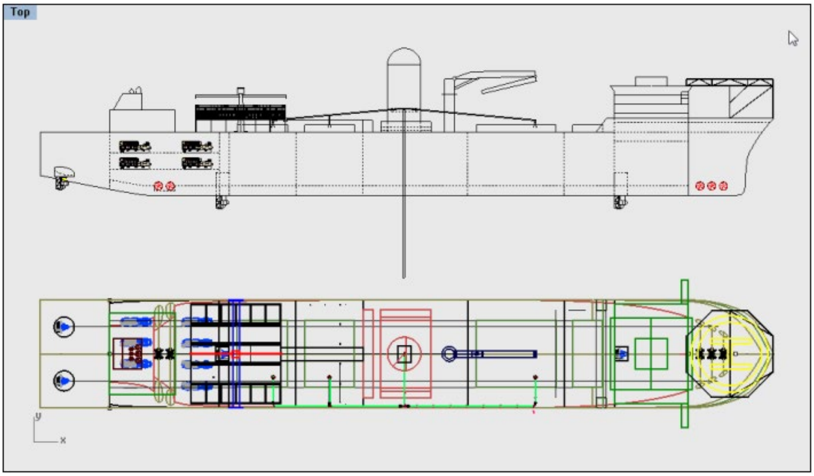
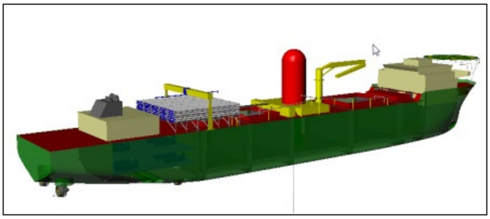
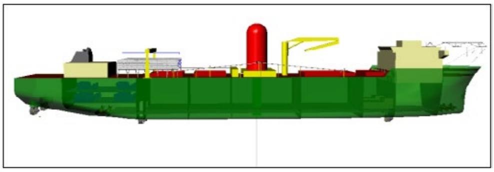


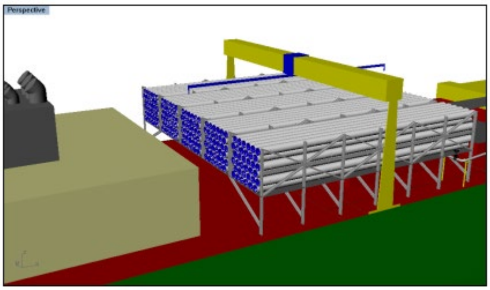
Fig. 4. Conceptual design of the mining ship



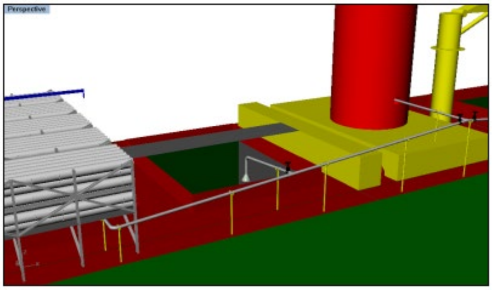
perspective view



side view



Pipes stored on the deck of the aft cargo hold



View of the deck- one of the aft cargo holds

Fig.5. Virtual concept of mining ship

2.2. Virtual concept of a self-propelled collector

The conceptual design of self-propelled collector has been developed for:

- target performance of a mining system,
- the average abundance of nodules on the sea bottom.

The collector is equipped with a bottom-grazing nodules collecting system performing also their pre-cleaning of mud and crushing. Nodules of appropriate size are pumped into the hydraulic lift pipe.

Visualization of the conceptual design of the self-propelled collector is shown in Fig. 6 (a full description of the design has been also prepared by IOM [4]).

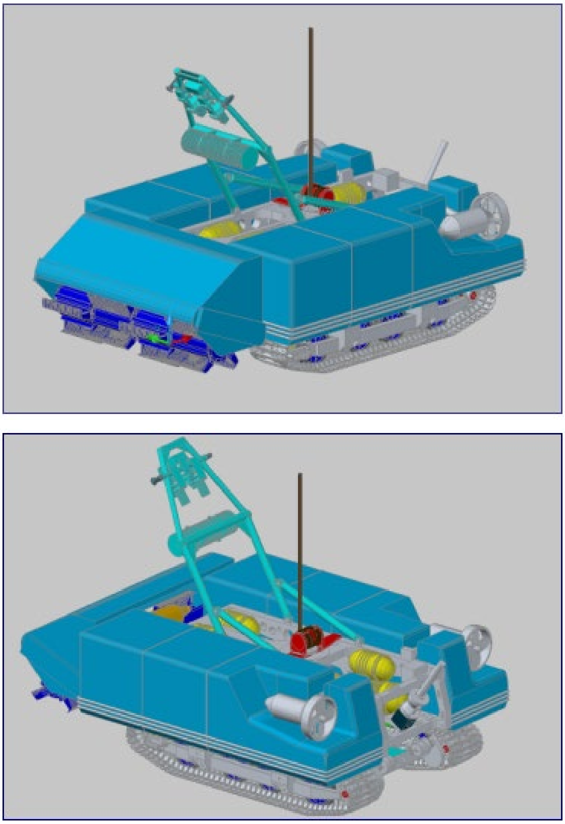
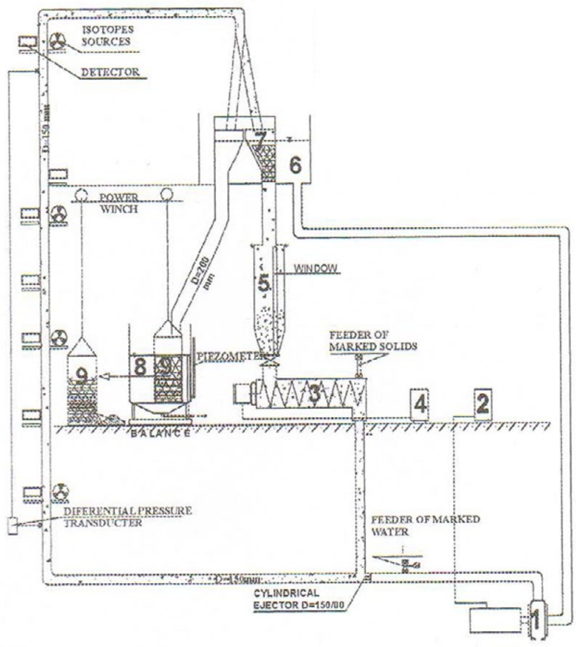


Fig. 6. Virtual concept of a self-propelled collector

2.3. Experimental stand used for measurements of nodule phase velocities in upward vertical flow lifting the nodules.

The experimental hydraulic test installation where a vertical lift of nodules was studied, was built at the Wrocław University of Environment and Life Sciences (Poland). The central device of this installation is a feeder of nodules supplied to a vertical mining pipeline.

A diagram of the installation is shown in Fig. 7 (a full description of the experiment is in [2]).



1. pump
2. device for controlling pump rpm
3. spiral-screw based feed mechanism for solids
4. device for controlling feed mechanism rpm
5. cylindrical collector
6. upper tank
7. a device separating the solid phase
8. measuring tank
9. tank for solids

Fig. 7. Diagram of the experimental system for testing the flow of water nodules [1]

2.4. Computer simulations of the movement of mining ship on the ocean surface

To develop the concept of the mining system based on the results of various numerical calculations and simulation of the motions of the mining ship, the hydraulic lift pipe and the nodule collector.

The following items were studied as part of this work:

- movements of the mining ship on the surface of the ocean (the influence of parameters of wind, waves and sea currents on the accuracy of maintaining the preset speed and direction of movement and rocking of the ship under the influence of waves)- Fig. 8,
- movement of the mining ship, the hydraulic lift pipe and the nodule collector- Fig. 9,
- studies of the relative position of the hydraulic lift pipe lower end (buffer) and nodule self-propelled collector- Fig. 10,
- analysis of the movement of nodule self-propelled collector in relation to the mining ship- Fig. 11,
- studies on the effectiveness of nodules collection from the ocean floor using of the towed nodule collector (the collector is dragged along the bottom with the mining ship's and the attached hydraulic lift pipe- Fig. 12.

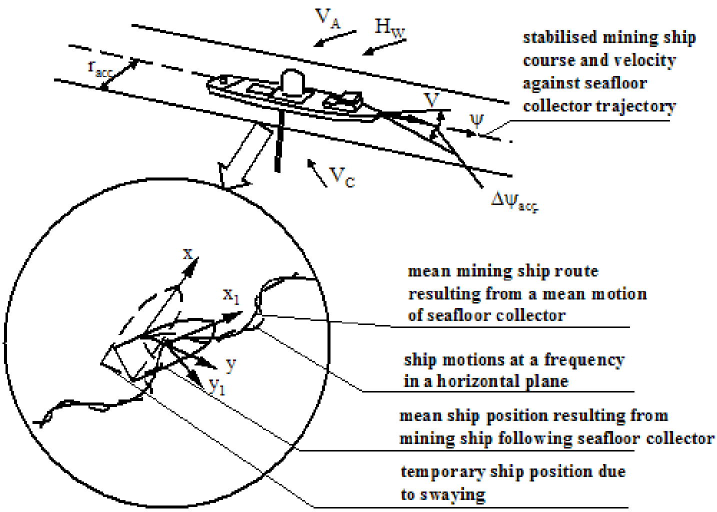


Fig. 8. Movement and motions of mining ship on the surface of the ocean
V – mining ship speed over nodule-rich area,y – mining ship course, maintained with DVacc accuracy, racc – acceptable deviation from a set mining ship trajectory, VA – wind speed, VC – surface current speed, HW – wave height

Full description of the tests performed in [3], [4].

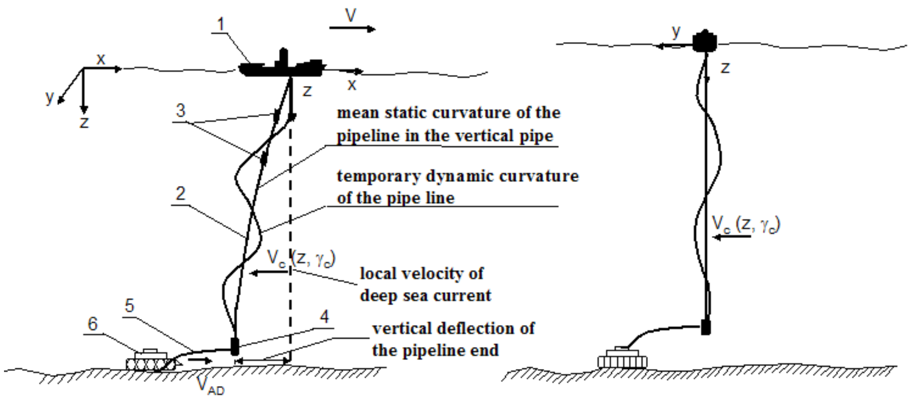


Fig. 9. Computer simulations of the movement of the mining ship, the hydraulic lift pipe and the collector
1. mining ship, 2. hydraulic lift pipe, 3. deep sea pumps, 4. Buffer, 5. elastic transport hose, 6. seafloor nodules collector,
V – speed of a mining ship, *VAD* – speed of a seafloor nodules collector, $V_c(z,\ g_c)$ – speed of a deep water current whose value depends on water depth „*z*" and geographical current direction.g_c

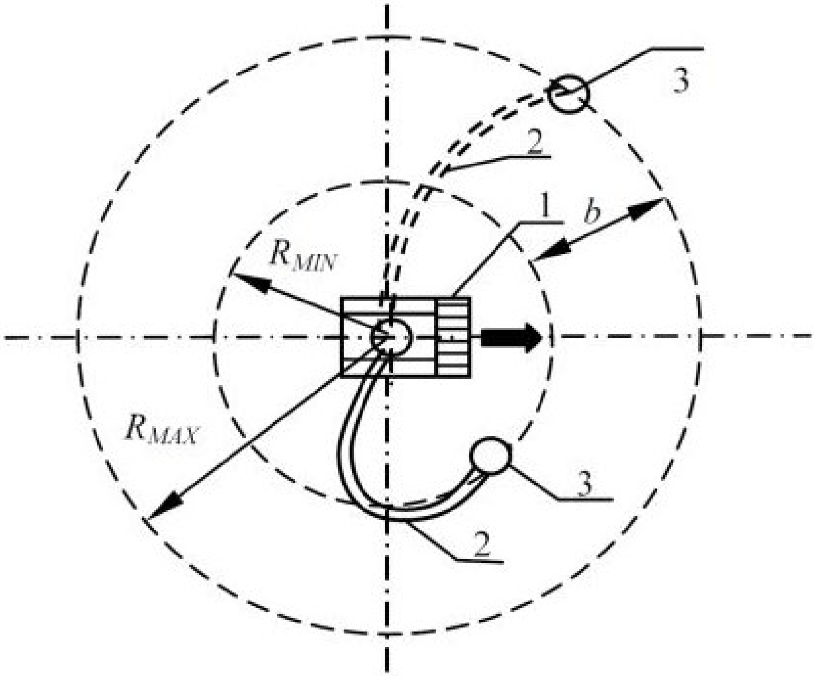
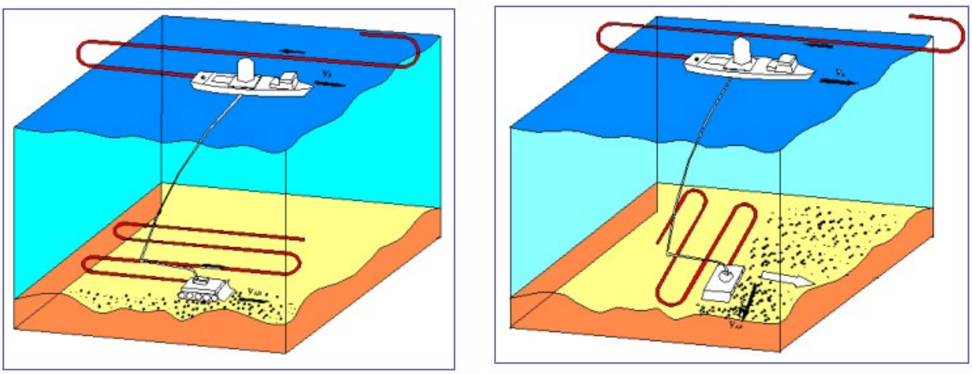


Fig. 10. Examination of the relative position of the nodules collector located at hydraulic lift pipe lower end.
1. seafloor collector, 2. elastic hose, 3. lower end of the vertical pipeline (buffer)



mining ship moves in the same direction as the nodule collector

mining ship moves transversely to the movement path of the nodule collector

Fig. 11. Movement of the nodule self-propelled collector on the seafloor in relation to the mining ship

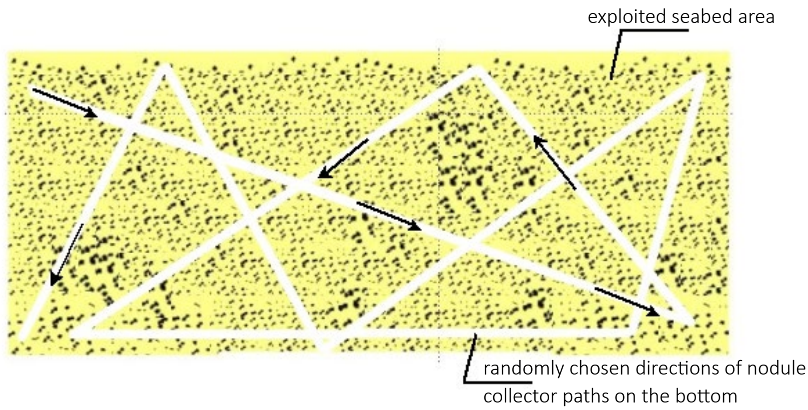


Fig. 12. Movement of towed nodule collector on the seafloor

2.5. Computer simulations of hydraulic lift pipe deformations and stresses

Basing on simulations of mining ship motions on the surface of the ocean, computer simulations of the deformation and stresses in the hydraulic lift pipe were carried out. Movement of the ship in this instance is the kinematic forcing exerted on the upper end of the pipe suspended beneath the hull. Particular cases of ship motions are other effects influencing the deformations and stresses are:

- longitudinal and transverse rectilinear movement of the ship,
- movement of the ship along a curve,
- motions of the ship in relation to the water level,
- the impact of deep-sea currents on the assumed distribution of speeds and directions.

Examples of the results of computer simulations are presented in Fig. 13 ÷ 15 (full set of results of computer simulations is in [3], [4]).

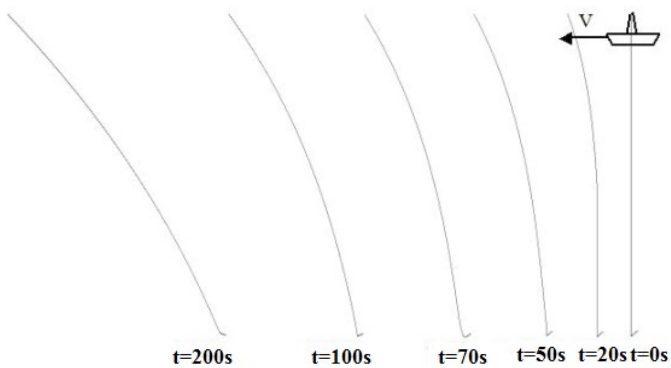


Fig. 13. Deformation of the hydraulic lift pipe at mining ship speed V = 1.285 m/s

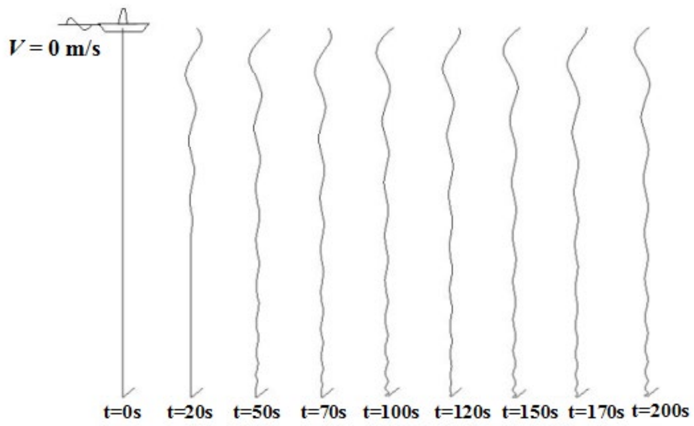


Fig. 14. Deformation of the hydraulic lift pipe as a result of mining ship motions (oscillatory amplitude SAX = 4 m, motions frequency ω = 1.0 1/s)

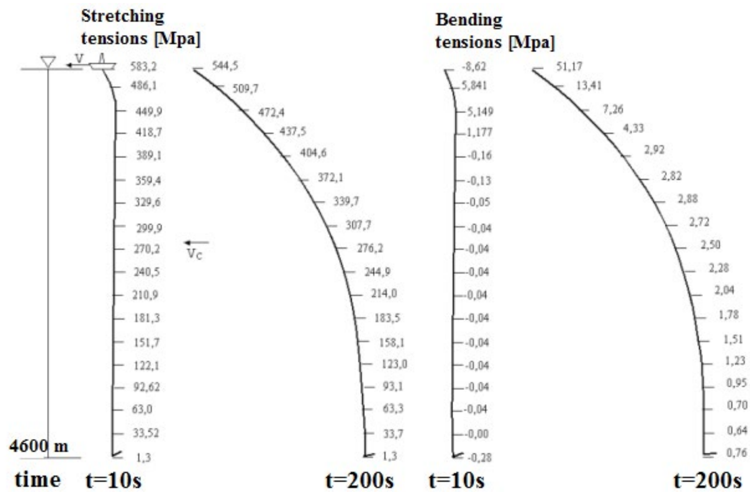


Fig. 15. Simulation of tensile and shearing stresses along the hydraulic lift pipe system for two time steps (stresses correspond to individual pipeline parts for a pipe shape in a given time moment), mining ship speed V=0.771 m/s, deep-sea current direction same as the mining ship speed.

2.6. Computer simulation (CFD) of water flow around hydraulic lift pipe

In order to determine the coefficients of drag and lift forces as well as the torque exerted on hydraulic lift pipe by the effects of water flow over the pipe (flow resulting from the pipe movement together with the mining ship and the influence of deep-sea currents), the calculations were performed using the method of computational fluid dynamics (CFD). The calculations were performed for various layouts of lift pipes (Fig. 16), and the examples of the results of computer simulations are presented in Fig. 17 and 18 (the full set of results of computer simulations is in [3]).

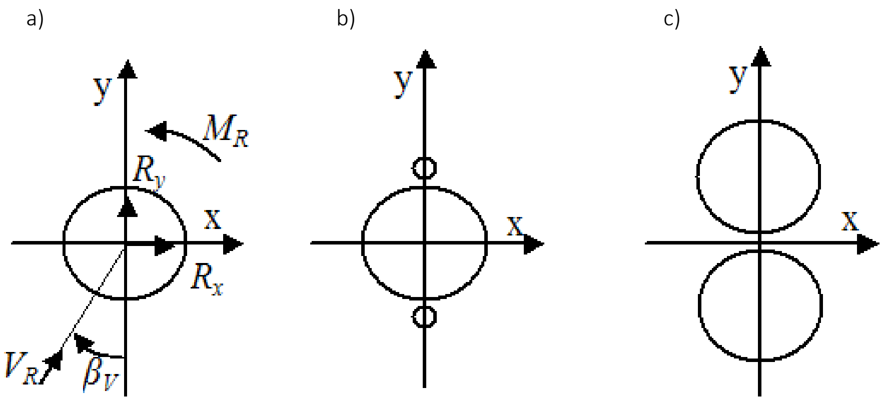


Fig. 16. The tested configurations of hydraulic lift pipes
a) single pipeline, b) single pipeline with mains cables, c) double pipelines

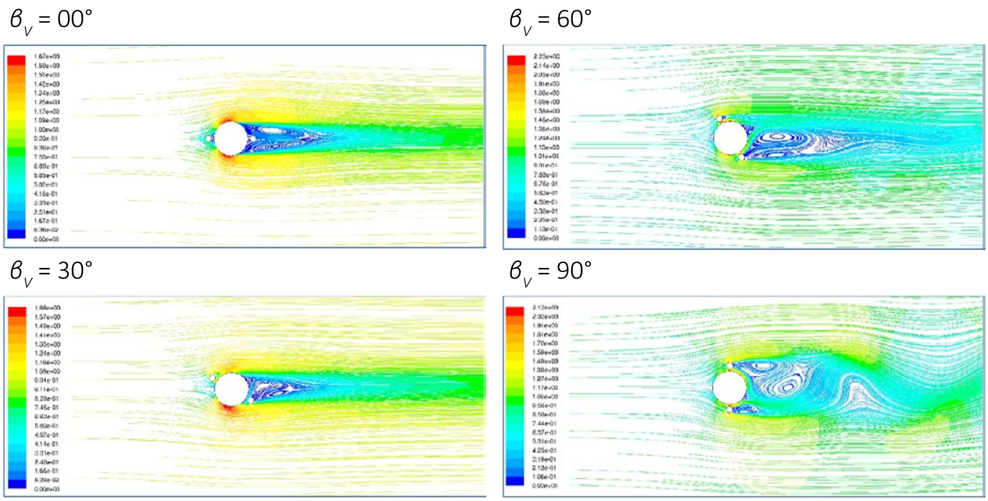


Fig. 17. Current lines for a single pipeline with mains cables for water velocity V =1 m/s and various angles of water velocity β_V

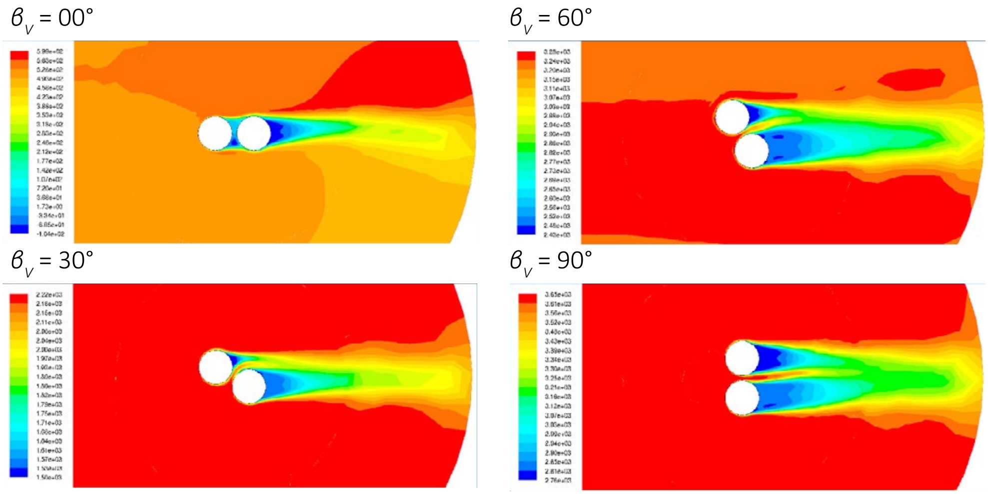


Fig. 18. Pressure distribution for double pipelines for water velocity V = 1 m/s and various angles of water velocity β_V

3. Conclusions

The result of the works performed on nodule mining technology is a conceptual design of a mining system together with a wide range of computer simulations of mining system dynamics. Some of these studies must be verified by experimental processes in real-life sea conditions. This applies primarily to the nodules collector and hydraulic lift pipe. The next step is therefore to plan and execute experimental testing of mining system at sea conditions.

4. Reference

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TECHNICAL PLANNING OF PILOT MINING TEST FOR POLYMETALLIC NODULES
PART II: THE PLANNED EXPERIMENTAL WORK MINING SYSTEM

Abstract. The Interoceanmetal Joint Organization (IOM) developed a conceptual design of a nodules mining system. The next stage of works on the industrial mining and transport complex of is to perform the tests on a mining system at sea. The article presents two phases of the planned tests. Basing on the results of pilot mining tests a coefficient of nodules exploitation process efficiency is going to be determined. The article presents the possibility that such a mining system could be built by Hydro-Naval company in Słupsk (Poland).

1. Introduction

The result of the works by the expert group for nodule mining technology is a conceptual design of a mining system together with a wide range of computer simulations of mining system dynamics. Some of these studies must be verified by processes in real-life sea conditions. This applies primarily to nodules collector and hydraulic lift pipe. The next step is therefore to plan and execute experimental testing of a mining system at sea conditions.

2. The planned experimental studies of mining system

Due to the very high costs:
- construction of the mining system,
- conducting the experimental research out in the ocean,

the design process was further divided into two stages:

- execution of the design, construction and mining system tests at shallow depths of ~ 300 m (Baltic Sea),
- execution of the project, construction and mining system tests at a depth of 4,000 m (Pacific Ocean, Clarion – Clipperton region).

Basing on the results of experimental studies it is going to be possibleto verify the earlier design works and then prepare a design for an industrial nodules mining and transport system.

2.1. A mining system for shallow depths

Mining system designed for tests at shallow depths is shown in Fig. 1.

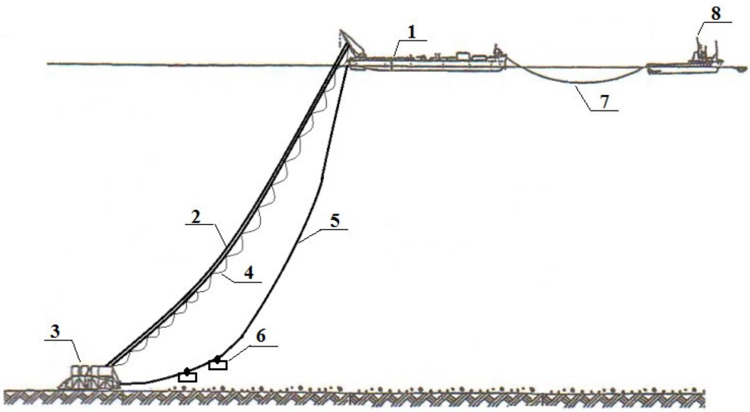

Fig. 1. Mining system for tests at shallowdepths
1. towed mining platform, 2. hydraulic lift pipe, 3. nodule collector, 4. umbilical cable, 5. steel wire, 6. lumped mass, 7. towed wire, 8. tugboat

Objectives of the test shallow depth mining system:

- research into the effectiveness of nodules collection using a towed collector,
- research into the self-propelled collector controlled from the mining platform,
- research into: collection devices, preliminary cleaning and feeding the pipeline with nodules research into the pumping system for vertical transport,

research into the systems used for the monitoring of marine environment and movement of the nodule collector. The preliminary design process schedule is as follows (Fig. 2):

1. technical design of a mining system- 6 months
2. development of the schedule and scope of tests and production- 2 months
3. preparation of a land base for the mining system (warehouse, workshop) - 8 months
4. production of all the elements of a mining system- 12 months

5. repeated development of a mining platform, installation of mining system- 10 months
6. mining tests:
   - towed nodule collector- 2 months,
   - self-propelled nodule collector- 3 months,
7. processing of test results and preparation of guidelines for the construction of a pilot mining system- 3 months.

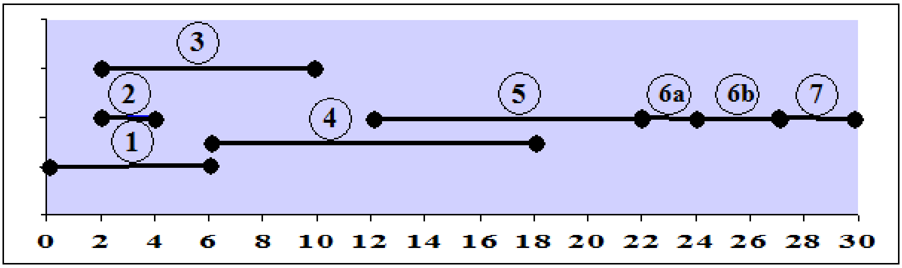

Fig. 2. The preliminary design process schedule for a pilot mining system to be operated at shallow depths.

Preliminary performance tests at shallow depths:

- total duration of the design process- 30 months
- duration of trials- 5 months
- amount of collected nodules- 10 tons
- project cost estimate:
  - design and construction of the mining system, as well as its installation on a mining platform – abt. 20 mln Euro,
  - execution of tests (including rental of tug) – 1 mln Euro.

2.2. Pilot mining

The pilot mining system is shown in Fig. 3.

An existing drilling vessel, properly rebuilt and equipped is going to be used for the execution of pilot mining system tests.

The objective of the pilot mining test is:

- testing the system for collection and lifting of nodules from oceanic depths,
- testing the driving characteristics and control of a self-propelled collector,
- research into of the dynamics and the relative position of the collector, hydraulic lift pipe and mining ship,
- researching of the effectiveness of collecting and lifting nodules from the ocean floor,
- monitoring of the marine environment during mining,

- monitoring of the propagation of the bottom sediment and sea water thrown up from the bottom with nodules.

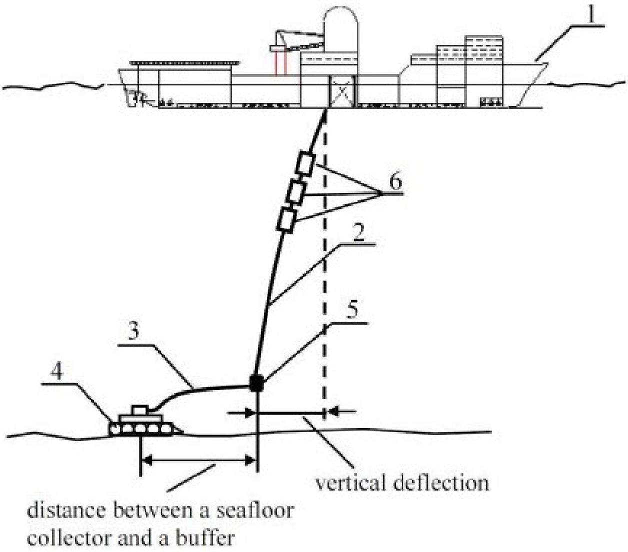

Fig. 3. The pilot mining system
1. mining ship, 2. hydraulic lift pipe, 3. elastic pipe, 4. self-propelled nodule collector5. buffer, 6. deep sea pumps

The preliminary design process schedule for pilot mining test as follows (Fig. 4):

1. technical design of the mining system- 12 months
2. development of the schedule and scope of tests and production – 4 months
3. construction of all elements of the mining system- 16 months
4. buying a used drilling ship and a technical design of its retrofitting- 8 months
5. drilling ship retrofitting, installation of a mining system- 12 months
6. pilot mining tests- 6 months
7. processing of test results and preparation of guidelines for the construction of an industrial mining and transport system- 2 months

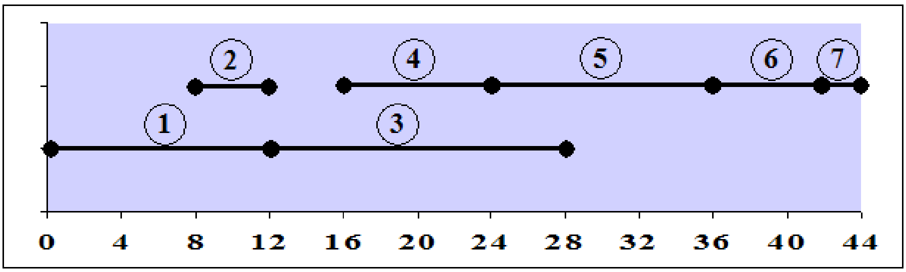

Fig. 4. The preliminary schedule of pilot mining system test

Preliminary performance tests of a pilot mining system:

- total duration of the project- 44 months
- duration of trials- 6 months
- amount of excavated nodules – 20,000 tons
- estimate of project cost
  - design and construction of a mining system – abt. 90 million Euro,
  - performance of trials (operation of the ship) – abt. million Euro.

3. The reserves of the ore deposit based on the pilot mining test

Documented resources of nodules lying on the ocean floor, will not be fully exploited for various reasons.

One of the objectives of the pilot mining test is to examine how much nodules can be mined in relation to the total amount of nodules on the bottom of the ocean within the specific minable area:

$$CEEN = \frac{\text{mass excavated nodules (reserves)}}{\text{mass of nodules on the bottom (resources)}} \tag{1}$$

CEEN- efficiency coefficient of nodule deposit exploitation .

The mass of collected nodule depends mainly on:

- technical parameters of the collector,
- maneuverability and possibilities of collector movement control on the ocean floor,
- shape of the ocean floor (bathymetric map of the ocean floor includes fields with specified difficulties eg. stemming from the criteria for maximum angles of slopes of area (Fig. 5).

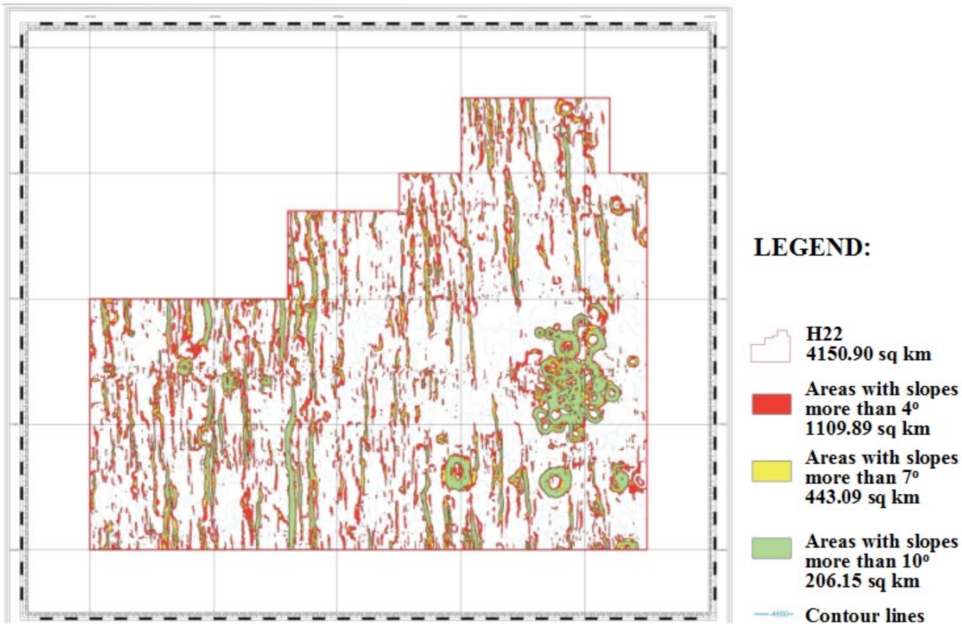

Fig. 5. Bathymetric map of H22 area

Technical parameters of the collector:

- accuracy of nodules collection from the ocean floor and range in size (diameter) of collected nodules, the possibility or the effectiveness of nodule crushing for the nodules that are too large in diameter,
- separation efficiency of nodules mined from the sea bottom clays or deposits,
- driving power and maneuvering performance on sea bottom slopes, in directions perpendicular and parallel to the slope.

Maneuverability of the collector:

- accuracy of location and trajectory of movement,
- accuracy of keeping a given direction of movement,
- turning radius and return to a given direction,
- the capability to surmount the obstacles on the bottom.

Basing on the parameters of the collector and knowledge of spatial parameters (bathymetric map) it will be possible to determine the shapes of ore fields (angle limit criteria) and the „run of mine" over the polymetallic nodules deposit..

Calculated CEEN for area H22, for only one criterion – the limits on bottom slope and with a uniform density around the nodules bottom this parameter takes the following values:

- up to 4^{o} of slope the CEEN = 0,733
- up to 7^{o} of slope the CEEN = 0,813
- up to 10^{o} of slope the CEEN = 0,950.

The above given calculated coefficient CEEN values for area H22 are theoretical. When other criteria for mainly technical parameters and nodule collector maneuvering characteristics are taken into account, these values are going to be significantly reduced. Works on the accurate determination of CEEN coefficient continue.

4. Industrial mining and transport system

The concept for an industrial mining and transport system is presented in Fig. 6.

After the tests of the experimental pilot mining system, the next phase of the research will be to determine the optimal parameters for the design and operation of the industrial mining and transport system.

Mathematical models of the parameters of design and operation of a mining and transport system will be developed. Using these models the optimal design and operational assumptions will be calculated for:

- annual output of mining and transport,
- unitary cost of operation of the mining and transport system,
- cost of production for a tonne of nodule ore on board the mining ship global cost of metal (or metal concentrates) may be obtained for mined nodules,
- unitary cost of processing the nodules at the processing plant.

Using the developed mathematical models of an industrial mining and transport system and taking into account the parameters of the marine environment occurring in the area of operation which affect the process of mining and loading, the following will be determined:

- cargo capacity, size and power of the mining ship,
- cargo capacities, speeds and number of transport vessels,
- nodules transfer systems used between the mining ship and transport vessels,
- theoretical output of the mining system.

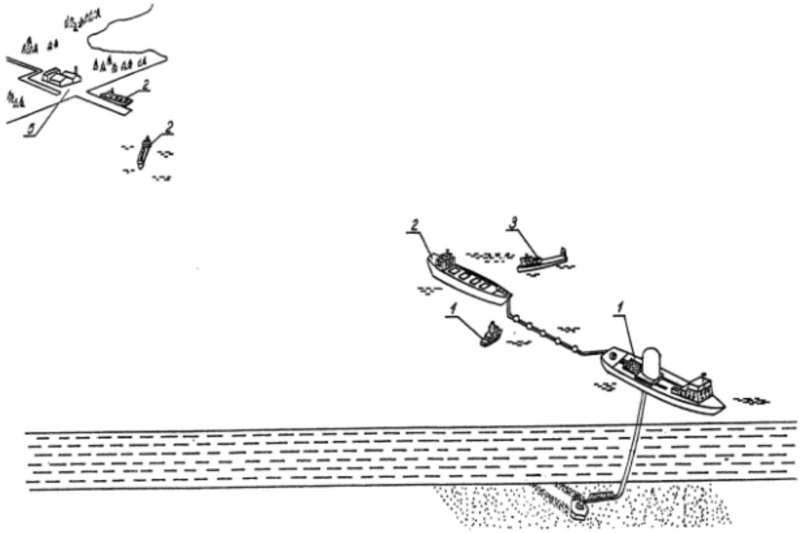

Fig. 6. Industrial mining and transport system
1. mining ship, 2. transport vessels, 3. supply vessel, 4. maintenance vessel, 5. onshore base

5. Output system-building possibility

Poland has enough potential in scope of scientific and technical knowledge to design and build the mining system. Polish Office of Design and shipyards specialize in the construction of vessels designed for the requirements of the offshore industry. There are also companies that can build a complete equipment for the polymetallic nodules mining ship.

In Słupsk (Poland) a company named HYDRO-NAVAL Sp. o.o. was founded in 1979specializing in the production of equipment destined for offshore or onshore operation, and also for the shipbuilding industry.

Fig. 7. Headquarters of Hydro-Naval, Słupsk, Poland

Company's areas of activity:

- equipment for drilling rigs and crude oil extraction ships
- pipe handling system and other dedicated equipment for offshore industry,
- hydraulic systems for the transport of pipes at drilling platforms and drilling ships,
- all types of winches for research boats (cables, seismic, deep sea winches, ROV winches, etc.),
- all types of winches for fishing industry,
- equipment produced for Polish Navy (positioning winches, RAS systems, special boat launching systems, etc.).

During the many years of its activity the Hydro-Naval company sought and implemented the following certifications and attestations:

- ISO 9001 Certificate,
- AQAP 2120 Certificate,
- ISO 3834-2 Certificate,
- Certificate of Navy Technical Service,

while the employees have all the necessary certifications for such production work, including those for welders granted by DNV and LR.

The main customers of the company are:

- National Oilwell Varco Norway,
- Aker Solutions,
- Rapp Hydema A/S Norway,
- Ship Equipment Centre, Holland i Ned Deck Marine, Holland,
- MH Wirth,
- Polish Navy,
- Atlas Elektronic GmbH, Germany.

Figs. 8 ÷ 11 present the some of the products of Hydro-Naval company.

Fig. 8. Drilling platforms equipment

Fig. 9. Equipment for the handling of drilling pipes

Fig. 10. Pipe handling systems for drilling platforms and ships

Fig. 11. Winches for research vessels – examples

6. Conclusions

1. IOM design works and computer simulations led to the development of a conceptual design of a mining system.
2. Further work should be focused on the design and the construction of the industrial scale system, whose test should be carried out in the real-life sea conditions.
3. Tests are to be executed in two phases
4. mining test at a shallow depth (Baltic),
5. pilot mining test in the Pacific. The results of pilot mining tests will provide data for the decisions concerning the construction of an industrial mining and transport system, and will determine the technical and economic relations between nodule ore reserves and the related resources.
6. The scientific and technical potential of Polish companies with international cooperation allows for the development, design, construction and testing of the industrial system to be used for the mining and transport of polymetallic nodules.