

PUBLIC REPORT

BLUE

MINING

Breakthrough Solutions for Mineral Extraction
and Processing in Extreme Environments

2014-2018

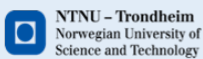


TECHNICAL COORDINATION



CONSORTIUM PARTNERS

RESEARCH INSTITUTES



INDUSTRY



SERVICE SUPPLIER



This project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 604500.

INTRODUCTION

Dear Reader,

Access to raw material resources is vital for the development of societies, and its importance for the development of the European Union is as evident. Coal and steel were the drivers of the EU in its early days, now we see a rapid transition to wind energy, solar power, highly developed IT systems, smartphones, the Internet of Things, electric cars and their endless possibilities. Is there still a role to play for raw materials in our highly developed 21st century society?

Yes. And this role is bigger than it has ever been. There is a paradox in building our sustainable society based on advanced technologies, and this is in the tremendous amounts of raw materials needed for that transition. Estimates indicate that the global demands for materials like cobalt, nickel, lithium and copper will increase ten to hundredfold in the foreseeable future. And the EU needs them.

The oceans have been identified as one of the major new potential resources for the EU. The seas and oceans contain many types of raw material deposits. In the deepest regions, between two and five kilometers of water depths, one finds vast amounts of seafloor massive sulphides and polymetallic nodules, containing the metals needed in our industries. Are these deposits a viable additional source of raw materials, next to terrestrial mining?

In 2014, 19 partners from EU industry, research institutions and academia joined forces to form the Blue Mining consortium. They set out to work on the development of deep sea mining, looking into exploration, identification, economic assessment and technology development for mining seafloor massive sulphides and polymetallic nodules. Now, four years later, our journey has come to an end. We have learned and grown together. We have developed knowledge and technology that brings deep sea mining closer to a realistic alternative. And we are ready to take the next step.

We want to take you along on our journey from seafloor to sea surface, sharing our results and achievements. Ready for a deep dive?

Delft, February 2018

Dr. Jort M. van Wijk, IHC MTI, Blue Mining Technical Coordinator

EXECUTIVE SUMMARY

The EU has identified the risk of an increasing supply shortage of metals identified as critical to Europe's high technology sector. The de-risking strategy comprises improving recycling technology, finding alternative materials and finding alternative resources.

One of the alternative resources of raw materials are deep sea deposits. The Blue Mining consortium has focused on extinct seafloor massive sulphide deposits and subsea polymetallic nodules. The consortium wants to provide breakthrough solutions for a sustainable deep sea mining value chain. This means development of the technical capabilities to adequately and cost-effectively discover, assess and extract deep sea mineral deposits in up to 6,000 m of water depths as this is the required range where valuable seafloor mineral resources are found.

During four years, from February 2014 to January 2018, the consortium obtained 10M€ funding from the EU FP7 framework under contract number 604500 to work on its mission. We have looked into exploration of the seafloor in order to find resources, the economic assessment and evaluation of resources and transport technology to get the material from the seafloor to the sea surface.

The main results of four years of work comprise data, computer models, new measurement technologies and technology concepts. Regarding data, unique data sets have been acquired during research cruises at sea and laboratory tests on small and even large scale vertical hydraulic transport tests, unique in size and scope. The computer codes developed in Blue Mining can be used for detailed simulation of riser dynamics and slurry transport processes. These codes are validated by the laboratory experiments. Even more tangible are the new sensor technologies for finding extinct seafloor massive sulphides, a blueprint for economic evaluation of deep sea resources and a concept design for vertical transport system technology with special attention for booster stations. For the latter a special deep sea motor has been developed and tested.

The impact of Blue Mining is found in the worldwide scientific community, in the research and development departments of the consortium partners, at the regulatory bodies as the International Seabed Authority and at the wider public. Blue Mining contributed with over 25 articles in scientific journals and on conferences and Blue Mining enabled the implementation of this knowledge in technology concepts. The consortium hosted multiple public events for a wider audience, including a dedicated museum exhibition in Lisbon, Portugal. The final workshop in Aachen engaged with representatives of the International Seabed Authority, placing the consortium at the forefront of the development of rules and regulations regarding deep sea mining.

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INTRODUCING BLUE MINING

“Seventy percent of the earth’s surface is covered by sea and oceans, yet we seem to know less about our ocean space than outer space.”

– Rodney Norman, IHC

BACKGROUND

Earth provides natural resources, such as fossil fuels and minerals, that are vital for Europe’s economy. As the global demand grows, especially for strategic metals, commodity prices rapidly rise and there is an identifiable risk of an increasing supply shortage of some metals, including those identified as critical to Europe's high technology sector.

Hence a major element in any economy’s long-term strategy must be to respond to the increasing pressure on natural resources to ensure security of supply for these strategic metals. In today's rapidly changing global economic landscape, mining in the deep sea, specifically at hydrothermal vents and the vast areas covered by polymetallic nodules, has gone from a distant possibility to a likely reality within just a decade.

The extremely hostile conditions found on the deep-ocean floor pose specific challenges, both technically and environmentally, which are demanding and entirely different from land-based mining.

At present, European offshore industries and marine research institutions have some global advantage through their significant experience and technology and are well positioned to develop engineering and knowledge-based solutions to resource exploitation in these challenging and sensitive environments.

However, against an international backdrop of state-sponsored research and development in sea floor resource discovery, assessment and extraction technologies, European operators are in need to keep up to pace by initiating pilot studies to develop breakthrough methodologies for the exploration, assessment and extraction of deep-sea minerals, as well as investigate the implications for economic and environmental sustainability.

FACTS AND FIGURES

The Blue Mining consortium consists of 19 partners from 6 different European Countries who collaborated during a 4 year period on increasing the level of deep sea mining technology.

Blue Mining key figures

Start date:	1 Feb 2014
End date:	31 Jan 2018
Duration:	48 Months
Total costs:	15 M€
Total EC Funding:	10 M€
EC Contract:	604500

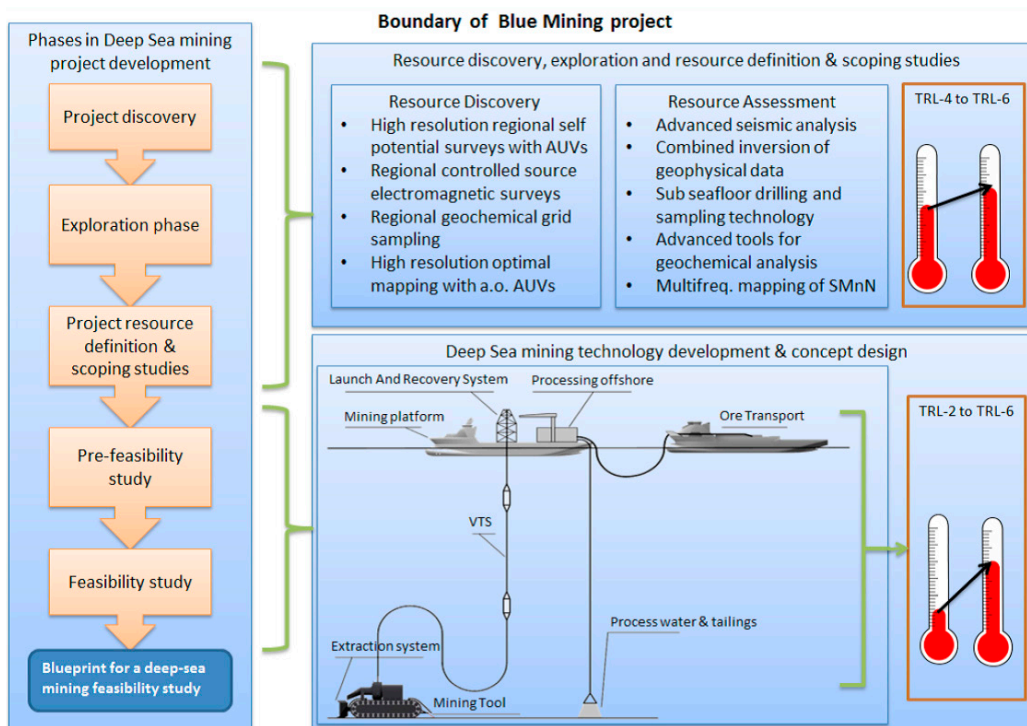


FIG.1. BOUNDARY OF THE BLUE MINING PROJECT. ON BOTH THE DISCOVERY, EXPLORATION AND DEFINITION AND TECHNOLOGY ASPECTS THE CONSORTIUM AIMS AT INCREASING THE TRL'S FROM 2 TO 6.

PROJECT OBJECTIVE

The overall objective of Blue Mining is to provide breakthrough solutions for a sustainable deep sea mining value chain. This means to develop the technical capabilities to adequately and cost-effectively discover, assess and extract deep sea mineral deposits up to 6,000 m water depths as this is the required range where valuable seafloor mineral resources are found. The control over these three capabilities is the key for access to raw materials, for decreasing EU dependency on resource imports and for strengthening Europe's mining sector and their technology providers.

Fig.1 on the left shows the phases in deep sea mining project development, going from project discovery, to exploration, resource definition and scoping studies, pre-feasibility study, feasibility study, to project approval and financing and finally to implementation. Even for the most advanced deep sea mining projects no professional full scale feasibility study is publicly available. Blue Mining will develop a blueprint for feasibility studies and validate this blueprint via the evaluation of deep sea mining projects of two different resources: extinct SMS deposits and Seafloor Manganese Nodules. A thorough and conclusive feasibility study is a pre-requisite for a mining company before taking the decision to go ahead with the implementation of the project.

On the right, Fig. 1 shows the focus of the scientific and technical activities related to resource discovery and assessment (upper image) and related to mining technology development and conceptual design of a complete installation (lower image). Blue Mining's aim is to develop all key technologies for exploration (discovery and assessment) and for exploitation of deep sea mineral resources up to TRL6, i.e. system/subsystem model or prototype demonstration in a relevant environment. Blue Mining will also prepare an exploitation plan for the next phases in the technology and business development of the sustainable exploration and mining of deep sea mineral resources: the Follow-Up and the Market Entry phase.

PROJECT STRUCTURE

A widely used code in the (land) mining industry is the Australasian Code for Reporting of Exploration Results (JORC Code), Mineral Resources and Ore Reserves. The JORC Code provides a mandatory system for the classification of minerals Exploration Results, Mineral Resources and Ore Reserves according to the levels of confidence in geological knowledge and technical and economic considerations in Public Reports. Fig. 2 shows Blue Mining's targeted breakthroughs and corresponding work packages positioned in the JORC-diagram.

The value creation chain, grouped in work packages, corresponds with the JORC code axes from Exploration results/Inferred mineral resources to Indicated, Measured and Proved resources. The flow of the value creation chain that follows the Blue Mining project work flow is shown as well.

Work Package 1 (Resource discovery) focuses on new and/or improved technologies for resource discovery for active/extinct Seafloor Massive Sulphides (SMS/eSMS) and for Seafloor Manganese Nodules (SMnN). WP1 links with the JORC-code first step for increasing the level of geological knowledge and confidence.

Work Package 2 (Resource assessment) focuses on more reliable resource assessment technologies, raising the level of confidence from inferred (i.e. speculative) to indicated (i.e. reasonable level of confidence). WP2 links with the JORC-code second step for increasing the level of geological knowledge and confidence.

Work Package 3 (Resource sustainable management and economic evaluation) evaluates the economic viability of the new Blue Mining technologies, and develops methods and instruments for a more sustainable resource management approach, to be applied to SMS/SMnN deposits (two cases). WP3 will develop concepts for fiscal incentives to promote the more sustainable resource management approach, and blue print feasibility studies for SMS/SMnN deposits. Work Package 3 links with the JORC-code "Modifying Factors" elements.

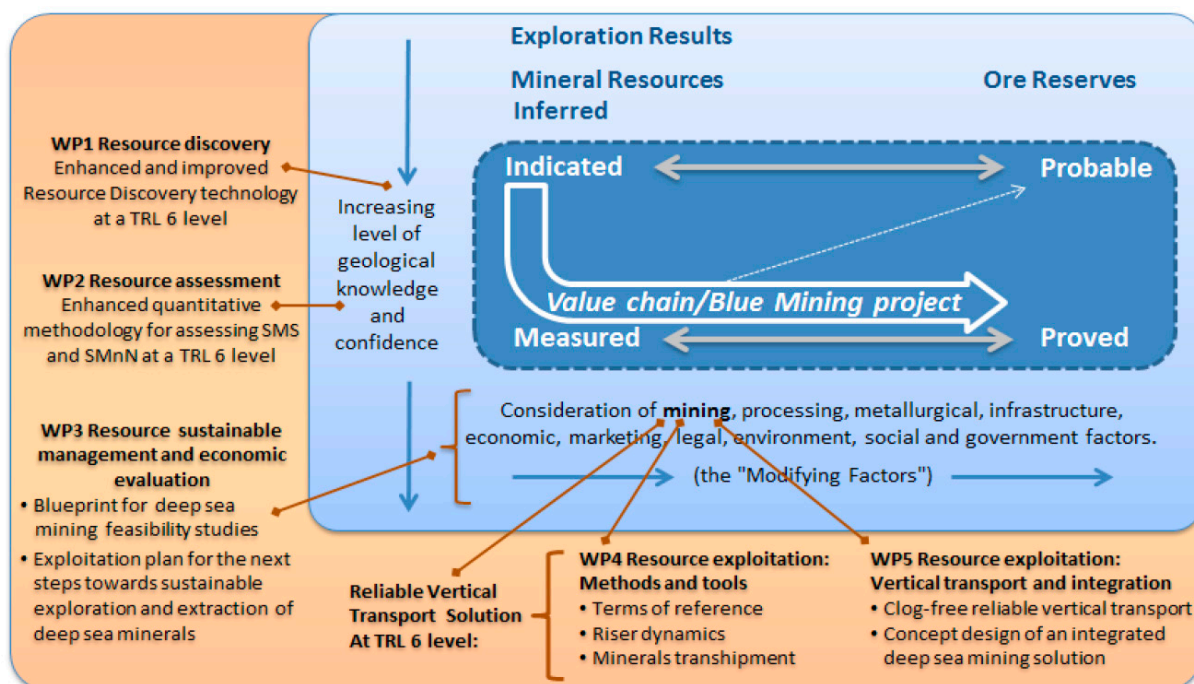


FIG. 2. BLUE MINING VALUE CREATION FOLLOWS THE JORC AXES.

Work package 4 (Resource exploitation: Design methods and tools) focuses on phenomena related to the dynamics of vertical transport (slurry dynamics, riser dynamics and dynamics of minerals transfer from mining-ship to transport-ship), using numeric and experimental methods.

Work Package 5 (Resource exploitation: Vertical transport and integration) deals first with the mechanism of clog-free vertical transport including riser wear and tear phenomena. WP5 concludes the work programme sequence by addressing the critical interfaces between the key functions within the context of a complete deep sea mining system solution. Work Packages 4 and 5 link to the mining element of the JORC-code “Modifying Factors”.

Work package 6 (Demonstration of eSMS characterization capabilities and VTS testing facilities) makes use of all earlier research efforts for combined demonstration purposes. It focuses on the validation of the developed capabilities for the discovery and assessment of surface and near surface seafloor massive sulphide deposits during cruise on target area (WP2), the developed capabilities for: 1) the field test of mineral handover (ship-to ship transfer) at sea (WP4), 2) the testing of critical components of the VTS (WP5) and for 3) the testing of riser lining materials (WP5).

GUIDE FOR READING

In this report the major findings and achievements of all workpackages are grouped thematically under the themes “Finding New Resources on the Seafloor”, covering WP1 and WP2, “The Value of Seafloor Resources” covering WP3, “From Seafloor to Sea Surface”, covering WP4, WP5 and WP6.

The impact of the research is addressed in the chapter “New Opportunities with Lasting Impact”.

FINDING NEW RESOURCES ON THE SEA FLOOR

“Our new model suggests that many of the smaller deposits are likely to be economically viable targets than their resource estimates based on the volume of the mound alone would suggest.”

– Dr. Bramley Murton, NOC (NERC)

THE CHALLENGE

Due to the lack of data and exploration it was not possible to answer the question, if the oceans can provide the resources for future generations. This knowledge gap was addressed during Blue Mining. The consortium’s aim was to develop and test new tools for the exploration of inactive, or extinct, seafloor massive sulphide deposits (eSMS) and Mn-nodule deposits (MnN). Extinct Seafloor Massive Sulphides (eSMS) are considered to be at least ten times more abundant than actively forming SMS deposits. Moreover, the extraction of eSMS is likely to have a significant lower impact on the surrounding marine life and environment than the extraction of actively forming SMS deposits.

Exploration at the seafloor is commonly slow and expensive due to the need of surface ships and manpower during, commonly, several weeks to months at sea. The areas that need to be covered are vast. For example, taking a 20-km corridor around the global Mid-Ocean Ridges in which eSMS are supposed to be accessible to modern mining technology would effectively mean that 3.2 million km² of permissive area have to be explored. The overall aim was therefore to develop methods and technologies that allow a more rapid and cost effective exploration.

MAIN INNOVATION AND TARGETED KEY RESULTS

- A new self-potential exploration tool for use with AUV capable of imaging inactive massive sulphide deposits on large-scale regional surveys
- Underway active marine controlled source electromagnetic survey to determine the regional electrical characteristics around extinct SMS deposits
- An automated image analysis system for structure recognition (SMnN and SMS)
- Predictive mapping and associated study of cover rocks to identify concealed sulphide mineralization
- The new geophysical tools and geological mapping and sampling will allow fast and reliable mapping and predictive numerical modelling of resource probability and potential (accuracy: > 90%) at a targeted cost per square km down to €10,000 for SMS, € 25,000 for eSMS and € 5,000 for SMnN respectively. This represents an improvement of a factor 2 in reliability, a factor 10 in time (to less than two weeks to carry out a 100 square km survey), and a factor 20 in costs.

- High-resolution geophysical data (including both seismic and electromagnetic) across type examples of extinct seafloor massive sulphides (eSMS) deposits
- Sub-surface samples of the mineral deposit recovered by novel, diamond-bit sea floor drilling.
- Integrated and joint inversion models for seismic, electrical and petrological properties of eSMS deposits.
- Quantitative interpretation of the SMS system, the 3D distribution of metal ores and their modification by postformation processes, by calibrating the geophysical data against geochemical and physical analyses of drilled material and ore.
- Remotely sensed sonar technologies to identify and quantify the size and abundance of surface and near surface SMnN nodules.
- Predictive model for nodule size and distribution based on multi-frequency sonar spectral characterization of nodule fields and models of Rayleigh scattering
- Development of a methodology for developing quantified and calibrated earth models of eSMS deposits using a combination of geophysical techniques calibrated against samples recovered by targeted seafloor drilling.

The methodology will be considered a breakthrough if it can: a) rapidly and quantifiably assess mineral resources over a range of scales from hundreds of square metres to several square kilometres; b) be sufficiently accurate to yield a reliable assessment of grade and tonnage (to better than 80%); and c) to be efficient and cost effective with an increase in cost effectiveness of ten times over the current state-of-the-art.

The new geophysical tools and methodologies will allow fast and reliable assessment of deep sea mineral reserve potential (i.e. grade and tonnage assessed to >80%) at a targeted cost per square km down to € 1,500,000 for SMS and eSMS and € 50,000 for SMnN respectively (relative to € 15,000,000 expended by Nautilus Minerals Inc. on the Solwara 1 SMS assessment). This represents an improvement by a factor 2 in reliability, 5 in time (i.e. taking less than two months to carry out a 1 square km eSMS assessment, or 500 square km SMnN assessment), and a factor 10 or more in improved cost efficiency.

EXPLORING THE SEAFLOOR

Over the past years of the Blue Mining project four tasks looked at different ways to achieve improvements in exploration technology. Autonomous mapping of the seafloor by underwater vehicles (AUVs) using dedicated sensors for the search of eSMS that were developed during Blue Mining has been shown to be an efficient exploration tool. During the Blue Mining cruise some 50 km² of the ocean floor were mapped in a resolution sufficient to detect deposits over 50m in diameter. This seems reasonable as the minimum target size for economic deposits is supposed to be in the order of 50-100 m. While the sensors and methodology have proven to be useful, the discrepancy between the area a single AUV can map and the size of the permissive area for eSMS (3.2 million km²) or even the size of the exploration area of a contractor to the International Seabed Authority (10,000 km²) indicates the progress that needs to be made.

The tools and methods developed in work package 1 are variable. The AUV surveys mentioned above are able to detect eSMS directly situated on the seafloor. Other methods such as the rapid ship-based geochemical

Magnetic and Conductivity Anomalies

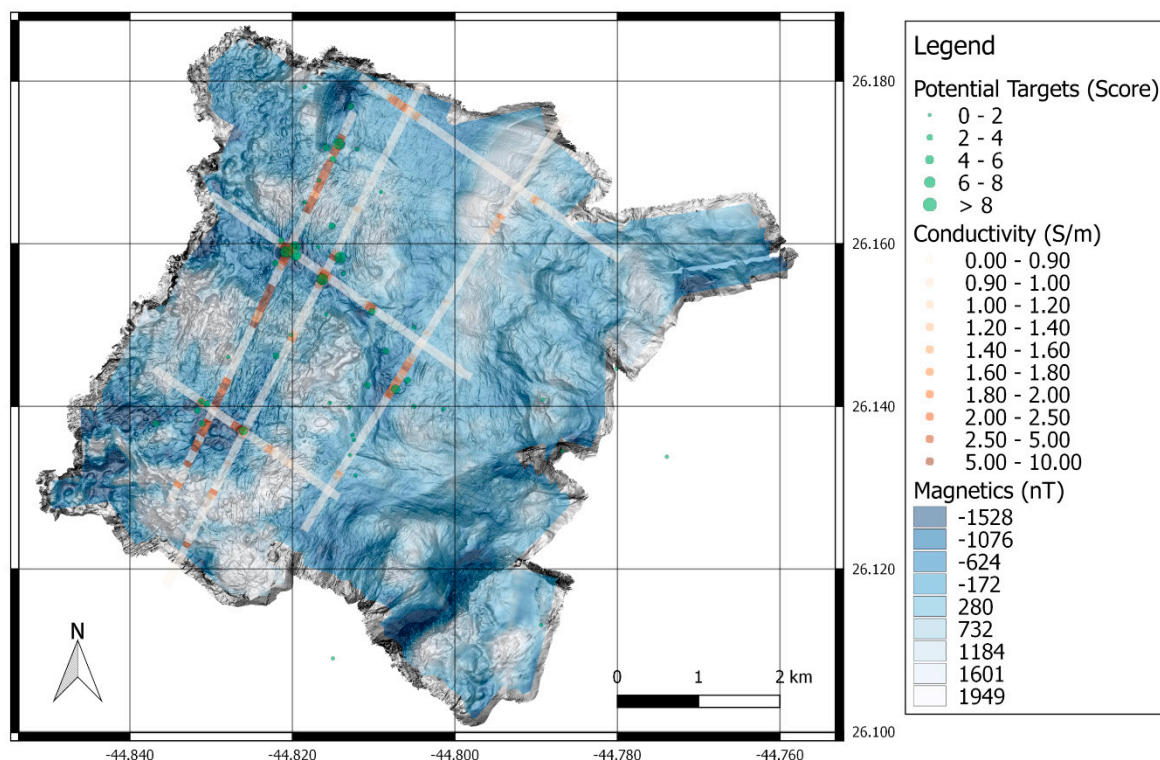


FIG. 3. COMBINATION OF DIFFERENT DATASETS OBTAINED BY VARIOUS PLATFORMS USED IN EXPLORATION FOR EXTINGUISHED SEAFLOOR MASSIVE SULPHIDES (eSMS) ALONG THE MID-ATLANTIC RIDGE. UNDERLYING HIGH-RESOLUTION (2M) TOPOGRAPHY IS FROM A SERIES OF AUV DIVES OBTAINED DURING THE EXPLORATION CAMPAIGN IN 2016.

and mineralogical analyses of regional sediments and electromagnetic surveys are capable of determining the thickness of the deposits or to detect deposits under cover. Ship-based analytical methodologies using portable instruments minimize the loss of time between sampling and shore-based analytics. Due to the three-dimensional sampling of the upper few meters of the sediments this exploration strategy has shown its potential to not only detect regional geochemical anomalies at the surface but also at depth providing evidence for past hydrothermal activity and therefore vectors to concealed mineral deposits at depth. Towed electromagnetic instruments have been developed and successfully tested not only to detect eSMS, but also to provide first estimates on the thickness of the conductive layer. Due to the need of measuring close to the seafloor, in order to enhance data quality, the surveys were flown using high-resolution topographic information derived from the AUV. Developing tools for data and error analysis and joint inversion of data from various instrument was an important step in the project minimizing uncertainties in the data.

The development of automated image analysis systems for eSMS and MnN was another paths taken to enhance exploration. Underwater hyperspectral imaging has been successfully tested to indicate the presence of eSMS on the seafloor. In contrast to visual information, hyperspectral imaging acquires images in hundreds of contiguous spectral bands so that each image pixel contains a full spectrum. After corrections of this full spectrum, objects of interest (OOI) can be characterized by an optical fingerprint and thereby classified. The use of image analysis is a standard tool in manganese nodule exploration. However, image analysis was previously assessing small amounts of data from individual photos or short video tracks. The amount of data coming from new AUV camera surveys with several hundred thousand photos requires the development of new tools and methods for data processing. During the project we enhanced software codes based on a neural network approach and successfully applied those to analyze seafloor with a special focus on the estimation of manganese nodule coverage and abundance.

Overall the developments in Blue Mining work package 1 have resulted in exploration strategies that reduce exploration costs and use ship-time more efficiently.

MAPPING ESMS DEPOSITS

Our work of four years of data collection has resulted in the most comprehensive geological and geophysical, three-dimensional characterisation of hydrothermally extinct, seafloor massive sulphide deposits, hosted by volcanic systems, at slow spreading mid-ocean ridges.

The main findings are that eSMS deposits comprise 4 zones: zone 1 comprises sediment and a thick jasper layer overlying, and protecting from alteration, an ore body comprising dense massive sulphide ore body from which the anhydrite has been dissolved and lost resulting in mound collapse. This overlies a sulphide-rich stockwork zone within an altered and silicified basaltic lava host. The evidence supporting and informing this new deposit model is based on a combination of various geophysical techniques, surface geological mapping and sub-surface drilling and coring of a number of eSMS mounds in the TAG area of the Mid-Atlantic Ridge (26°N).

The presence of highly conducting and high-seismic velocity material down to 50-100 mbsf indicates that the main ore body forms a lens that is massive in character, probably with little gangue material. The seismic evidence points to a further body of material below the main ore lens that extends to 200 mbsf where it forms a downwards-narrowing cone of sulphide stockwork. Previous geological models for SMS mounds interpret their formation as a process driven by sulphide precipitation in the form of chimneys, the subsequent collapse, autobrecciation and accumulation of sulphide debris building a positive morphological feature that we see today as the mounds.

We have been able to combine the geophysics data with the boundaries and volumes of the internal mound structure to yield an estimate of the metal content of the eSMS. Our data show that the main ore body extends to a sub-seafloor depth of about 100 m and comprises between 34% and 80% sulphide with abundances increasing with depth. The underlying stockwork extends to another 100 m depth and comprises up to 17% sulphide, on average. The higher concentrations most probably occur at the top of the stockwork zone and decrease in abundance downwards where the zone narrows and grades into an altered basalt host rock.

In general, our data indicate a volume of massive sulphide that is, on average, 3.7 times greater than that expressed by the surface expression of the eSMS mounds, has been precipitated beneath the. This estimate could be 50% greater if the metal rich sediment aprons that surrounds the eSMS mounds are included.

From a resource perspective, estimates by members of the Blue Mining consortium indicate that there are about ten time more extinct SMS deposits exposed on the seafloor or under a few metres of sediment, within a corridor spanning 20 km to each side of the mid-ocean ridge axis, compared with the number of known hydrothermally active systems. Of the active systems, 350 are known, with another 1000 estimated yet to be discovered. If we consider only the eSMS deposits, then the accessible inventory may be of the order of 13,000 deposits worldwide.

Combining the geophysical data yields a composite structure for the eSMS mounds, shown in Fig. 4. Combining this with the surface geology information and drill core from across the eSMS mounds allows us to construct a composite model for the structure of the eSMS mounds in the TAG area (Fig. 4). Despite their differences, Shinkai, Southern, Rona and MIR zone all have similarities. The eSMS mounds are draped in a veil of pelagic sediment. This is underlain by 1–3 m of iron-oxide/oxyhydroxide-rich sediments that are derived from hydrothermal activity. Below these is a ubiquitous layer (3 to 5 m thick) of silica (jasper) the structure and composition of which indicates it has been precipitated from hydrothermal fluids, probably during the late, waning stage of the hydrothermal cycle. The jasper partially silicifies the iron-rich sediments and is itself partly mineralised by sulphide. The jasper gives way to a transitional zone of vuggy massive sulphide (4–6 m) in which pyrite dominates (with some sphalerite), while silica decreases in concentration with depth. Below this the deposits transition into massive sulphide (pyrite and chalcopyrite) with ~5–15% porosity, up to 20% copper, and little or no gangue material. The presence of inward dipping, arcuate faults also seems to be a common feature for the oldest and largest eSMS deposits. These indicate reduction in volume within the mounds and is probably related to the dissolution of anhydrite. The geophysics data are consistent with the geological interpretation and indicates further structure extending to depths of 200 mbsf. The eSMS mounds are divided into four geophysical zones. The core and surface geology data show the sediment jasper layer constitutes Zone 1. Zone 2 is massive sulphide that extends to 50–100 mbsf, and Zone 3 is a mixture of sulphide and gangue material that extends to ~200 mbsf. Zone 4 is altered basalt crust.

Using the dimensions derived from the bathymetric, seismic and CSEM data, we can make estimates for the volumes and tonnages of sulphide in the eSMS mounds and derive relationships to predict this from surface morphology. The volumes of the zones are calculated assuming the mounds approximate a cone, with depths and velocities derived from the seismic data. These are used to calculate the tonnage of the sulphide assuming: the lowest grades are near the surface of the mounds, pore-space reduces the density in the interior of zone 2, and silica is the gangue material in zone 3, the stockwork.

As a prediction of the potential resource in the sub-surface we can compare the surface expression of the mounds with the calculated sulphide tonnages. There is a general relationship between the surface expression of the eSMS mounds and their calculated potential tonnages of sulphide (Fig.5). This assumes that the eSMS deposits are expressed as positive topographic features and they have similar sub-surface structure. With the data currently available it is not possible to make predictions about the chemical composition, or metal tenor, of the interior of the mounds at depths greater than 12 mbsf. This requires drilling of holes that are much deeper than those made during the Blue Mining project.

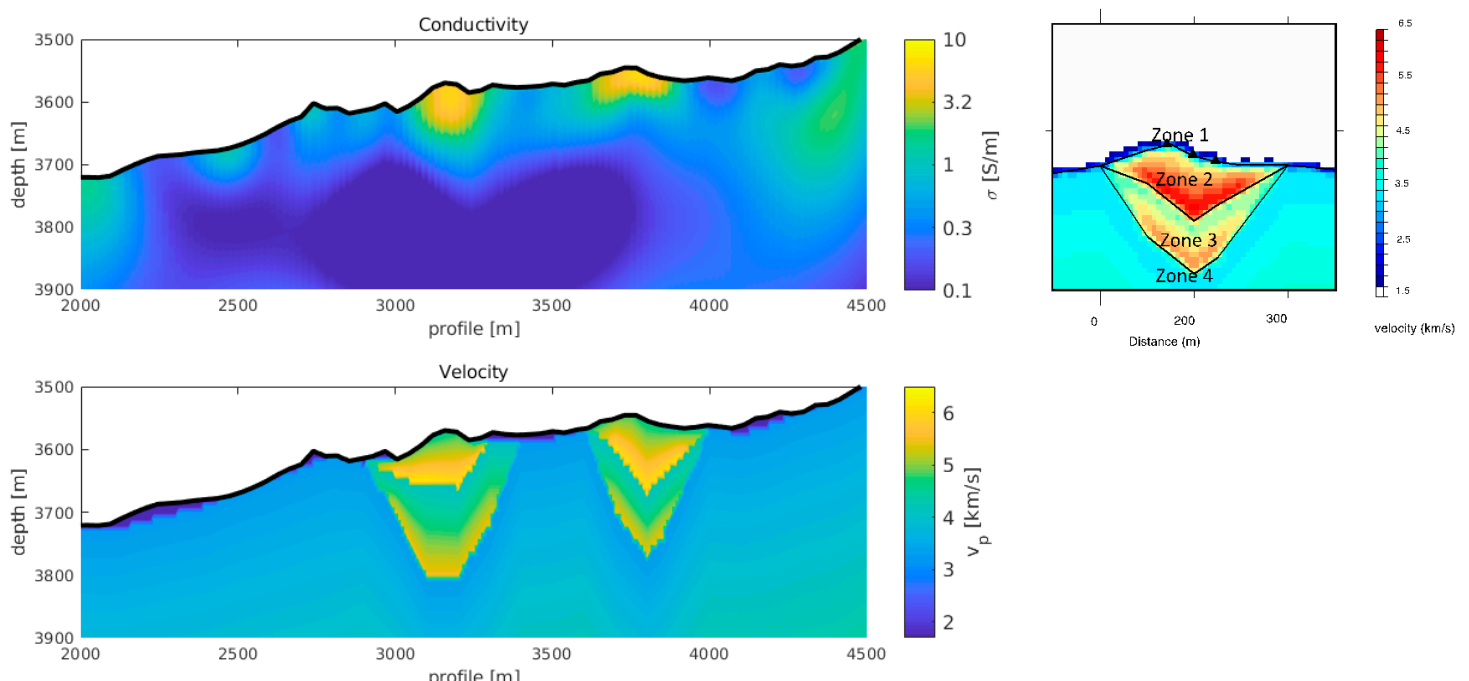


FIG. 4. TOP LEFT SHOWS THE CONDUCTIVITY MODEL FOR SHINKAI AND SOUTHERN MOUNDS, BOTTOM LEFT SHOWS THE SEISMIC VELOCITY STRUCTURE AND ZONE BOUNDARIES UNDER THE SAME MOUNDS; RIGHT SEISMIC P-WAVE STRATIGRAPHY MODEL FOR SMS MOUNDS (BASED ON SOUTHERN MOUND) SHOWING AVERAGE VELOCITIES AND ZONES DEFINED BY REFLECTORS: ZONE 1&2 (4.2 KM/S) COMPRISES 10M SEDIMENT AND JASPER (ZONE 1) OVERLYING 90M MASSIVE SULPHIDE (ZONE 2); ZONE 3 MIXED SULPHIDE AND NON-SULPHIDE (GANGUE), ZONE 4 ALTERED BASALT WITH UNALTERED BASALT SURROUNDING. LAYERS ARE INTERPRETED AS: 1 = SEDIMENTS AND JASPER, 2 MASSIVE SULPHIDE AND PORE-SPACE, 3 STOCK-WORK, 4 ALTERED BASALT HOST. NOTE THAT THE GRADIENTS IN SEISMIC VELOCITY SHOWN INSIDE THE ZONES ARE ASSUMED IN THE MODEL AND ONLY THE AVERAGE P-WAVE VELOCITY FOR EACH ZONE HAS BEEN DETERMINED. HOWEVER, SHARP SEISMIC VELOCITY IMPEDANCE CONTRASTS ARE REQUIRED ACROSS THE ZONE BOUNDARIES TO YIELD THE REFLECTION EVENTS OBSERVED IN THE SEISMOGRAMS.

The implication of our results is for a significant increase in the resource potential presented by eSMS deposits at slow-spreading ridges (Fig. 6). Compared with the estimates indicated by the volume presented by the morphological expression of the mounds alone, the total resource potential is considerably greater. Compared with the mass of sulphide calculated from the surface, the total tonnage ranges between 3 and 6 (average 3.7) times greater. A compilation of deposits taken from the global data base indicates a higher proportion of SMS comprise smaller deposits, compared with larger ones. Our new model suggests that many of the smaller deposits are likely to be economically viable targets

than their resource estimates based on the volume of the mound alone would suggest. However, a consequence of the new model is that any future exploitation will require more substantial excavation below the seafloor than was previously envisaged. Hence SMS deposits are truly three-dimensional deposits and both exploitation plans and impact assessments need to take this into consideration.

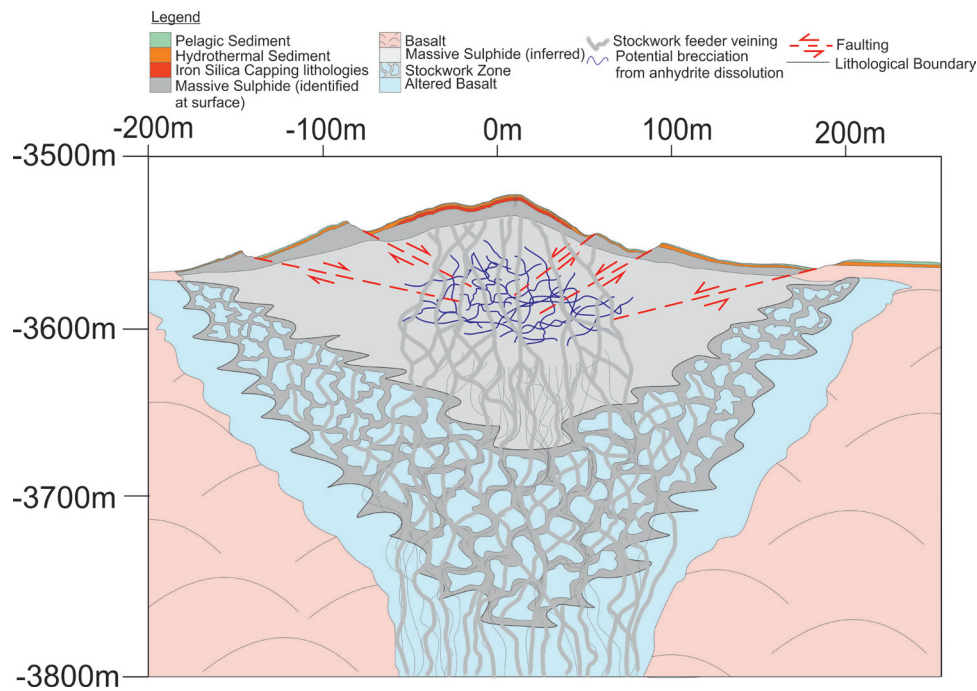


FIG.5. COMPOSITE 3D GEOLOGICAL MODEL OF THE TAG ESMS MOUNDS BASED ON A SYNTHESIS OF THE SURFACE GEOLOGY, DRILLING AND GEOPHYSICS SHOWING SEDIMENT COVERED MOUNDS WITH AN INTERIOR COMPRISING AN UPPERMOST JASPER LAYER UNDERLAIN BY MASSIVE SULPHIDE THAT MERGES DOWNWARDS INTO A STOCKWORK. THE INTERIOR OF THE MASSIVE SULPHIDE BODY IS BRECCIATED AS A RESULT OF DISSOLUTION OF ANHYDRITE THAT IN TURN LEAVES OPEN PORE SPACE AND CAUSES CONTRACTION OF THE VOLUME OF THE MOUND RESULTING IN INWARD FAULTING. NOTE THE SIGNIFICANT PRESENCE OF ORE MATERIAL LIES BENEATH THE MOUND AT A DEPTH THAT IS AT LEAST TWICE THE HEIGHT OF THE MOUND ITSELF.

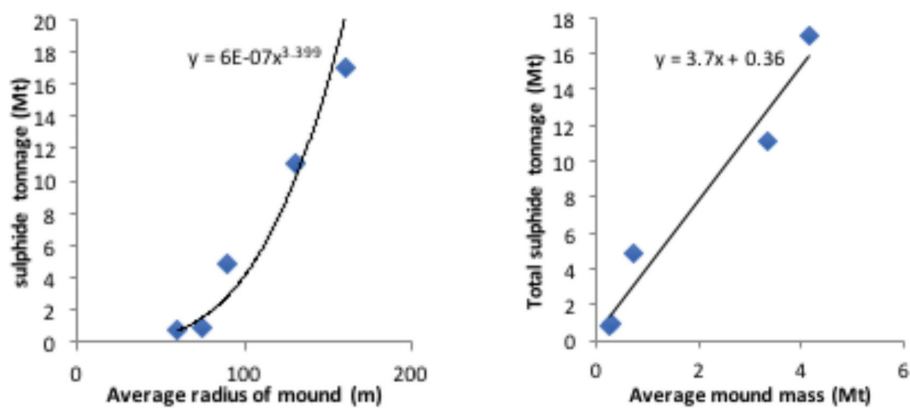


FIG. 6. THE NEW MODEL PREDICTS THE TONNAGE OF SULPHIDE IS ON AVERAGE 3.7 X GREATER THAN THAT PREDICTED FROM THE MOUND VOLUME ALONE. IT ALSO PREDICTS THAT MOUNDS WITH A RADIUS OF 50 M OR LESS HAVE SUB-MILLION TONNE ORE BODIES THAT ARE PROBABLY UNECONOMICALLY VIABLE TO EXPLOIT.

THE VALUE OF SEA FLOOR RESOURCES

“As part of Blue Mining research, a set of different tools, methods and approaches have been developed, which can be used by both industry and authorities to establish mine plans.”

– Dr. Felix Lehnen, RWTH Aachen

THE CHALLENGE OF CALCULATING THE FUTURE

The deep-sea may become a new field of human mining activities in the future. Going into the deep-sea to explore new resources to cover our raising needs for metals is challenging and expensive. For this reason, knowledge and data of ore deposits are scarce and estimations of reserves and resources are not very precise and not yet reliable. The development of mining technologies and methodologies as well as tools to plan a sustainable exploitation currently takes place in parallel to current exploration activities. However, the technological readiness level (TRL) of some special mining equipment is still low. Nevertheless, Blue Mining has pushed towards the development of prototypes.

Furthermore, mining in the deep-sea will only be economical under certain market conditions. This means that metal prices and demand of copper or cobalt need to be high enough to cover the high costs and risks of deep-sea mining. Market developments are uncertain and forecasts are difficult to make. In addition, one has to be able to quantify the mineral potential of deep-sea deposits. To estimate the potential metal production of an underwater mine, one has to be aware of capacities and restriction of machines and the given geology.

ASSESSING FUTURE RESOURCES

As of today, 26 contractors have received 15-year contracts for exploration for Seafloor Manganese Nodules (SMnN), Seafloor Massive Sulfides (SMS) and Cobalt-rich Ferromanganese Crusts (ISA, 2017). The International Seabed Authority (ISA) organizes and controls such licences. ISA is an autonomous international organization established under the 1982 United Nations Convention on the Law of the Sea. Fifteen of these contracts are for exploration of SMnN in the Clarion-Clipperton Fracture Zone (CCZ) and Central Indian Ocean Basin, each covering 75,000 km². SMnN are lying on about 38 million km² of the ocean floor, of this only about 1.3 million km² are explored today (Petersen et al., 2016). Six contracts are in place for exploration of SMS in the Indian Ocean and the Mid-Atlantic Ridge. These licenses divide into blocks to a total size of 10,000 km². SMS deposit potential in the neovolcanic zone is estimated to 600 million t (Monecke et al., 2016) covering an area of 3.2 million km² (Petersen et al., 2016). Today's licenses only cover 60,000 km² in the Area. These numbers are only estimates and need much more research and exploration to know exactly what quantity of ores from the ocean floor are mineable.

To foster a most sustainable use of resources and seafloor, a spatial management strategy and a concept to measure sustainability needs to be developed. Against this background, further research, mining tests and comprehensive environmental studies are crucial. A mining code containing regulations on the exploitation of mineral resources in the Area beyond the limits of national jurisdiction is on the agenda of ISA for the next upcoming years. Blue Mining has developed approaches on how to measure sustainable mining operations by indicators and how to foster positive responsible behaviour of entrepreneurs by incentives. Further developed tools allow for spatial management and control of seafloor areas and the sustainable use of their resources.

BUILDING DEPOSIT MODELS AND MINE PLANS

Geological modelling is an important step in order to calculate the resource potential of a deposit and it provides the base for an economic assessment. A geological deposit model therefore enhances the knowledge of the target area. The data base for the models often are drill-holes in the case of confined deposits such as SMS and box-core samples and remote operated vehicle (ROV) data for areal deposits such as SMnN. Data interpretation and interpolation was achieved during the Blue Mining project (Rahn, 2016) by a number of statistical approaches (e.g. ordinary kriging) resulting in a best-fit model of a 3D orebody or a 2D map.

These deposit models provide mining engineers with information (e.g. bathymetry, grade, nodule abundance) to do mine planning. Mine planning covers the whole value chain – from the exploration to the scheduling of machines and from the financing of mining projects to the study of the economics. As part of Blue Mining research, a set of different tools, methods and approaches have been developed, which can be used by both industry and authorities to establish mine plans (Volkman & Lehn, 2017; Volkman et al., 2018).

With this knowledge, Blue Mining has also developed detailed project plans for the preparation and execution of SMS and SMnN mining operations. Economic models base on such project dimensions and allow for financial assessments and plans. All the work done, reaching from exploration and deposit modelling through mine and project planning as well as economic assessments and market studies contribute to the preparation of blueprint feasibility studies. Blue Mining has filled considerable gaps in these crucial documents used by companies and authorities.

PROJECT ECONOMICS AND MARKET OUTLOOK

Although reliable assessments are still lacking, Blue Mining research indicated high economic potential for both SMnN and SMS mining (Volkman and Osterholt, 2017). Nevertheless, the confidence of these estimations and key figures needs to be improved e.g. by testing the developed technologies and methodologies and tools, the release of the mining code and further exploration. At the present time, the processing & refining of SMnN and related thereto the annual metal output and costs underlie large uncertainty. Moreover, further research is required with respect to the recovery of trace metals such as rare earth elements (REE), which may become economically important to sustain the expansion of renewable energies and e-mobility on surface.

Forecasting future market development is very challenging and uncertain. This is particularly true when assessing markets for products that do not currently exist. In an attempt to overcome these challenges, the developed Blue Mining market analysis bases on a

broad and diverse fundament to derive an outlook into the deep-sea mining market. Assessments of mineral potential, mining, markets, jurisdiction, investments and competitors include inputs from experts and independent reports. Different views and expectations have led to a number of scenarios representing the possible future development of the deep-sea mining market. This is not only relevant to calculate the impact for European mineral supply but especially important to quantify the market size for European original equipment manufacturers (OEMs). It can be seen that European OEMs may play a significant role in this future mining market.

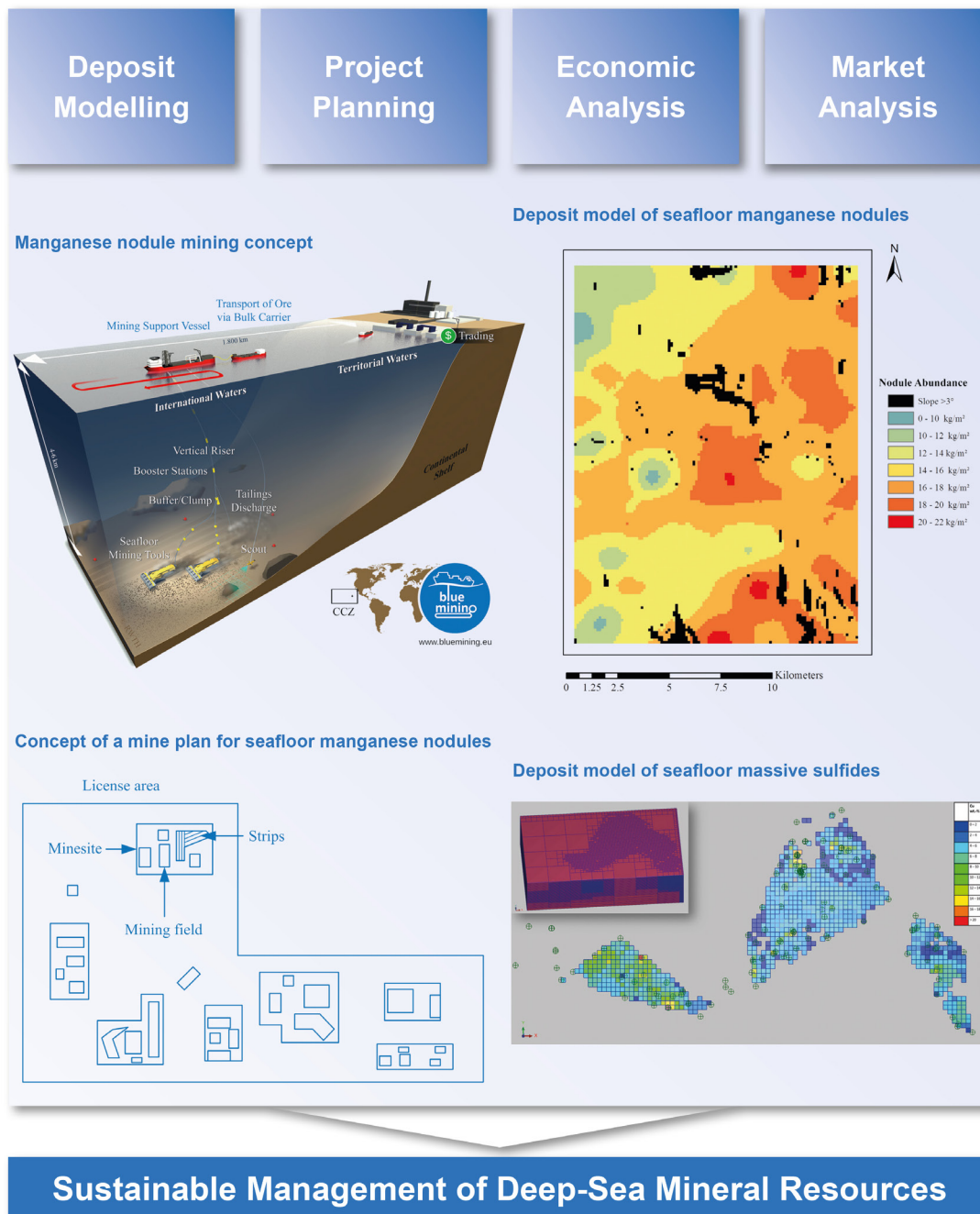


FIG. 7. GRAPHICAL REPRESENTATION OF THE ASSESSMENT OF DEEP SEA MINERAL RESOURCES.

FROM SEAFLOOR TO SEA SURFACE

“An important aspect of the appropriate perspective on technology development for deep sea mining, is raising awareness for resource security. The EU mainly relies on trade relations for access to resources. Since many resources are key for the EU to prosper, deep sea mining as a future alternative to current supplies emerges as a viable option.”

– Dr. Jort van Wijk, IHC MTI

THE CHALLENGE

To acquire the technical knowhow and develop advanced models, design methodologies and technologies (TRL6) for a clog-free reliable vertical transport system (VTS), transshipment technology for minerals hand-over up to sea state 6 and a concept design of a full scale deep sea mining operation up to 6,000 m water depth.

MAIN INNOVATIONS AND TARGETED KEY RESULTS

- Clog-free reliable vertical transport solution of sufficient technology readiness (TRL6) consisting of a configuration of riser pipes and underwater pumping technology that will allow up-scaling/ engineering towards a reliable vertical transport of slurries over a distance up to 6,000 m, with sufficient capacity/throughput
- Basic design of a vertical slurry transport system based on Airlift technology consisting of design parameters, implementation concepts, application ranges and its interfaces for deep water mining applications.
- Basic design of a vertical slurry transport system based on Centrifugal Pump technology consisting of design parameters, implementation concepts, application ranges and its interfaces for deep water mining applications.
- Advanced insight in the dynamics of offshore minerals extraction riser and transshipment systems
- Advanced insight in the upward and downward slurry transport dynamics
- Integrated system for deep sea mining by specifying the critical interfaces between the key functions.
- A validated computer code on riser dynamic behaviour, including fatigue phenomena, in deep water
- Knowledge regarding riser lining wear & tear and choice of suitable materials for 24-month life expectancy
- Knowledge regarding the dynamic aspects of offshore minerals ship to ship transfer from mining vessel to cargo vessel and the optimum mutual positioning of these vessels under varying environmental conditions to guarantee minerals transshipment up to sea state 6 (see Fig 1-1).

- Altogether this will provide the solid basis for making a concept design of a full scale deep sea mining installation at a depth up to 6,000 m, a capacity/throughput of between 300 – 500 tonnes ore per hour, includes the vertical transport system, the ship to ship transfer technology minerals and all critical interfaces with the other key systems, such as the excavation/extraction system, crawler/collector and its connection to the VTS, surface platform including the assembly/disassembly system, ore receiving and storage system, offshore processing plant, control systems, power supply and mechanical interfaces. Critical interfaces with operational aspects include: mining plan and procedures, production requirements, start-up and shut down procedures, operational procedures, emergency circumstances and a safe operational window up to sea state 6.

DEVELOPMENT OF BOOSTER STATION TECHNOLOGY AND THE DEEP SEA SPECIAL MOTOR

One of the key technologies in the VTS is the booster station. The centrifugal pump booster station concept as developed in Blue Mining consists of two centrifugal pumps and several valves, assembled in member-type frame.

Deep sea conditions pose special requirements on all components due to the extreme pressures at large water depths. Within Blue Mining a Deep Sea Special Motor has been developed and tested on laboratory scale and in the field. The motor is completely filled and cooled with sea water due to its open structure, thus it does not require any lubricants minimizing the environmental pressure of the motor.

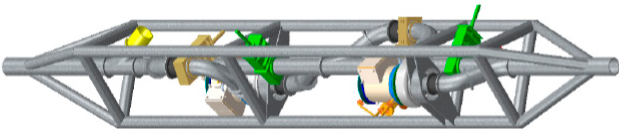


FIG. 8. MEMBER TYPE CONCEPT BOOSTER STATION FOR THE VTS, CONSISTING OF TWO CENTRIFUGAL DREDGE PUMPS AND SEVERAL VALVES.



RISER DYNAMICS

The vertical transport system will be subjected to a variety of external loads. In the aNySIM simulation package a wake-oscillator model is implemented with which time-domain simulations can be conducted for deep-sea mining riser systems. This model requires hydrodynamic coefficients as input, which can be determined with model tests or CFD calculations. In Blue Mining the booster station of Fig.8 has been tested in the MARIN test basin on a scale 1 to 6 in order to find the appropriate hydrodynamic coefficients.

VERTICAL HYDRAULIC TRANSPORT PROCESS

Deep knowledge of transport processes is a prerequisite for a clog free vertical transport system. Research efforts thus far have focused on computational modelling of the long distance vertical transport, backed by laboratory scale experiments of specific phenomena. After finishing the laboratory experiments there was a need to take a next step in the scale of experiments to increase confidence and understanding. Besides that, one of the unresolved issues at the start of Blue Mining was the occurrence of density waves, a topic that needed to be revisited.

Density waves are regions of increased material concentration that travel through the riser, comparable to sound being a pressure wave through air and comparable to traffic jams occurring in dense traffic when someone suddenly hits the brakes. These waves are a potential source of instability, i.e. they might diminish after creation or they could grow into massive plugs. An example is given below. These plugs could be a showstopper for the mining operation, so methods for prediction would be a valuable competence in flow assurance analysis.

The prediction of density waves however is not trivial. In Van Wijk et al. (2016) analytical methods for density wave prediction were explored. Although for the case of fluidization the method seemed promising, the application to actual transport conditions weren't conclusive.



FIG. 9. TESTING THE DEEP SEA SPECIAL MOTOR AT THE RDM ROTTERDAM TEST FACILITY (TOP LEFT) AND ON THE TAURUS (TOP RIGHT, BOTTOM LEFT) IN MANGERSFJORDEN. BOTTOM RIGHT THE UNDERWATER CAMERA VIEW ON THE MOTOR-PUMP COMBINATION.

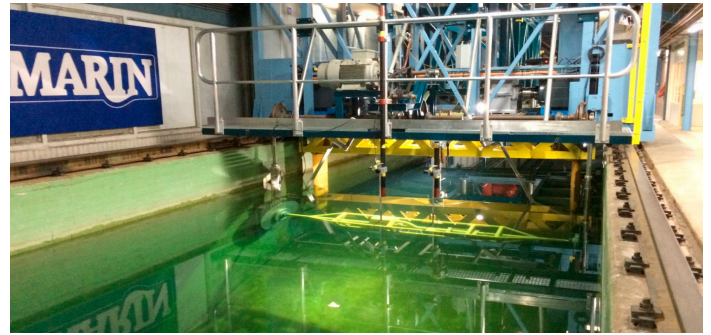
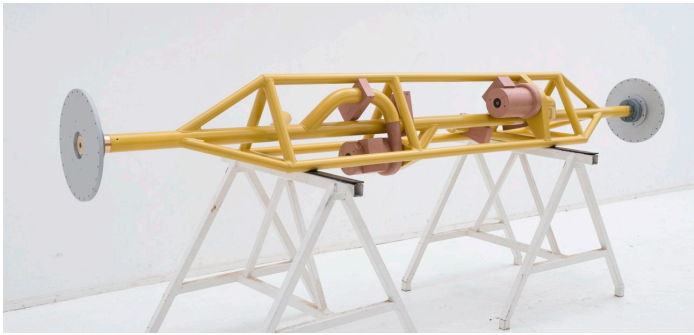


FIG. 10. SCALE 1:6 BOOSTER STATION TESTED IN THE MARIN BASIN TO FIND THE HYDRODYNAMIC COEFFICIENTS WHICH ARE NECESSARY FOR CFD MODELLING OF RISER DYNAMICS.

In order to get more clarity on these density waves, two directions were chosen in Blue Mining. The first direction aimed for numerical modelling of the phenomenon with CFD (a 2D Immersed Boundary Method), see Fig. 11. In 2017 this method proved successful in qualitatively mimicking the occurrence of density waves as shown below, making it a promising technique for actual prediction of waves during operational conditions.

The second direction was an investigation into vertical transport of sand, gravel and real (crushed and sized) manganese nodules in a 136 meter long riser in a mineshaft in Freiberg, Germany. This test setup (Fig. 12) is unique in its size: it is the largest vertical test section ever built in Europe dedicated to the vertical transport of solids. A team of IHC and TUBAF engineers and scientists investigated the validity of the models used in the transport simulations with a focus on the occurrence of density waves, the frictional losses in the vertical riser and control techniques for the pump system.

SHIP TO SHIP TRANSFER

Typically deep sea deposits are located at relatively long distances to shore. Due to this long distance deep sea mining Vessels will have to transfer the mined material to transport vessels at sea (on the actual mining location). This to maximize the amount of operational hours of the mining vessel and therewith optimize the overall economics of the deep sea mining operation.

The minerals from the mining vessel are transferred to the transport vessel via a floating hose. Dedicated computer codes were used to quantify the motions (displacement, velocity and acceleration) of the floating hose connections on the mining vessel and the transport vessel. From an Engineering point of view the calculated motions enable us to specify design requirements for the ship-to-ship transfer hose and its launch and recovery system. This to obtain the wanted offloading operability.

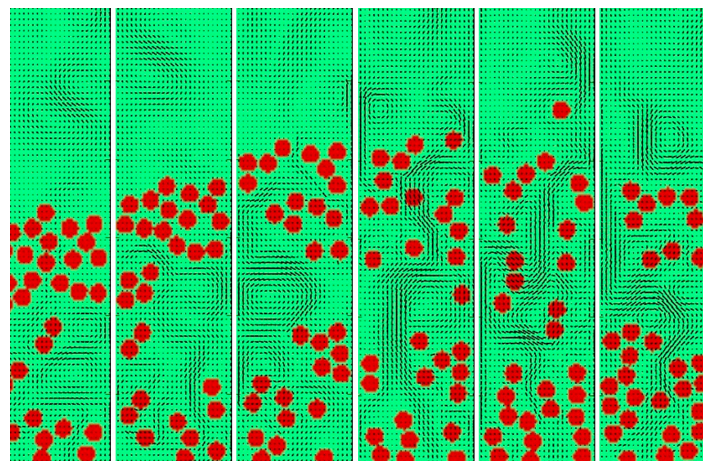
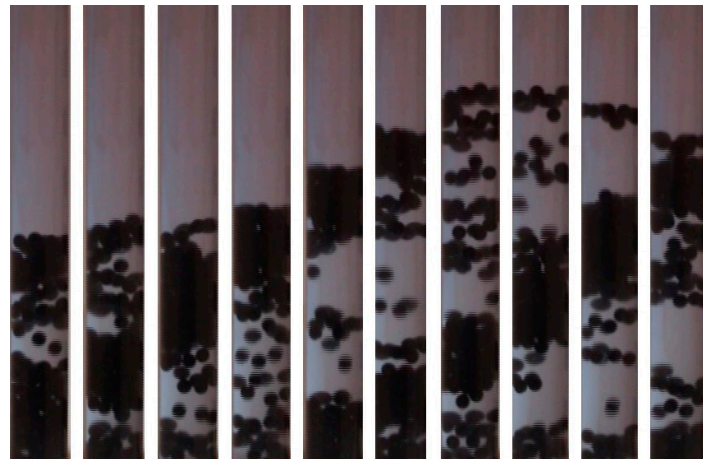


FIG. 11. EXPERIMENTS AND SIMULATION OF DENSITY WAVES OCCURRING DURING FLUIDIZATION OF RELATIVELY LARGE PARTICLES. DETAILED NUMERICAL SIMULATIONS COMBINED WITH LARGE SCALE TRANSPORT EXPERIMENTS.

Experience on offshore operations like the placing of windmills and pipe-laying has learned that there is a need for objective decision support tools. This to support the (subjective) operator regarding decisions to start, abort or complete operations as a function of the actual weather conditions and forecasts.

To minimize false decisions regarding the start or stop of ship-to-ship transfer operations the Blue Mining project developed a dedicated operator decision support tool.

Field tests in offshore wave conditions were performed to substantiate the Technology Readiness Level of a ship-to-ship transfer operation via a high capacity floating line. During the field tests state-of-the-art data acquisition technology was used to collect all parameters in one synchronized data set. Amongst others wind, wave and vessel motion data was collected for wave heights up to 4.5 m. The data set serves as basis for the validation of hydrodynamic computer codes.

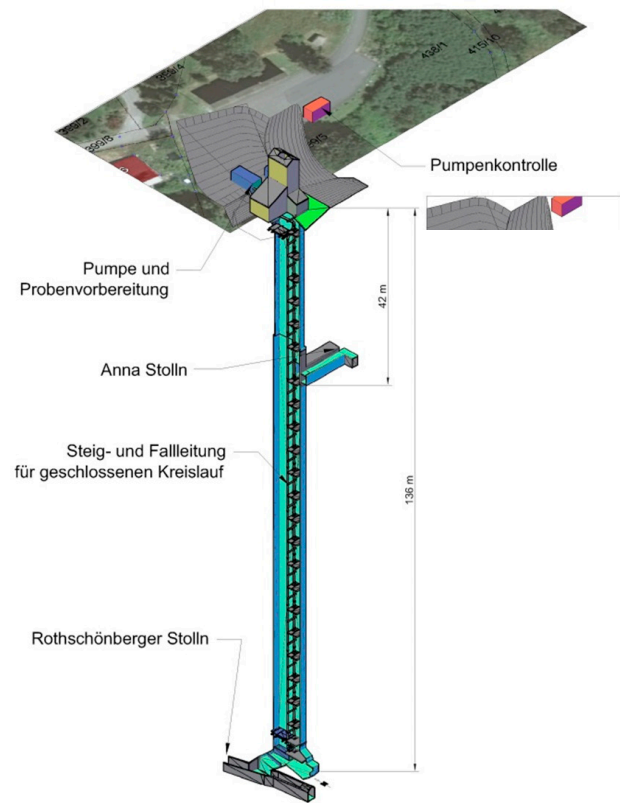


FIG. 12. THE VERTICAL TRANSPORT TESTS AS CONDUCTED IN HALSBRÜCKE, NEAR FREIBERG, GERMANY, ARE TRULY UNIQUE IN SIZE AND SCOPE. THE 136 M LONG TEST SECTION BELOW SURFACE LEVEL (TOP), SURFACE LEVEL SEDIMENTS PLANT AND PUMP STATION (MIDDLE) AND A LOOK DOWN THE MINESHAFT (BOTTOM).



FIG. 13. TANDEM OFFLOADING (TOP) REELED FLEXIBLE HOSE (TOP LEFT), FIELD TESTS (TOP RIGHT) AND A VIEW IN THE OPERATORS CONTROL ROOM (BOTTOM).

NEW OPPORTUNITIES WITH LASTING IMPACT

“Further issues, which urgently need to be discussed, concern the enforcement of the established regulations as well as the need for over-regional scientific studies in international cooperation to find solutions to minimize environmental, technical, and financial risks associated with individual steps along the DSM value chain”

– Dr. Christian Reichert, chairman of the International Seabed Authority’s Legal and Technical Commission

PUBLIC DISSEMINATION ACTIVITIES

Dissemination of research results covered the entire spectrum from detailed research articles in peer reviewed scientific journals and conferences, cross-consortium workshops, public events, general assemblies of the consortium to a museum exhibition. This resulted in not less than 115 individual activities. The consortium more specifically reached out to the wider public by the following activities:

Blue Mining – Final Workshop: Towards sustainable deep-sea mining

The workshop was held in Aachen, 10 October 2017 and the report is authored by Luise Heinrich (Jacobs University Bremen), Felix Lehnert (RWTH Aachen University) and Sven Petersen (Geomar) and was facilitated through Konsortium Deutsche Meeresforschung (KDM).

The complete report from the final workshop has been published and printed. The printed document are distributed towards the partners, stakeholders and authorities, like ISA, NGOs etc.

Museum Exhibition

The exhibition “Mar Mineral – Science and Riches on the Deep Seafloor” is open to the public since July 13th, 2017, in MUHNAC, in Lisbon, Portugal.

The main purpose of the Mar Mineral exhibition is improving Ocean literacy among the general public, providing science-based information in plain terms about/regarding seafloor resources, society needs and demands, technological developments and environmental preservation related to the possible near future beginning of seafloor mining.



FIG. 14. IMPRESSION OF THE MUSEUM EXHIBITION.

Public Event in UK during General Assembly meeting

On 4 July, the NOC hosted the EU Blue Mining group and key members of the group (the Principal Investigator and the Chief Engineer) have given two 25-minute presentations to the public in conjunction with their conference. This was an unique opportunity for the Marine Life Talk audience to quiz a panel of scientists and engineers about the subject.

Stakeholders from the direct surroundings of Freiberg, e.g. students, citizens, were fully engaged in the program and were very enthusiastic about the technology development and the broader scope of Blue Mining. The demonstration was received very well by the consortium and project partners as well. It triggered interesting technical discussions and it provided a platform to share intensify our network, enhancing collaboration.

Demonstration Days at Halsbrücke, Germany

The aim of the Demonstration Day was to inform the consortium and stakeholders on one of the larger (or even largest) experiments within the group and to engage the consortium in discussions on technology development. Invitations had also been given to representatives of local administrations.



FIG.15. CONSORTIUM PARTNERS, GOVERNMENT REPRESENTATIVES AND THE LOCAL COMMUNITY TOGETHER ON THE PUBLIC EVENT WITNESSING THE DEMONSTRATION OF THE VERTICAL TRANSPORT EXPERIMENTS IN HALSBRÜCKE, GERMANY.

SCIENTIFIC DISSEMINATION ACTIVITIES

Tables 1 and 2 present an overview of the publications that resulted from the Blue Mining research programme.

TABLE 1. PUBLISHED PEER REVIEWED SCIENTIFIC ARTICLES IN JOURNALS AND ON CONFERENCES.

Nº	Title	Author(s)	Title of the periodical or the series	Date of publication	Open access
1	Simulation and experimental proof of plug formation and riser blockage during vertical hydraulic transport	J.M. van Wijk , F. van Grunsven , A.M. Talmon , C. van Rhee	Ocean Engineering	01/06/2015	No
2	The influence of grain size on the performance of conductivity concentration meters	J.M. van Wijk , B.W.G. Blok	Flow Measurement and Instrumentation	01/10/2015	No
3	Design and internal flow simulation of a vertical hydraulic transport system for mining manganese nodules	J.M. van Wijk and P.M. Smit	17th International Conference Transport & Sedimentation of Solid Particles, September 22 to 25, 2015, Delft, The Netherlands	22/09/2015	No
4	Stability of vertical hydraulic transport processes for deep ocean mining: An experimental study	J.M. van Wijk , A.M. Talmon , C. van Rhee	Ocean Engineering	01/10/2016	No
5	Production key figures for planning the mining of manganese nodules	Sebastian Ernst Volkmann , Felix Lehnen	Marine Georesources and Geotechnology	21/04/2017	Yes
6	On electric fields produced by inductive sources on the seafloor	Roxana Safipour , Sebastian Hölz , Marion Jegen , Andrei Swidinsky	Geophysics	01/11/2017	
7	A self-potential investigation of submarine massive sulfides: Palinuro Seamount, Tyrrhenian Sea	Roxana Safipour , Sebastian Hölz , Jesse Halbach , Marion Jegen , Sven Petersen , Andrei Swidinsky	Geophysics	01/11/2017	No
7	A comprehensive approach for a techno-economic assessment of nodule mining in the deep-sea.	Sebastian Ernst Volkmann, Thomas Kuhn, Felix Lehnen	Mineral Economics	21/02/2018	Yes
8	Scientific rationale and international obligations for protection of active hydrothermal vent ecosystems from deep-sea mining	Van Dover, C., ..., Petersen, S. et al.,	Marine Policy	2018	No

TABLE 2. OVERVIEW OF SUBMITTED AND ACCEPTED, BUT NOT YET PUBLISHED SCIENTIFIC JOURNAL AND CONFERENCE ARTICLES.

Nº	Title	Author(s)	Title of the periodical or the series	Date of publication	Status
9	Controls on the seafloor exposure of detachment fault surfaces	Olive, J.-A., ..., Petersen, S., et al.,	Geology	2018	Submitted
10	Underwater hyperspectral imaging using a stationary platform in the Trans-Atlantic Geotraverse Hydrothermal Field.	Dumke, ..., Murton, B., et al.,	IEEE Transactions on Geoscience and Remote Sensing	2018	Submitted
11	Morphology of corrugations on oceanic detachment faults and their tectonic implications.	Parnell-Turner, R., ..., Petersen, S., et al.	Earth and Planetary Science Letters	2018	Submitted
12	Durchführung von Strömungsversuchen zur Untersuchung von auftretenden Effekten bei der vertikalen Förderung von Feststoff-Wasser- Gemischen in einem Großversuchsstand über 136 m Höhe im Rahmen des europäischen Forschungsprojektes „Blue Mining“	T. Mueller, H. Mischo, J.M. van Wijk	Kolloquium “Foerdertechnik Im Bergbau”, University of Clausthal	2018	Submitted
13	Planning and construction of a large scale test facility for flow analysis of vertical transport of water and coarse material as part of the European research project “Blue Mining”	T. Mueller, H. Mischo, J.M. van Wijk	2018 SME Annual Conference, Minneapolis, USA	2018	Submitted
14	AUV-based exploration for inactive seafloor massive sulphides	Petersen, S., et al.,	Tbc	2018	In preparation
15	Geological control of hydrothermal systems on slow-spreading ridges – a GIS - based approach to define exploration criteria	Graber, S., et al.,	Tbc	2018	In preparation

TABLE 2 – CONTINUED. OVERVIEW OF SUBMITTED AND ACCEPTED, BUT NOT YET PUBLISHED SCIENTIFIC JOURNAL AND CONFERENCE ARTICLES.

Nº	Title	Author(s)	Title of the periodical or the series	Date of publication	Status
16	Magnetic, acoustic and seismic data unveil the TAG Segment tectonic evolution (26°N)	Szitkar, F., Petersen, S.,	Tbc	2018	In preparation
17	Offshore and onshore XRD studies of TAG sediments (MAR at 26°N, 44°W) applied to seafloor mineral exploration.	Milinovic, J., Barriga, F.J.A.S., Martins, S. et al.,	Tbc	2018	In preparation
18	Extinct massive sulphides exploration with towed controlled-source electromagnetic surveying at the TAG hydrothermal field.	Gehrmann, R., et al.,	Tbc	2018	In preparation
19	Geochemistry of the deep sea distal metalliferous sediments of the TAG area	Martins, S., et al.,	Tbc	2018	In preparation
20	TAG deep-sea sediment colour spectroscopy data: proxies for sediment mineral composition and sedimentary environments identification	Martins, S., et al.,	Tbc	2018	In preparation

EXPLOITATION OF RESULTS

The knowledge developed within this project is built further upon by the individual partners, but we are reaching out to a wider scientific audience since all scientific results from Blue Mining are directly feeding the science and engineering communities worldwide, showcasing Europe's efforts in this field and setting new standards.

The most tangible result in the exploitation is the Blue Mining consortium having paved the way for further development of deep sea mining technology, thus taking the step from knowledge development to technology development. A subgroup of the consortium takes part in the EU H2020 research programme Blue Nodules, which aims at further developing of subsea harvesting technology for polymetallic nodule mining up to the level of prototype testing. Their website can be found at www.blue-nodules.eu.

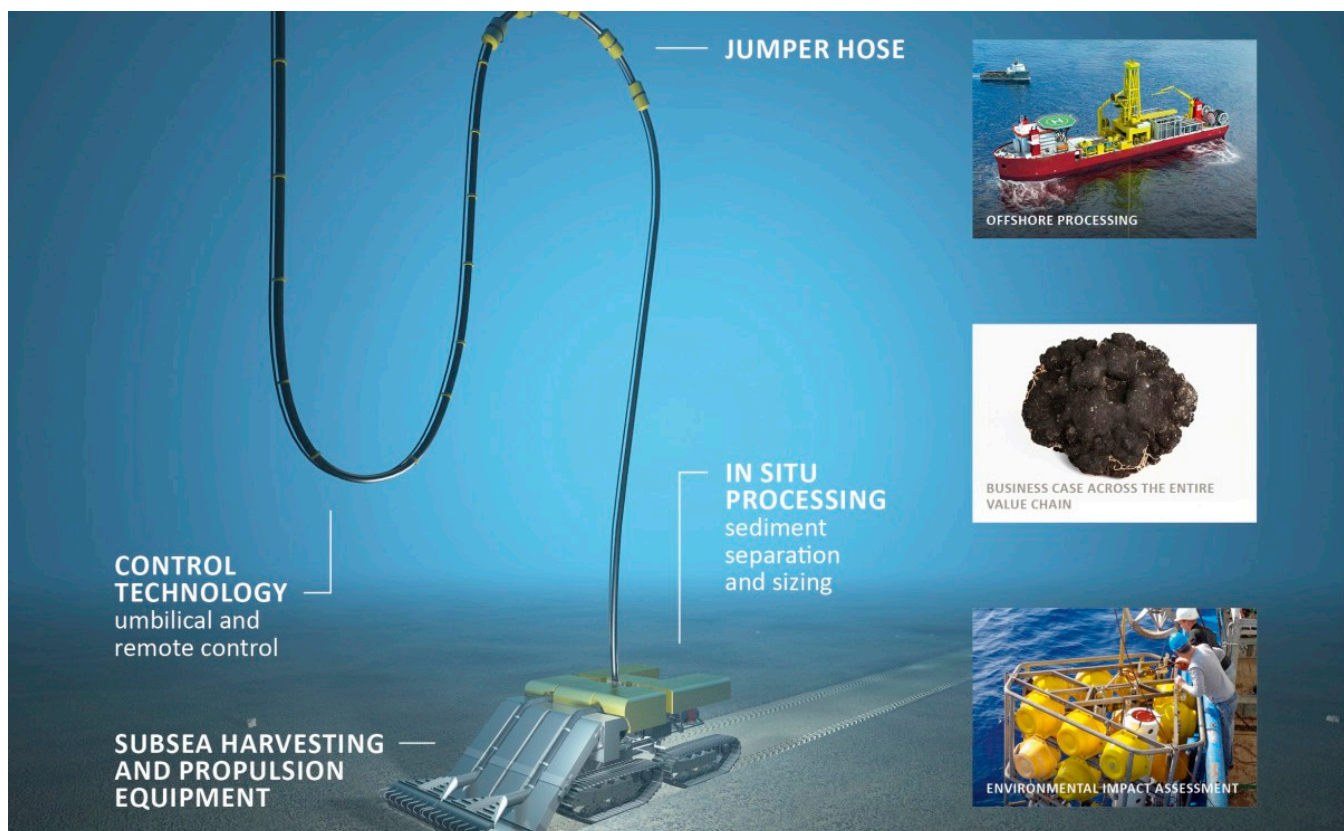


FIG. 16. SCOPE OF BLUE NODULES, THE EU H2020 PROJECT THAT IS A FOLLOW-UP OF BLUE MINING AIMING AT TECHNOLOGY DEVELOPMENT FOR SUBSEA HARVESTING OF RESOURCES. A SUBGROUP OF THE BLUE MINING CONSORTIUM HAS JOINED BLUE NODULES AS WELL. SOURCE: WWW.BLUE-NODULES.EU.

TOWARDS RESPONSIBLE EXPLORATION AND EXPLOITATION OF DEEP SEA RESOURCES

After nearly four years of intense interdisciplinary cooperation, the project ended in January 2018 and representatives of the participating organizations as well as external governmental and non-governmental organizations and stakeholders from industry and academia met in Aachen, Germany, on October 10th, 2017, to present and discuss the accomplishments as well as a potential continuation of the project.

Fig. 17 shows an ocean of opportunities, literally, and in this context the workshop participants took part in a survey aimed at collecting opinions on different questions regarding the drivers and timeline of the DSM process, the DSM value chain, and DSM legislation. How to approach the deep seas?

We used the EduVote system, an interactive system to use the brainpower of all people attending the final workshop in answering questions relating to the approach of the deep sea. The main questions and results are discussed next.

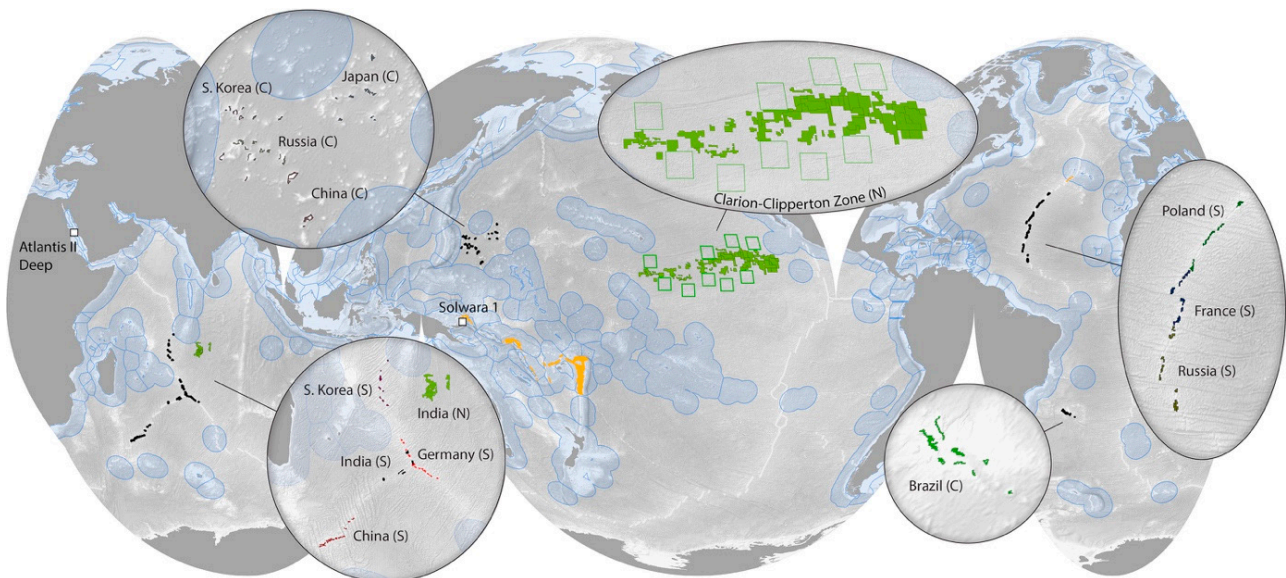


FIG. 17. AN OCEAN OF OPPORTUNITIES. LOCATIONS OF GLOBAL EXPLORATION LICENSES FOR MANGANESE NODULES (N), CO-RICH FERROMANGANESE CRUSTS (C) AND SEAFLOOR MASSIVE SULPHIDES (S FOR LICENSES WITHIN "THE AREA", ORANGE FOR LICENSES WITHIN EEZS). THE LOCATIONS OF THE ONLY TWO DEEP-SEA MINING LICENSES (ATLANTIS-II-DEEP IN THE RED SEA AND SOLWARA1 IN PAPUA NEW GUINEA) ARE INDICATED BY THE WHITE SQUARES. THE LOCATION OF THE "AREAS OF PARTICULAR ENVIRONMENTAL INTEREST" (SIZE OF 400KM BY 400KM EACH) IN THE CCZ IS PROVIDED AS RECTANGLES WITH A GREEN OUTLINE. MODIFIED FROM PETERSEN ET AL., 2016.

The majority of the survey participants believe that DSM will primarily contribute to securing the metal supply of the European Union and in general. Furthermore, decreasing the dependence on exporting countries outside the EU, as well as the contribution to research and technology markets were considered important. However, some participants indicated that they believe DSM to only play a minor role in the European economy. One participant elaborated that in his or her opinion, DSM will start once commodity prices rise, which will, however, lead to an oversupply of metals on the market.



A large share of survey participants mentioned that monitoring is crucial and that monitoring should be conducted by, for example, independent inspectors, audited observers or ISA-controlled institutions. The second most common recommendation was to establish an inspectorate, for example in form of a 'water-police' or similar executive organ, such as a mining department in an existing agency. Other participants suggested the use of best practices already applied in the oil and gas industry. Many participants agreed that rules need to be enforced through a strict penalty system.



A large number of the participants answered that the additional income should be invested in Research & Development for DSM. Other participants recommended to utilize the funds to support developing countries. Furthermore, environmental studies and the repair of damages caused by mining should be financed. One participant also suggested to establish an annual prize for sustainable technology, which would act as an incentive to contractors to ensure the application of best practices and sustainability measures.

The most common answer to this question was to reduce the sediment plume during mining. Furthermore, the reduction of the environmental footprint is an important aspect of sustainable mining. Some participants answered that the environment should not be harmed at any cost.

The survey participants provided very diverse answers to this question. The most common suggestion was to assign protected areas, followed by the reduction of the sediment plume during mining and to collect sufficient environmental baseline information prior to mining. Furthermore, monitoring mining activities and associated environmental impacts was suggested as well as to study possible remediation measures.

The majority of survey participants indicated the processing of SMnN to be the most significant challenge. They further believe the improvement of the reliability of machines on the seafloor and the construction of an effective vertical transport system to be challenging. Furthermore, the reduction of the plume, the exploration of the mining sites and environmental friendly mining were mentioned.



Following the survey results, the consortium sees a role for deep sea mining in securing the supply of critical raw materials to the EU industries. It is important to have legislation keeping pace with project and technology development, which should be monitored and controlled by an independent body. Future technology development should pro-actively include mitigation measures for environmental pressures of the technology in all design stages. The main concern is plume formation during harvesting.

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THE FINAL BLUE MINING GENERAL ASSEMBLY IN LISBON, PORTUGAL, IN JANUARY 2018.



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PUBLIC REPORT
BLUE
MINING

