China Council for International Cooperation on Environment and Development (CCICED)

Special Policy Study on

Global Ocean Governance and Ecological Civilization

CCICED Task Force Report

Mineral Resources Extraction

CCICED 2020 Annual General Meeting

Month and day, 2020 (Depends)

Task Force Members

Co-chairs of SPS:

SU, Jilan	Second Institute of Oceanography, MNR, China
WINTHER, Jan-Gunnar	Norwegian Polar Institute, Norway

Co-chairs of TT #6:*

LI, Jiabiao	Second Institute of Oceanography, MNR, China
MYHRVOLD, Arne	Equinor ASA, Norway

Task Force Members:*

WU, Nengyou	Qingdao Institute of Marine Geology, CGS, China
GROGAN, Renee	Gro Sustainability Pty Ltd, Australia
LILY, Hannah	The Pew Charitable Trusts, Seabed Mining Project, London
QIAN, Peiyuan	The Hong Kong University of Science and Technology, China

Research Support Team:

ZHUO, Xiaojun	Changsha Research Institute of Mining and Metallurgy Co., Ltd, CMC, China
HAN, Xiqiu	Second Institute of Oceanography, MNR, China
ZHANG, Dan	China Institute for Marine Affairs, MNR, China
LI, Xiaohu	Second Institute of Oceanography, MNR, China
HU, Gaowei	Qingdao Institute of Marine Geology, CGS, China
YANG, Xiaocheng	Second Institute of Oceanography, MNR, China

Coordinators:

NJÅSTAD, Birgit	Norwegian Polar Institute, Norway
LIU, Hui	Yellow Sea Fisheries Research Institute, Chinese Academy of Fishery Sciences, China
XU, Xuewei	Second Institute of Oceanography, MNR, China

** Co-Chairs and Task Force members serve in their personal capacities.*

CONTENTS

Coral gargen on Daimao seamount,
the South China Sea (2018)

EXECUTIVE SUMMARY

The report discusses the economic, technical and environmental challenges of seabed mineral exploration and exploitation as well as exploration and exploitation for gas hydrates. It covers current technical approaches, practical experience and environmental policies, reviewing and analyzing the processes of potential development of these resources. Mitigating measures and recommendations are suggested. The aspects discussed include technology needs for resource exploration and exploitation, suggestions for sound environmental management, and linkages with the United Nations (UN) Sustainable Development Goals (SDGs). The report provides a set of recommendations to facilitate the development of seabed mineral resources and gas hydrates in an environmentally sustainable way.

Deep Sea Mining (DSM)

China has a major stake in the sustainable use of the oceans. The huge reserves of mineral resources found on the deep seabed may be of great significance to China's economic development as well as to the strategic reserve of mineral resources.

Seabed mineral deposits are categorised into four resource types:

- Polymetallic Sulphides (PMS), which are associated with hydrothermal vents, and which host minerals including copper, gold, silver and zinc.
- Polymetallic Nodules (PMN), that sit freely on sediment on the ocean floor at great depths in the ocean's abyssal plains, and which host minerals including manganese, cobalt, nickel and rare earth elements.
- Cobalt-rich Ferromanganese Crusts (CRC), which are associated with thin ridges of crusts usually found on seamounts or mid-ocean ridges, and which host minerals including cobalt, iron, manganese, nickel and rare earth elements.
- Rare Earth Elements (REE), which may be found in deep-sea sediment muds, but are also present in the resource types above.

To date, 30 deep-sea mineral exploration contracts have been issued by the International Seabed Authority (ISA) for resources beyond national jurisdiction, including 7 for PMS, 18 for PMN and 5 for CRC, covering a total area of approx. 1.397 million km^2. Chinese State-sponsored companies hold 5 of these contracts (PMS, PMN and CRC): the most out of any of 168 member States of the ISA.

Seabed mining will require cutting (PMS, CRC), collecting (PMN) or dredging (REE muds) technology, and a rise-and-lift and return water system. Engineers are currently working to develop such machines, which need to be capable of enduring harsh operating conditions at high depths and high pressures. It is likely that for all forms of seafloor mining, the entire mining system will be portable and can be moved from mine site to mine site.

Natural Gas Hydrates (NGH)

Gas hydrates are widely distributed in most of the world's marine deep-water areas (~99%) and permafrost sedimentary environments (~1%). The amount of gas stored in the world's hydrate accumulations is significant but estimates are highly uncertain.

In gas hydrates deposits the methane is trapped as a solid form and cannot flow freely in the geological formation. Methane recovery from gas hydrates has not yet entered commercial scale, but some field production tests have been carried out, both on- and offshore. Although significant progresses have been made so far for understanding the occurrence, distribution and characteristics of gas hydrate, longer duration production tests under a wider range of reservoir conditions are required in order to fully assess the resource potential of NGH.

There are a significant number of technological challenges related to both exploration and exploitation of NGH resources which are currently not solved. In addition to the general need to understand the ecosystem in the area, NGH exploitation also comes with strong environmental risks such as increased risk of seabed landslides and huge amounts of methane released into the water column and atmosphere.

Environmental Management and Environmental Challenges

Ocean health is vital to the wellbeing of humanity. Ocean health is currently under threat and it is imperative that a future exploitation of deep sea minerals and NGH can be carried out without causing significant environmental harm. States are required by international law to manage the environmental impacts of any seabed mineral activities. International rules, standards and guidelines for seabed mining are currently under negotiation at the international level (at the ISA). Sound environmental management in DSM will involve the use of numerous tools that are already in use in other industries, including impact assessment, ecosystem-based management, adaptive management, risk assessment and management, and continuous improvement.

There is however a challenge that deep-sea environments in general are little-explored and poorly understood. To mitigate that risk, the ISA is also focussing efforts to produce ‘Regional Environmental Management Plans’ (‘REMP’s) for the geographic regions in which there is exploration interest. The purpose of REMPs is to take an integrated ocean management approach to ensuring the effective protection of the marine environment in the context of the unique values of each region, and taking into account cumulative impacts and competing ocean stressors.

For a specific project, the relevant ecosystems will need to be assessed and understood as part of the exploration phase for each potential mineral resource, and a plan for exploitation of the resource needs to include adequate mitigating actions and measures to avoid significant environmental harm.

Governance – Status and Challenges

The ISA is the autonomous intergovernmental body which was established by the United Nations Convention on the Law of the Sea (UNCLOS) to manage the mineral resources of the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction ('Area') on behalf of mankind as a whole.[1] The ISA also has the responsibility to protect the marine environment, and to protect human life.[2] Exploration or exploitation of seabed minerals in the Area can only be carried out:

- under a Plan of Work, agreed by way of a contract, with the ISA,
- by States or State-sponsored entities, and
- in compliance with rules set by the ISA.

The ISA has in place Regulations on prospecting and exploration. Nowadays, the activities in the Area are facing a crucial juncture of transition from exploration to exploitation, and draft Exploitation Regulations (and subsidiary instruments called 'Standards and Guidelines') are being developed.

The Law of the People's Republic of China on Exploration for and Exploitation of Resources in the Deep Seabed Area (a national Deep Seabed Area Law) was adopted on 26 February 2016 and entered into force on 1 May 2016. This is the first Chinese law specifically regulating relevant activities conducted in the Area by citizens, legal persons or any other organizations of China. Environmental Protection principles and measures are well covered in the Deep Seabed Area Law, and stringent rules, standards and effective measures regarding the protection of environment are reflected and adopted. Since the Deep Seabed Area Law is general in nature and lacks provision on regulating activities of exploitation, relevant implementation regulations should be developed in the future (which complement the ISA's regulations on exploitation), in order to establish fully China's domestic legal systems with respect to the Area.

[1] UNCLOS, art. 137(2), and Section 1, paragraph 1 of the Annex to the 1994 Agreement provides that the Authority is the organization through which States Parties to the Convention shall organize and control activities in the Area, particularly with a view to administering the resources of the Area.
[2] UNCLOS, art. 145, art. 146 and annex 3, art. 17 para. 2 (f).

Recommendations

1. Improvement of environmental management system

Engage with development of environmental rules: China should actively engage with ISA regarding development of Regulations, Standards and Guidelines, specifically towards environmental baseline, EIA, and EMMP development.

Further improve national legislation: China may review and update the Deep Seabed Area Law in order to comply with the new requirement of the exploitation regulatory framework developed by the ISA within the context of the domestic legal system, to deal more specifically with future exploitation activities, including financial terms, inspection and management, and indemnities to ensure the State is properly protected. Based on the assessment China may seek to develop additional regulations to supplement the ISA requirements, drawing on the concepts of sound environmental management.

2. Filling gaps in environmental understanding and technology

Strengthen scientific understanding and develop key technologies: China should aim to improve the understanding of, and better assess both the risks and opportunities associated with DSM as well as exploitation of NGH. This includes (but is not limited to) (1) strengthening environmental data collection in important marine areas to improve the understanding of deep-sea ecosystems; (2) developing environmentally critical technologies concerning environmental monitoring, EIA, safe operations and environmental restoration; (3) actively promoting the development of environmentally friendly solutions to key technical problems for exploration, exploitation and transportation of deep-sea mineral resources and natural gas hydrates.

Improve the understanding for NGH: China should aim to improve the understanding of, and better assess both the risks and opportunities associated with NGH exploitation.

3. Expanding value chain and promoting circular economy

Expand value chain: China should seek opportunities for Chinese industry to engage at all levels of the DSM value chain, including research, exploration, exploitation, equipment manufacturing, technology design and mineral processing.

Promote circular economy: China's DSM policies should proactively support the intentions described in SDG #12, where the ambition of creating a circular economy is embedded in the design from the beginning of the design and concept phase and that "all" collected materials are fully utilized while waste streams are minimised. In addition, should NGH exploitation be deemed environmentally and economically feasible, China should promote the development of carbon capture and storage to accompany the development of hydrate extraction technologies that enable NGH to become a "bridge fuel" towards a low carbon future.

4. Creation of cooperative and transparent mechanisms and platforms

Enhance data sharing: Seabed mineral contractors should be encouraged to share widely through globally and publicly accessible databases all environmental data acquired through DSM research programmes. China should play a leading role in establishing good practice for quality control, data sharing and transparency.

Conduct cooperation: China should strengthen international cooperation, especially bilateral and multilateral cooperation and exchanges, including jointly contributing to the development of cooperation mechanisms and platforms, jointly building open markets, and jointly promoting marine technology exchanges.

5. Enhancement of leadership towards the ISA and active support of the UN SDGs

Support the UN SDGs: China should actively relate to the UN SDGs when further maturing the business case for DSM, such as contribution towards # 14 - life below water and #5 - gender equality in education and training for DSM professionals within geology, engineering and environmental technology.

Enhance of leadership: China should continue to initiatives to strengthen ISA as a regulator, and actively engage with ISA, such as to take opportunities for convening group discussions as well as take active leadership both within thematic groups and in its geographic group (Asia-Pacific); to show the leadership around a good model for State sponsorship, to establish a network for consultations and informing of its national positions on DSM.

Support REMP process: China should support a standardised, transparent and consultative REMP process at the ISA. This should include the establishment of a network of biologically representative, fully protected no-mining zones

Conclusion

Global ocean health is under threat from pollution, waste, climate change, loss of biodiversity and an over exploitation of its natural resources. To be able to harvest even more from the ocean in the future we need to take better care of it than we currently do.

The nascent DSM sector has reached a crucial juncture of transition from exploration to exploitation, and the regulatory framework is still not complete. Establishing such a new industry will require a joint effort and a collaborative "partnership for the SDG goals" to succeed in establishing a sustainable industry, and also to achieve the principles laid out in UNCLOS, which include the designation of the seabed minerals of the Area as 'the common heritage of mankind'[3], and the objective that any economic benefits from mining in the Area should be shared equitably.[4]

There are still many significant knowledge gaps related to the ecosystems that might be affected from deep-sea minerals exploitation, as well as the technology that could be used in mining operations. Between operators and interested parties, there should be focus on collaboration to carry out studies to reduce the environmental risk as well as sharing of data and experience to ensure the industry is reflective of best environmental practice and continuous improvement.

[3] UNCLOS, art. 136; 1994 Agreement, Preamble, para. 2.
[4] UNCLOS, art. 140.

1 INTRODUCTION

The Special Policy Study on Global Ocean Governance and Ecological Civilization (Ocean Governance SPS) is a task of China Council for International Cooperation on Environment and Development (CCICED). It focuses on the study of core issues related to comprehensive ocean governance from perspectives of marine ecological civilization and marine ecosystem protection. Task Team #6 of Seabed Resources Extraction, belonging to the Ocean Governance SPS, focuses on the study of marine ecosystem protection and marine ecological governance during the processes of seabed mining.

The Task Team #6 Report addresses the economic, technical and environmental challenges of seabed mineral exploration and exploitation, introduces the current technical approaches, practical experience and environmental policies, and reviews and analyzes the processes of development. In terms of the Chinese government's development of seabed mineral resouces, the report examines challenges presented, puts forward some countermeasures and recommendations, including: future technology fields of resource exploration and exploitation, solutions of environmental issues during seabed mining activities, priorities in technology development and engineering, and involvement of China in the development and management of international seabed resources. The report also discusses the linkages with the United Nations (UN) Sustainable Development Goals (SDGs) and the importance of ocean health. Recommendations include elements that will promote cooperation among governments, social organizations, Non-Government Organisations (NGOs) and private sectors, and provide a basis for the future sustainable development of deep-sea mineral resources.

An unnamed sulfide structure at Longqi vent field on the SWIR (2015)

2 DEEP SEA MINING (DSM)

2.1 Introduction

China has a major stake in the sustainable use of the oceans. First, the huge reserves of seabed mineral resources are of great significance to China's economic development as well as the strategic reserve of mineral resources. China has put the “opening up more space for the blue economy” into the outline of the 13^{rd} Five-Year Plan for the National Social and Economic Development Plan and invested heavily in the development of marine infrastructure and technology. China carried out a successful gas hydrate production test in the South China Sea. China has currently exploration contracts for five mining areas in the Area Beyond National Jurisdiction (ABNJ), and is a country with all types of resource and the largest size of mining areas in the world.

To date, 30 deep-sea mineral exploration contracts have been issued by the International Seabed Authroity (ISA) for resources beyond national jurisdiction, including 7 for polymetallic sulphides (PMS), 18 for polymetallic nodules (PMN) and 5 for cobalt-rich ferromanganese crusts (CRC), with a total area of about 1.397 million km^2.

2.2 Seafloor Resource Types

2.2.1 Polymetallic Sulphide (PMS)

PMS deposits are predominantly found on mid-ocean ridges, and also occur along volcanic arcs and at backarc spreading centers. PMS are usually rich in metallic elements such as iron (Fe), copper (Cu), zinc (Zn), gold (Au) and silver (Ag), and can be accumulated in large deposits of several million tonnes in certain geological environments. The global PMS resource is estimated to contain approx. 600 million tonnes of ore.

PMS deposits are associated with hydrothermal vents on the seafloor, and sites are usually described as either ‘active’ (venting), or ‘inactive’ / ‘extinct’ (not venting) (**Figure 2-1**). Active sulphide deposits usually consist of a ‘black smoker’ chimney complex on top of a sulphide mound (ISA, 2002). It has been widely established that circulating seawater is the principal carrier of metals and sulphur which are leached out of the zone below the seafloor. Precipitation of sulphides at and beneath the seafloor takes place in response to mixing of the high temperature (up to 400°C) metal-rich hydrothermal seawater fluid with ambient seawater (ISA, 2002).

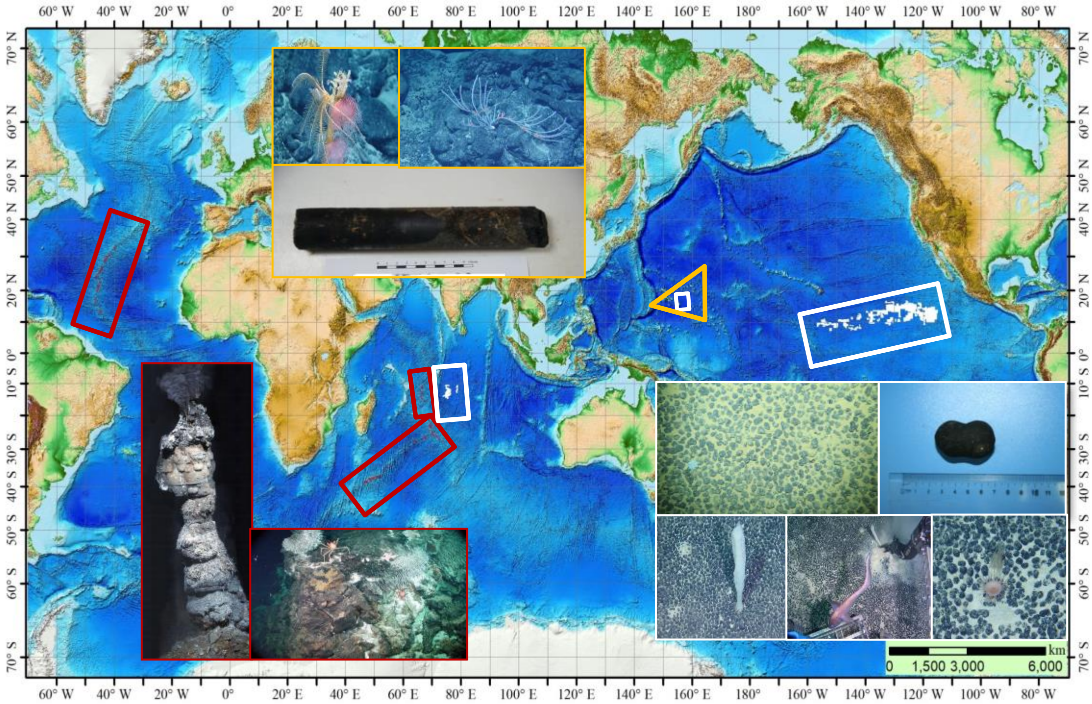


Figure 2-1 Distribution map and photos of PMS (red box), CRC (brown box) and PMN (white box) as well as megafauna. The photos from the Chinese surveys.

It is estimated that PMS deposits discovered to date range in resource size up to approx. 5 million tonnes, and often carry high concentrations of copper, zinc, and lead in addition to gold and silver. PMS deposits are typically extremely small in geographic size (usually less than 10 hectares), compared to both analogous terrestrial deposits, and deposits of other seafloor mineral types. Due to the high concentration of base and precious metals, seafloor PMS deposits have attracted the interest of the international mining industry.

2.2.2 Cobalt-Rich Ferromanganese Crust (CRC)

CRC, so named due to their major constituents of iron (Fe) and manganese (Mn) form on seamounts, ridges and plateaus in areas where prevailing currents prevent the deposition of unconsolidated sediments. In addition to the major constituents above, crusts can also contain numerous other minor and trace elements including cobalt, nickel, copper and rare earth elements (REE) (Zhang, 2014). The crusts form over millions of years as minerals precipitate from seawater to form crusts on rocky surfaces, ranging in thickness from less than 1mm to approximately 260 mm (SPC, 2013a). The crusts form in a range of water depths from less than 400 m to in excess of 5,000 m. The manganese, cobalt and nickel decrease in concentration with increasing water depths, while, iron, copper and REE increase in content with increasing water depth. Since the former have a higher metal market potential than the latter, the shallow-water deposits are likely to present the most economically viable deposits for extraction (Sharma, 2017).

Little is known about the abundance of CRC in most areas of the global ocean. The thickest crusts with the highest concentrations of cobalt have been found on outer-rim terraces and on broad saddles on the summits of seamounts (Hein, 2004; SPC, 2013a).

China has been active in exploration for CRC through the China Ocean Mineral Resources Association (COMRA) which holds an ISA exploration contract in the northwestern Pacific (expiring in 2029). In addition to China, also Japan, Russia, Brazil, and South Korea have exploration contracts for CRC deposits.

Research and development on the technology of mining crusts is in its infancy. Detailed maps of crust deposits and a better understanding of small-scale seamount topography will be required to design the most appropriate mining strategies. Once a promising area is located, detailed studies are required to determine the grade, thickness, and areal extent of the prospective ore deposit (Hein, 2004).

2.2.3 Polymetallic Nodule (PMN)

The presence of PMN, commonly referred to as manganese nodules, on the abyssal plains has been known for more than a century, first discovered by the HMS Challenger expedition 150 years ago. The nodules, often potato-sized rocky lumps that sit freely on the sea-floor and form over millions of years. PMN are made up of iron and manganese hydroxides, and contain a variety of other metals of commercial interest, particularly in relation to the transition to carbon-free energy production (such as copper, cobalt, molybdenum and lithium) (SPC, 2013b) and possibly some rare earth elements (Spickerman, 2012).

The greatest known concentrations of PMNs occur in the CCZ, where nodule densities have been observed between 15-75 kg/m^2 (SPC, 2013b). Nodule fields (with lower abundance) also occur in the Peru Basin, the Penrhyn Basin near the Cook Islands, and at abyssal depths of both the Indian and Atlantic oceans. Currently there are eighteen ISA contracts for exploration for PMN. China holds two of these exploration contracts in the CCZ, via COMRA and China MinMetals, as well as one contract awarded last year in the North Western Pacific through Beijing Pioneer Hi-tech Development Corporation, giving China the largest holding of nodule exploration tenements of any State.

2.2.4 Rare Earth Elements (REE)

In recent years, strategic and emerging industries such as electric vehicles and data-chips have grown. This has increased international market demand for metal such as cobalt, lithium, manganese, and rare earths. It is estimated that the total deep-sea REE reserves in the Pacific Ocean may exceed 80 billion tonnes, and while this has not been quantified, it is generally accepted that REE resources on the ocean floor exceed those hosted in terrestrial deposits.

2.3 Environmental Challenges

2.3.1 Challenges Applicable to All Resource Types

The deep sea and the seafloor have so far been subject to limited biological investigation. Sampling of biology, chemistry and oceanographic data as part of exploration programmes for DSM as well as preparations for DSM operations will increase our common understanding of the ocean ecosystems.

The most significant environmental impact associated with seabed mining will be the mortality of benthic fauna, and the removal of benthic habitat, throughout the mining area (Figure 2-2). This represents a challenge for several reasons, including:

- Little is known about the life cycles, population connectivity, and abundance of deep sea benthic fauna. With such a paucity of knowledge, it is extremely difficult to determine the impact that a localised loss of diversity, abundance and habitat may have on the function of deep sea ecosystems and the survival and recolonization of species;
- It is understood that some deep sea fauna (such as sponges and corals) are extremely slow growing and live for hundreds, if not thousands of years. In addition, the habitat upon which many species rely (such as the crust surface associated with CRC, and the nodules associated with PMN) is formed over a geological time scale, and as such the recovery if this habitat is not likely to occur within human time scales.
- The potential impact of DSM activities on ecosystem services (such as marine genetic resources and fish resources) is currently unknown.

In addition to the removal of habitat, the processes of mining and the return of filtered seawater to the seafloor will create a plume of suspended particulate matter that will ultimately result in higher than natural sedimentation rates within the area of the plume footprint. This can impact on benthic animals in several ways:

- Changing sediment grain size which can affect porosity/ stability, biogeochemical fluxes, rates of faunal movement and bioturbation;
- Potential for increased toxicity due to the mobilisation of metals within the sediments and rock hosting the minerals (this is less likely to impact on vent associated fauna which are largely chemosynthetic and obtain their energy from chemicals emitted from the vent);
- Processes of nutrient cycling and organic matter remineralisation may also be affected by disturbance at the seafloor, because the sediment that forms the plume will be redeposited with very low average organic carbon content (and in altered grain-size distributions), leading to a change in organic matter remineralisation processes (Pabortsava et al., 2011; Purser and Thomsen, 2012; BGR 2018);
- Enhancing suspended sediment and turbidity, which can clog feeding structures of suspension feeders. This may lead to the clogging of respiratory or filter-feeding organs, and/or the release of potentially toxic or oxygen-consuming substances (BGR, 2018; SPC, 2013b, Jones et. al. 2017, Simon-Lledó et. al., 2019);
- Sediment settling out can settle on animals, burying/smothering them and covering the sediment surface causing anoxia;
- When mining occurs on a large scale, loss of habitat and biodiversity may also influence gene flow or connectivity of species, due to the large size of disturbed areas.

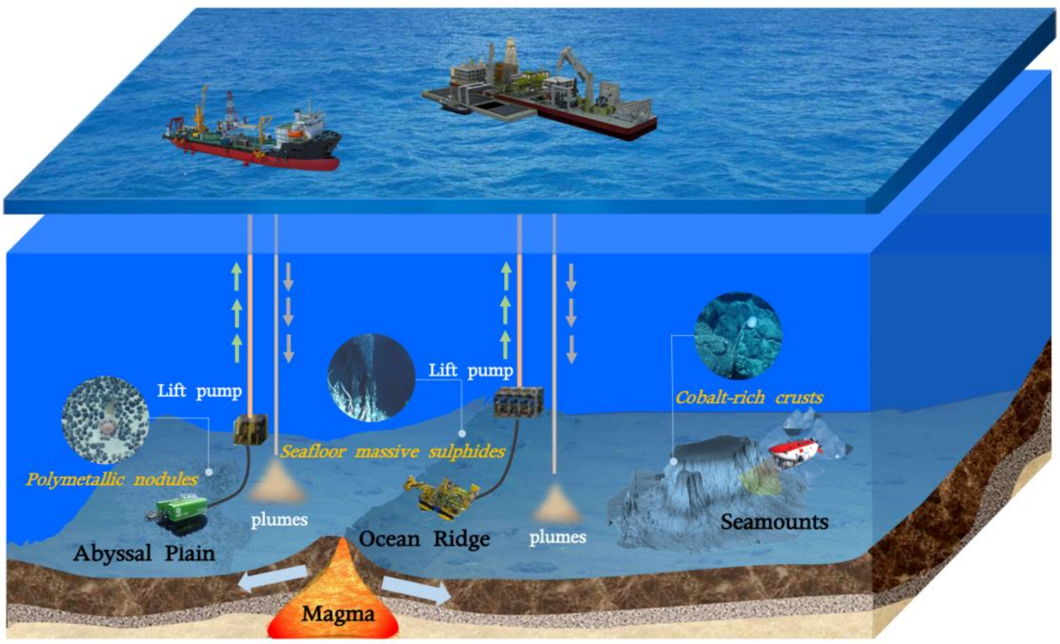


Figure 2-2 Schematic diagram showing potential effects of DSM

Additional impacts likely to occur at the seafloor from DSM include noise, vibration and light. Finally, the potential for hydrocarbon spills from machinery breakdowns is relevant for both the seafloor and the surface. The use of biodegradable hydrocarbons (Coffey, 2008) would at least to some extent mitigate the impacts associated with hydrocarbon spills.

In the mid-water column there are not expected to be any significant impacts associated with mining, with the exception of the noise and vibration associated with a rise and lift system, and the transit of seafloor production tools during descent and ascent (AMC, 2018). This assumes that any dewatering discharge will be returned to the seafloor, rather than discharged in the mid-water column. It is suggested that this represents best practice, and is likely to minimise any plume impacts associated with return water discharge (Coffey, 2008). Potential impacts to the water column may arise from transporting the material from the sea floor to the production support vessel, particularly if the rise and lift system is not fully enclosed. At present, most contractors appear to be favoring an enclosed rise and lift system, as well as seafloor discharge for return water (BGR, 2018; GSR, 2018). Both of these project design features would limit impacts in the mid-water column. The discharge of return water in the surface or mid-column, unless filtered to background quality levels (which is likely to be cost prohibitive) would have significant impacts on communities in these habitats, particularly as a result of mobilisation of metals, reduced light penetration and depressed phytoplanktonic production (SPC, 2013b).

At the surface, impacts for all types of DSM are similar, and are likely to be comparable with normal shipping operations, and will include underwater noise (particularly from the vessel power generation and dynamic positioning systems), lighting, routine discharges and emissions to air. Given these impacts are currently being addressed in other industries, it is considered that these can be managed using existing and emerging protocols, guidelines and regulatory instruments such as MARPOL (International Convention for the Prevention of Pollution from Ships).

2.3.2 PMS Specific Environmental Challenges

The most significant impact in PMS mining will be the removal of vent habitat and ecosystems at the mine site, which might have a very high degree of biological endemism and biodiversity. As a result, extensive studies of the communities associated with the vent ecosystem are required in order to fully understand the environmental values of these areas and the potential impact from mining in these areas, particularly given it is anticipated that loss of fauna and habitats will be almost complete within the mining zone. The environmental values of active vent ecosystems have been recognised as areas in need of protection like e.g. FAO (UN Fisheries and Agricultural Organisation) guidelines on vulnerable marine ecosystems. As such, there is a need to ensure the environmental risks associated with this type of mining have been comprehensively assessed.

It is also essential to consider the characterization of patterns of genetic diversity and connectivity within (and among) vent populations that will be affected by mining, in order to manage the potential far-field effects of the removal of specific populations. At the Solwara 1 site (in the Manus Basin of Papua New Guinea) studies into genetic differences between the population to be affected by mining and other surrounding populations, has shown that key vent-associated species have a high degree of connectivity, providing evidence that the surrounding protected sites may serve as a reservoir (or 'parent' system) of genetic diversity for some species (Thaler et al., 2014). Understanding the impact that removal of one population may have upon surrounding regional populations is an essential aspect in determining the significance of the loss of fauna at the impact site.

2.3.3 CRC Specific Environmental Challenges

The specific geographical and hydrological conditions of seamounts create unique community structures, which may have high levels of endemism and biodiversity. A large number of benthos, including sponges and soft corals with life spans of thousands of years, have been discovered to occur on seamounts. Currently, seamounts are hotspots for research on marine biodiversity, and may be important ecosystems for fisheries resources and migratory fauna.

As outlined above, the habitat associated with CRC forms over geological time scales, and will therefore not reform within human time scales, and any recovery is likely to be very slow. In addition, the knowledge on biogeochemical cycles, deep-sea ecosystems and ecological function of organisms in crust areas is currently insufficient, and it is difficult to accurately assess the potential impact of mining activities on the CRC ecosystems. It is important to gain a better understanding of the ecosystems related to potential mining of CRC including the potential re-colonisation and regrowth of important species.

2.3.4 PMN Specific Environmental Challenges

The collector for nodules will likely take in bottom sediment along with the nodules, and as a result the mortality of both sediment infauna as well as sessile nodule fauna is likely to occur.

PMN fields, thought to be empty of life just decades ago, are now known to be biodiverse environments, though most species remain largely undiscovered or unidentified. For example, in the eastern CCZ, over 50% of species over 2 cm in size collected by Amon et al. (2016) and 34 of the 36 species of xenophyophores (large single-celled organisms) collected by Gooday et al. (2017) in 2013 and 2015 were new to science.'

Removal of nodules (and at least to some extent, the fine-grained muds on which they sit) will also disturb the benthic habitat in the mining area, resulting in a loss of habitat for both nodule and sediment fauna. The disruption of the soft sediment (through compaction or pore water expulsion), may alter the sediment biogeochemistry and structure to the extent that it is also 'lost' as a potential habitat for rehabilitation post-mining, at least in the short to medium term (Jones et. al., 2017; Simon-Lledó et al., 2019; BGR, 2018; GSR, 2018; SPC, 2013b).

While the area in which organisms may be smothered as a result of the sediment plume associated with mining may be relatively small (GSR, 2018), increased sedimentation rates are likely to be experienced much further afield than the immediate mining area, due to the extremely low background sedimentation rates in the deep abyss (BGR, 2018; SPC, 2013b).

Long-term studies show that, in general, epifaunal abundance, abundance of sessile fauna attached to the nodules (such as sponges), filter feeder abundance and mobile fauna associated with the nodule hard substrate (such as brittle stars and crustaceans), are significantly reduced in impact areas for at least decades after the impact occurs (Vanreusel et al., 2016; Jones et. al., 2017; Simon-Lledó et al., 2019). When mining occurs on a large scale, this impact may also influence gene flow or connectivity of species, due to the large size of disturbed areas.

Almost all previous studies show some recovery in faunal density and diversity for meiofauna and mobile megafauna, often within one year (BGR, 2018; SPC, 2013b). On the other hand, some faunal groups showed no evidence of recovery, even after multiple decades (such as nodule-dependent fauna). Despite the potential for some recovery, long term studies show that very few faunal groups return to baseline or control conditions after (at least) two decades, and so the effects of PMN mining are likely to be long term (Jones et. al., 2017; BGR, 2018; SPC, 2013b).

2.3.5 REE Specific Environmental Challenges

The removal of muds containing REE will have similar impacts to other forms of seabed mining, with the immediate mortality of all sediment infauna within the mining area, as well as any seafloor epifauna. The removal of the soft sediment will also remove the habitat for potentially all sediment infauna within the mining zone (depending on the depth of sediments extracted).

While there are relatively few studies available into the effects of deep sea dredging, it is generally accepted that dredging in shallower ocean environments is likely to impact benthic habitats for a period of between 2-30 years following the completion of turbidity generating activities, and that considerable areas of benthic habitat are likely to be permanently lost as a result of dredging activities (EPAWA, 2006; Fisher et. al., 2017; Jones et. al., 2019). Further, it is well acknowledged that these impacts to the marine benthic habitat may result in flow-on effects that impact regional habitat structure and food webs (EPAWA, 2006; Simon-Lledo et. al., 2019; Jones et. al., 2017).

2.4 Technology Challenges

2.4.1 Challenges Applicable to All Resource Types

Energy supply technology for production systems. According to the current scale of mining tests, in order to meet the production scale of the current technical and economic model, the mining systems are expected to operate at sea all year round. The acquisition, transportation, ship positioning and operator's life require a large amount of energy. The design of the vessel and the mining equipment, including the lifting of the nodules from the seabed need to be designed with “minimum use of energy” in mind.

High-performance new material technology. The long-term and stable operation of DSM systems needs to overcome adverse factors such as harsh sea conditions, low temperatures (the bottom temperature is about 2 °C) and seawater corrosion, which place significant requirements on the technology associated with mining, transportation equipment, transport of crews and supplies, and underwater components. The development of new materials that are light weight, high strength, resistant to high pressure, corrosion and fatigue, will be required to guarantee safe and efficient operation of commercial mining.

2.4.2 PMS Specific Technology Challenges

Some PMS contractors have carried out extensive exploration activities and developed a series of targeted techniques. Their main exploration technique and equipment includes:

- Chemical sensor detection of hydrothermal plume anomalies, e.g. sensors of temperature, turbidity, methane, and geological sampler, including television grab, trawl, box-corer;
- Near seafloor high-precision techniques, e.g. multi-beam bathymetric sonar, side-scan sonar, magnetometer, spontaneous potential detector, vertical electric sounding, and so on;
- New exploration platforms, e.g. Human Operated Vehicle (HOV), Autonomous Underwater Vehicle (AUV) and Remotely Operated Vehicle (ROV).

There has been some (limited) progress to date with developing the technology required for PMS mining, including:

- The Japanese Ministry of Economy, Trade and Industry (METI) and the Japan Oil, Gas and Metals National Corporation (JOGMEC) conducted the world's first pilot test of excavating and ore lifting for deep sea PMS on the Okinawa Trough. The pilot test involved the collection of ore from the seafloor which had already been excavated and crushed in advance by an excavating test machine, and the use of a rise and lift system to pump 16.4 tonnes of ore 1,600 m to the sea surface and onto the support vessel. (METI, 2017).
- A similar system was also planned to be used for the Solwara 1 project, with a production support vessel, a riser and a lifting system and three machines at the seabed – an auxiliary cutter, a bulk cutter and a collection machine. The system has not yet been tested at relevant depth or as an integrated operational unit.
- Bauer Maschinen GmbH have developed a prototype for vertical mining. Where a modified land-based trench cutter is used as a basis and the ore is deposited in a container which is lifted to the support vessel when full, creating a discontinuous ore transportation system.

Technological challenges for PMS mining include the following:

- Prospecting stage: with the technology currently available it is often difficult to find inactive vent sites, because (a) they are not venting so plume detection cannot be used, and (b) they can be buried under significant depths of sediment (which makes location hard, and also gives additional mining challenges);
- Exploration stage: PMS deposits are similar to terrestrial volcanic massive sulphide deposits, and are likely to extend to depths of tens of metres at least,

requiring resource definition at depths resembling open pit depths on land. The 3D mapping (or resource definition at depth) for PMS deposits relies on drilling at intervals aligned with terrestrial mining resource codes, which represents a significant cost and technological challenge in the deep ocean;

- Exploitation stage: due to the complex topography, deep mining depth and high tectonic activity associated with PMS deposits, there is a risk of loss or damage of mining equipment that may increase the cost of mining.

2.4.3 CRC Specific Technology Challenges

In the 1980s, the United States carried out research on exploration, mining systems, and smelting schemes of CRC, and proposed a technology of cobalt-rich crust mining systems consisting of tracked collectors, hydraulic pipeline transportation systems and surface mining vessels. In 1990s, Japan used multiple methods of rake, disc cutter cutting, roller cutting to carry out crushing comparison tests on CRC samples, which showed that the above methods are effective to break CRC.

Mining of CRC is facing another type of technological challenge (compared to PMNs and PMS deposits), as the crust is found as a relatively thin layer, and needs to be removed from the substrate for a commercial mining operation. Therefore, efficient and high-precision cutting, and separation of CRC are the main technology challenge on the development of CRC.

2.4.4 PMN Specific Technology Challenges

In 1970, Ocean Mining Associates (OMA) carried out the first prototype test of nodule mining at a depth of 1,000 m using a drag-type hydraulic collector and pneumatic lifting. In 1978, OMA conducted a 5,500-meter water depth test using the same system. Since 2000, China, India, South Korea, Japan, Germany, Belgium and other ISA contractors have carried out research, development and testing of key technologies for PMN mining. For example, South Korea used the OMA system as a prototype to conduct mining tests of 100 m, 1000 m, and 2000 m water depth in 2009, 2012, and 2015, respectively. In cooperation with Germany, India conducted a beach test with a depth of 410 m in 2000 and a depth of 500 m in 2006 and a mine test with a depth of 500 m in 2009 by adopting a full hose conveying method. China also carried out a mine-lifting experiment at a depth of 500 m in 2018 and will conduct related work such as a walking test of a collection system with a depth of 5000 m.

The collection system and lifting system for PMNs is one of the main technical challenges associated with mining of this resource, due to the low shear strength of the underlying sediments. The current prototype collection systems either have a self-propelled nodule collector or a towed collector for collecting submarine PMN and pushing them directly or via an indirect buffer unit to the lifting system.

There are two types of lifting system: hydraulic and pneumatic. Of course, in order to achieve a comprehensive mining system for mining polymetallic nodules at a depth of 6,000 m, it is necessary to conduct in-depth research on many subsystems which will form part of the overall system, and these must be tested in stages. These subsystems include the deep-sea high-pressure tank hydraulic device system, acoustic positioning and imaging system, seabed PMN acquisition system, underwater crushing system, flexible riser system, and related infrastructure (high-pressure tanks, test tanks, winch test devices, etc).

2.4.5 REE Specific Technology Challenges

At present, there is limited research on mining of a REE sediment resource.

The processing of REE resources (both terrestrial and marine) remains the major challenge associated with commercialising REE mining. Given REE deposits on the ocean floor are likely to vary in composition, grade and type, the development of processing technologies that may be applicable to multiple deposits has yet to be considered. Preliminary research indicates that in-situ leaching may represent a more feasible mining approach than traditional processing, however considerable further research is required in this area.

2.5 Economic Challenges

2.5.1 Challenges Applicable to All Resource Types

There have been no commercial-scale DSM operations to date. As such, an accurate assessment of economic aspects of mining different deep-sea resources is difficult. Many parameters are as-yet uncertain e.g. ramp-up costs (including development of new hi-tech machinery), operating costs (including those associated with environmental management, and transporting the ore), resource grades and volumes that can be mined, processing capabilities, the payment regime (royalty rates) for mining.

Another factor is timing. DSM production is not likely to occur for several years yet, so an economic evaluation involves commodity forecast, for metals that have had historically highly fluctuating prices, and whose demand is driven by fast-paced technology development.

One case study providing useful insight on the risks to the economic realisation of DSM is the Nautilus Solwara 1 project (for PMS deposits in the EEZ of Papua New Guinea), which noted the following risks (AMC, 2018):

- Given the capital cost of the mining equipment, redundancy will be more costly. Loss or failure of equipment could materially affect the economic performance of the project;
- Estimates in relation to the timeframe required for ramp-up of production were based on assumptions from the terrestrial mining industry. Actual production ramp-up of seafloor production may be much slower and longer than expected, resulting in higher operating costs;
- DSM deposits may be developed without meeting the definition of the Mineral Reserve category of international classification standards, because data are insufficient to demonstrate geological and grade continuity. The actual deposit characteristics could vary from the predictive models, resulting in a lower (or higher) grade or volume of recovered ore.

Positive economic features of DSM include:

- DSM deposits are polymetallic and likely to yield from one mine a wider range of target metals than comparable terrestrial mines;
- Metal grades may be higher than similar ore bodies found on land;
- The entire mining system is portable. While the upfront capital investment into mining systems and vessels may be similar to that for mining on land, being able to move infrastructure to a new mine site when the current mine has been fully exploited may give a significant cost saving;
- Site restoration options for DSM projects at this stage appear limited, and as such the rehabilitation liability may be significantly less than for a comparable terrestrial mine.

2.5.2 PMS Specific Economic Challenges

It is estimated that an PMS deposit would need to be at least 3 million tonnes in order to present a commercially viable mining opportunity with current technology. New technologies should be expected to be more efficient and - consequently - reduce the commercial size threshold. The sizes of most deposits are currently incompletely known, pending further exploration and drilling to understand the depth extension. Of 64 deposits modelled in one study, eight had dimensions indicating sizes larger than 2 million tonnes. However, the median deposit size was only 70,000 tonnes, and more than a third of the deposits were considered to be smaller than 3000 tonnes.

In relation to capital and operating costs, only the Nautilus Solwara 1 project (approx. 3 million tonnes of ore) is available for consideration, and indicates a capital cost of USD$530 million and an operating cost of approximately USD$1.36 per pound of payable copper, net of gold credits (AMC, 2018). While this compares favorably with terrestrial mining operations, the uncertainties and risks outlined above could impact significantly on this cost.

To achieve an economically viable PMS project, in most cases a pipeline of deposits will be required for sequential mining. This is because many PMS deposits are limited in volume, and consequently mine-life.

2.5.3 CRC Specific Economic Challenges

CRC generally have a relatively simple mineralogy which means that processing and refining technologies may be less complex and expensive than, for example, PMN.

CRC on seamounts in the central Pacific are estimated to contain about four times more cobalt, three and a half times more yttrium, and nine times more tellurium than the entire land-based reserve base of these metals. As such, CRCs could play an important role in the provision of metals required to fuel the ‘green economy’ (SPC, 2013a).

Pacific crust occurrences appear to present a higher market value per tonne of dried ore material than the respective deposits of the Atlantic and Indian Ocean (Sharma, 2017).

Most estimates of CRC resources have been based solely on a price per tonne of metal calculation, and have not considered parameters such as the amount of substrate likely to be recovered with the crust and the amount of overlying sediment (both likely to be treated as waste), and the percentage of the flanks of an edifice that could not be mined because of the roughness of small-scale topography.

2.5.4 PMN Specific Economic Challenges

A cost-benefit analysis prepared for the Cook Islands government in relation to the PMN within the country’s EEZ found that a mining project may be profitable for an operator which is able to process the nodules itself and extract successfully all four target metals (Mg, Ni, Co, Cu).

Analyses prepared by Global Sea Mineral Resources (GSR), an ISA PMN exploration contractor (sponsored by Belgium), and by the Massachusetts Institute of Technology on behalf of the ISA, suggested that the risks associated with PMN mining at this stage of the industry required a higher hurdle rate (minimum acceptable rate of return for an investor) than for terrestrial mining. This in turn suggested that for a PMN mining project to be viable for the operator the costs must be minimised, including through a low level of taxation from the resource owner (in this case, the ISA on behalf of humankind). There have been criticisms to this proposal, notably by the African Group of countries at the ISA, who prefer to see a higher level of taxation at the ISA, in order to secure greater financial returns for humankind. Indeed, the ISA's system of payments for contractors is complex and contentious matter, currently under negotiation. Until a rate and mechanism is adopted by the ISA, the economics of PMN mining under an ISA contract remain difficult to assess with any accuracy.

Though the economic analysis of PMNs in recent years indicate that PMN mining has a feature of high risk and potential high return, it is also likely to be highly dependent on metal prices.

2.5.5 REE Specific Economic Challenges

Deep-sea mud containing over 5,000 ppm total REE content was discovered in the northwestern Pacific Ocean near Minami Torishima Island, Japan, in 2013. The resource amount was estimated to be 1,200,000 tonnes Mt of rare-earth oxide for the most promising area (105 km^2), which accounts for 62, 47, 32, and 56 years of annual global demand for yttrium, europium, terbium, and dysprosium, respectively (Takaya, 2018).

As mentioned in section 2.2.4, there is an increased international market demand for REE, and the presence of rare earth resources in polymetallic nodules and deep-sea mud attracts more attention. The rare earth elements in polymetallic nodules is proposed to be processed and extracted together with copper, cobalt, and nickel. But the current knowledge of REE and deep-sea mud is so limited that we are not able to provide more data and will not discuss the economic challenges further in this report.

Gas hydrate production tests in the South China Sea

3 GAS HYDRATES

3.1 General Description

Natural Gas Hydrate (NGH) has the following characteristics compared to conventional oil and gas. Firstly, NGH is trapped as a solid form in hydrate and cannot flow freely in the geological formation. Thus, extra steps are required to decompose hydrate into methane and water for gas production. Secondly, because of the low level of global hydrate exploration, the amount of resources or recoverable reserves depends on the change in technology maturity. The energy density of hydrate is about one-sixth of crude oil (i.e., 1 m^3 Hydrate = 0.157 m^3 crude oil).

Techniques for NGH production usually focus on in-situ dissociating natural gases from NGHs and creating a conduit to flow recovered natural gases to surface. Currently, most of the gas production methods are based on shifting the NGH reservoir condition to its dissociation side by the following methods:

- Depressurization, involving the production of gas from NGH reservoirs by lowering the pressure below to the NGH equilibrium pressure at the local temperature.
- Thermal stimulation, involving the increase of temperatures of the local NGH reservoirs for hydrate dissociation. The disadvantage of this method is that heating energy consumption and transmission heat loss is huge.
- Chemical inhibitor injection, which involves shifting the NGH phase equilibrium curve to higher pressure and lower temperature, leaving the NGHs unstable and able to dissociate to gas and water. Chemical inhibitors generally include thermodynamic inhibitors and kinetic inhibitors. The crucial issue for this method is the injecting fluid diffusion efficiency, as well as the environmental impact of the chemical fluids.
- CO_2–CH_4 replacement. This method means to inject CO_2 into reservoir to replace methane gas from hydrate and generate CO_2 hydrate. The advantage of this approach is that the replacement of methane hydrates makes the original space filled with other hydrate formation, promoting stability and achieving the dual purpose of recovering natural gas and CO_2 sequestration. But in general, the displacement efficiency of this method is not high.

Several field tests of production level gas hydrate extraction have been carried out in recent years, including:

- The Mallik gas hydrate field in Canada’s Mackenzie Delta, an area underlain by over 600 m of permafrost within a sequence of Tertiary sediments. In 2002, 2007 and 2008, several field tests were carried out with thermal stimulation and subsequent depressurization methods, with results indicating that the depressurization method has higher efficiency than that of thermal stimulation.

- The U.S. Ignik Sikumi field tests were carried out in 2012 in Alaska, with a CO_2/N_2 (23% / 77%) gas mixture injected into the well to replace the CH_4 from the methane hydrates.
- Japan carried out a test in the Nankai Trough in 2013, and again in 2017. The production wells produced gas for up to 24 days, and this is considered a reasonable reference for longer term production wells;
- In 2017, China carried out the first offshore production test in an argillaceous silt reservoir (this type of reservoir accounts for 90% of known gas hydrate deposits). In the test on this reservoir, the gas production process was stable, and the bottom hole condition good, which is a major breakthrough in the progress towards gas hydrate production.

3.2 Economic Considerations

NGHs are widely distributed in most of the world's marine deep water areas (~ 99%) and permafrost sedimentary environments (~ 1%). The amount of gas stored in the world's hydrate accumulations is enormous (Table 3-1), but estimates are speculative and the range is from about 2.8×10^{15} to 8×10^{18} m^3 of gas. By comparison, conventional natural gas accumulations (reserves and technically recoverable but undiscovered global resources) are estimated to be approximately 4.4×10^{14} m^3 (Ahlbrandt, 2002).

Table 3-1 World estimates of the amount of gas within gas hydrate

No.	Terrestrial gas hydrates		Oceanic gas hydrates	
	Cubic meters	Reference	Cubic meters	Reference
1.	1.4×10^{13}	Meyer, 1938	3.1×10^{15}	Meyer, 1938
2.	3.1×10^{13}	McIver, 1981	$3\text{-}5\times10^{15}$	Milkov et al., 2003
3.	5.7×10^{13}	Trofimuk et al., 1977	$5\text{-}25\times10^{15}$	Trofimuk et al., 1977
4.	7.4×10^{13}	MacDonald, 1990	1.25×10^{17}	Klauda and Sandler, 2005
5.	3.4×10^{13}	Dobrynin et al., 1981	2×10^{16}	Kvenvolden, 1988
6.	—	—	2.1×10^{16}	MacDonald, 1990
7.	—	—	4×10^{16}	Kvenvolden and Claypool, 1988
8.	—	—	7.6×10^{18}	Dobrynin et al., 1981

**At standard pressure and temperature, 1 atm and 20 ℃ (68 ℉), 1 m^3=35.3 ft^2*

The reasons for the huge difference in prediction of methane resources in methane hydrates worldwide are the uneven distribution of gas hydrate and uncertainty of reservoir porosity and saturation. Porosity and saturation are two basic parameters for estimation of gas hydrate volume. Because porosity, gas-liquid seepage channels, and control conditions for conversion of organic material into methane can all change significantly over short distances, the distribution of gas hydrates is very uneven in most cases. As for NGH, there is not only uncertainty in resource assessment, but also uncertainty in how much of it can be used for actual exploitation as an energy resource.

The properties and development potential of NGH reservoirs are affected by factors that are highly uncertain and vary from location to location. These factors include the local supply of methane gas, the structure of gas migration and accumulation path, the zone and range of temperature and pressure conditions suitable for gas hydrate formation, the properties and characteristics of reservoirs, their ability to enrich hydrates, and the regional geological conditions under which hydrates can form and continue to accumulate. Since these factors vary greatly, the distribution of NGH is very uneven even at a local scale. Therefore, despite the huge amount of methane gas contained in gas hydrates on earth, not all gas hydrates are recoverable. At least in the near term, only a small proportion of natural gas resources in this form are technically or economically recoverable.

3.3 Technology Challenges

Although significant progresses have been made so far for understanding the occurrence, distribution and characteristics of natural gas hydrate, as well as a series of gas production tests from both the permafrost and marine hydrate deposit have been carried out worldwide, longer duration production tests under a wider range of reservoir conditions would be required to fully assess the resource potential of gas hydrates. The main challenges and uncertainties that restrict hydrate commercial exploitation are shown below.

(1) Exploration:

- Equipment R & D technology: High-resolution 3D seismic exploration of natural gas hydrates, deep-sea deep towed seismic investigation, hydrate drilling, thermal insulation and pressure geological sampling are still under development or perfected, and have not been applied in engineering;
- Target evaluation technology: Basic technologies, testing methods, numerical simulations, and inversion calculations related to NGH gas source evaluation, fluid migration process, reservoir formation factor analysis, and dynamic process related technologies are not enough to support the theory of hydrate accumulation system under different types and different structural conditions in global seas.

(2) Hydrate Resource Characterization:

- Refinement of current gas hydrate resource assessments is required, with a focus on moving from mostly in-place gas volume assessments to technically recoverable assessment and eventually to reserve estimates.

(3) Gas Hydrate Production Methods:

- Improving the development of new gas hydrate production models that incorporate advanced macro-and pore-scale mechanical models;
- Reviewing existing and new completion technologies, including horizontal completions, multi-lateral drilling, and their potential application to NGH production.

3.4 Environmental Challenges

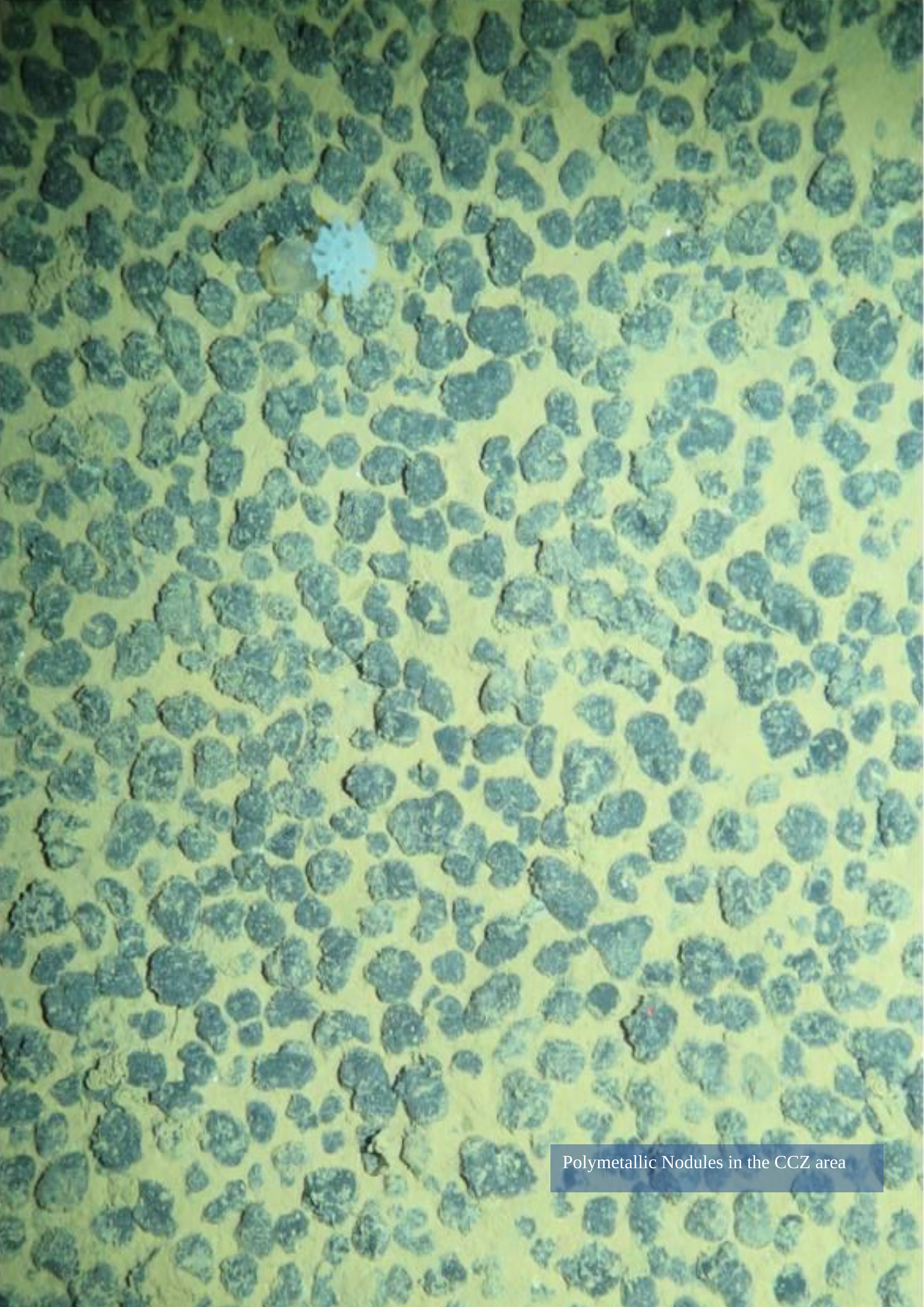
NGH production may bring environmental/engineering geological risks during well drilling/completion stage, gas production stage and gas transportation stage.

Dissociation of gas hydrates may lead to two results: strength reduction and pore pressure increase of the sediments. If the load on the sediments is greater than its strength, the sediments would fail and deformation or landslide may occur. In addition, the decreasing of strength could cause the displacement to increase, generating further subsidence or seafloor instability. Numerical simulation indicates that the seafloor subsidence can extend to several meters after 4 years of production. The subsidence would lead to the seafloor instability and other failure of ocean structures. Global climate change and seawater warming may dissociate marine gas hydrates in nature, and naturally dissociated gas hydrates have a great potential to trigger submarine landslides which may cause tsunamis (Maslin et al., 2010). While there is historical evidence of these submarine landslides occurring naturally, the production of NGH has the potential to cause similar outcomes if the geomechanical risks cannot be managed.

Geomechanical failure may also occur with wellbore collapse. The most extensive yield zone for a vertical well is around the perforated production interval where the pressure gradient is the highest. In practice, such yielding and shearing of the sediments leads to breaking of bonds between sand grains, which in turn could result in sand production if not prevented with appropriate sand control technology (Rutqvist et. al., 2012). Another risk of the wellbore is the vertical compaction of the reservoir can be substantial because of the soft sediments. Some numerical results indicate that the vertical compaction strain can exceed 10%, which will cause buckling failure of the well assembly.

Potentially of greatest importance in the context of global warming, one volume of hydrate contains more than 160 volumes of methane at standard temperature and pressure (STP) conditions. The estimated amount of carbon sequestered in gas hydrate resources is more than 15 % of Earth's total mobile carbon, which includes that in soils, land biota, fossil fuels, peat, and other reservoirs. As evidence mounts for sustained global warming during the last half of the 20th century and the start of the 21st century, there is increased awareness of the relative importance of hydrate to greenhouse warming. Even its small quantities, methane is taken as a powerful greenhouse gas because is deemed 21 times more potent than CO_2. In natural conditions, hydrate release from hydrate dissociation is slow-occurring. However, abrupt release of methane is also believed to happen due to giant submarine landsides, chronic releases resulting from warming subsurface sediments. Without careful management of the risks associated with NGH production, it is possible that NGH production could inadvertently cause large and abrupt releases of methane to the ocean (and subsequently to the atmosphere), contributing significantly to global warming.

Therefore, clarification of possible engineering geological risk types, the inducing factors, and their effect on the safe and effective exploitation of the marine natural gas hydrate is needed to explore the prevention and control measures for different engineering geological risks in a controlled range, and ensure long-term safe hydrate production.



Polymetallic Nodules in the CCZ area

4 ENVIRONMENTAL MANAGEMENT

4.1 Insufficient Environmental Knowledge

Deep-sea environments are little-explored and poorly-understood. The relevant ecosystems will need to be assessed and understood as part of the exploration phase for each potential mineral resource, and a plan for exploitation of the resource needs to include adequate mitigating actions and measures to avoid significant environmental harm. The main gaps in environmental knowledge related to DSM are provided in the sections below.

4.1.1 Habitat Mapping

Protecting the structural and functional integrity of benthic communities is essential for the maintenance of ecosystem services and function in the deep sea. In considering large scale exploitation of minerals from the deep-sea floor, it is critical to understand the spatial distribution of benthic communities, and their relationships with environmental variables, so that effective management practices can be developed and implemented (Leduc et. al., 2015).

Spatial distribution of communities (also known as habitat and community mapping) uses seabed samples taken from a study area to describe fauna diversity and community structure, and habitat information (such as slope, presence of hard substrate, latitude and longitude, nutrient cycling and sedimentation rates), to form the basis for predictive models of the distribution of benthic communities (Leduc et. al., 2015). The number of samples used to inform predictive models directly influences the accuracy of habitat distribution maps, and it is likely that significant numbers of samples will be required to inform a large-scale habitat mapping model (such as would be required for a PMN project) (Porskamp et. al., 2018). Use of multibeam bathymetry, backscatter and video and still imagery from towed camera systems combined can give a much finer scale of information to inform the habitat mapping process (Purser et. al., 2019).

Using habitat mapping with habitat suitability models can also predict where communities will be associated with different seabed morphologies (such as uneven topography, slopes or flat seabed), and produce contrasting predicted spatial distribution patterns among communities across the study area (Leduc et. al., 2015).

The results of these habitat and community mapping processes can inform the management of seabed mining projects by determining areas, topographic features and habitats that need to be protected from mining impacts in order to preserve ecosystem function (Leduc et. al., 2015).

4.1.2 Genetic Connectivity

One of the critical management strategies for seabed mining will be the establishment of protected areas, reserves, or no-mining areas to maintain the regional genetic connectivity and ecosystem function. Reserve design will depend on estimates of connectivity and scales of dispersal for the taxa of interest.

Deep-sea taxa are hypothesized to disperse greater distances than shallow water taxa, which implies that reserves would need to be larger in size and networks could be more widely spaced (Baco et al., 2016). On smaller spatial scales within regions, local topography and current regimes may have a profound impact on gene flow, leading to the differentiation of populations at different habitats (Bors et. al. 2012). In addition, some species exhibit stepping-stone dispersal along relatively linear, oceanic, ridge axes, while other species exhibit very high rates of gene flow, while natural barriers associated with variation in depth, deep-ocean currents, and lateral offsets of ridge axes often subdivide populations (Vrijenhoek 2010). Finally, species-specific life histories and behaviours also impede or facilitate dispersal rates and distances (Vrijenhek 2010, Bors et. al. 2012, Baco et. al 2016).

It is therefore critical to consider the enormous variety of taxa, life histories, hydrodynamics, spatial configuration of habitats and patterns of species distributions when undertaking genetic connectivity studies, in order to ensure that the environmental management strategies for seabed mining preserve the regional genetic connectivity both during and after seabed mining operations.

4.1.3 Hydrodynamic Plume Modelling

The fate of sediments suspended during mining is one of the most important aspects to understand when determining the significance and scale of impacts associated with seabed mining. It is particularly important to determine the potential for DSM activities to interfere with other marine uses and industries, and/or cause transboundary impacts. The most robust method for predicting the fate of suspended sediments is to conduct hydrodynamic modelling of the mining operation, including all its discharges and activities at the seafloor. Hydrodynamic modelling is the study of fluids in motion and includes the movement and eventual settling location of sediments and particles suspended by disturbance or discharged as part of an extractive operation.

There are numerous models available to predict both the extent of water quality (plume) impacts, as well as the extent of sedimentation (when compared against natural sedimentation rates for the area). The most comprehensive and accurate models will include the following (RPS, 2017):

- Simulation of near field as well as far-field (larger than 20m scale) effects, in which the mean transport and associated with ambient currents are dominant over the initial turbulence generated at the release point;
- Consideration of all particle sizes in the one model to ensure that sinking rates of clay and fine silt-sized particles are modified at increased concentrations of larger particle sizes to account for clumping or flocculation;
- Consideration of sediment re-suspension if the combined shear-stress increases above critical thresholds;
- Consideration of baseline water quality and sedimentation rates in order to determine appropriate model cut-off values for impact assessment.

Only by ensuring that the most robust modelling approach, and model inputs, are used, can hydrodynamic modelling be used as both an accurate predictor of plume impacts, and a valuable tool for mine planning and environmental management purposes.

4.1.4 Toxicity of Plumes

Most mining projects will involve a release of chemical elements to the water column as part of the plume generation. In order to determine the extent of elements likely to be released, and the toxicity of any such material, it is necessary to undertake elutriate testing. Elutriate testing involves sampling of waters using ultra trace-metal techniques, analysis of waters for trace-metals, characterisation of minerals, and laboratory-based tests to assess the release of metals that may occur during the dewatering of crushed minerals (CSIRO, 2008). The outcome of such testing, when compared against relevant water or sediment quality guidelines (such as ANZECC/ARMCANZ 2000) will determine the number of dilutions necessary to achieve the relevant water quality guideline. This information, coupled with the hydrodynamic modelling results can determine the physical extent of the potential toxicity from the discharge or mine site, and thus determine an area of potential impact in relation to water quality and toxicity.

Benthic fauna toxicity testing can determine the length of time fauna can be exposed to various dilutions of the plume or discharge stream, without the occurrence of serious or chronic effects (such as loss of fecundity or mortality). Furthermore, the test results can assist with the determination of appropriate compliance limits for water quality, for the purposes of environmental management and regulation.

4.1.5 *Assessing the Significance of Impact*

One of the most important aspects of an EIA process is to assess whether a predicted impact is likely to be 'significant', and therefore to cause 'serious' environmental harm. All extractive industries projects cause harm on some level (particularly mining and dredging projects), and therefore the challenge is not to determine whether harm is being caused, but rather whether this harm is significant or serious in the context of the existing environmental values (Gro Sustainability, 2017; Levin et. al., 2016).

Elements to be considered in determining significance may include:

- Sensitivity of the environment which will be impacted;
- Timing, duration and frequency of the action and its impacts;
- All on-site and off-site impacts;
- All direct and indirect impacts;
- Total impact which can be attributed to the action over the entire geographic area affected, over time (i.e. the end of project impact);
- Existing levels of impact from other sources;
- Degree of confidence with which the impacts of the action are known and understood.

Finally, some regulatory agencies recommend using the 'zone of influence' approach to inform discussions on whether an impact is considered significant or serious. This involves the delineation of zones of high and moderate impact, as well as the zone of influence, where changes are predicted, but would not result in detectable impacts. Such predictions can assist with determining the potential impacts of a project, in the context of uncertainties that cannot yet be resolved (due to the early stages of the DSM industry).

4.2 Sound Environmental Management in DSM

Sound environmental management in deep sea mining will involve strategic practice policy and planning, as well as operation-level regulation. Global rules for seabed mining (and the seabed mining industry) do not yet exist (see Governance section, below). One challenge to the development of rules is the lack of scientific knowledge for the relevant ecosystems. This triggers the international law doctrine of the precautionary approach, which means that - while proceeding with seabed mineral activities does not have to halt - the high-level of scientific uncertainty dictates that activities must only proceed with high caution, prioritising measures that will prevent environmental damage, and taking time to monitor and review, and adjust, measures employed to avoid causing serious environmental harm. There are numerous tools that are already in use in other industries that will be useful here, including impact assessment, ecosystem-based management, adaptive management, risk assessment and management, and continuous improvement.

Seabed mineral activities in the ABNJ will operate under a dual management regime: the national law of the sponsoring State, and ISA rules (see governance section below). China has an opportunity both to influence the ISA rules being negotiated now, and to adapt or further develop domestic rules to ensure that China's interests and duties as a sponsoring State are comprehensively covered. There may be aspects important to China, which are not covered in the ISA rules, for example national stakeholder consultations during an EIA process.

4.2.1 Strategic Management

Integrated Oceans Management (IOM) is an approach that brings together relevant actors from government, business and civil society and across sectors of human activity to assess the interactions and importance between major marine uses, e.g. fisheries, tourism, oil and gas, and potential future industries like mining and bioprospecting. The aim is to see that benefits from marine sectors can be maximised, and negative impacts on ocean or human health can be minimised. An IOM process for a given area will typically include:

- scoping phase where status reports on relevant parts of the environment and socioeconomic aspects are developed;
- assessment phase for environmental and socioeconomic impact from the various activities and sectors. The assessments should also take into consideration external factors like climate change and pollution from other sources;
- aggregated analyses of total environmental impacts and identify gaps in knowledge.

The balance between use and protection is the fundamental question which needs to be addressed when an IOM is developed. Scientific data can only provide objective answers, and some of the answers associated with spatial planning are value based. As such, the development of IOM for an area also requires a development and maturation of conservation goals and objectives as well as the goals and objectives of multiple (and potentially conflicting) industries.

For activities within the EEZ, China would be responsible to manage an IOM process, for activities beyond national jurisdiction, the coordinator is the ISA.

The ISA has commenced this process through a programme of developing regional environmental management plans (REMPs). An initial plan was adopted in 2012

(ISBA17/LTC/7), for the Clarion-Clipperton Fracture Zone (CCZ). The CCZ plan is currently under review, and the ISA has initiated a process to develop REMPs in the other regions where there are currently exploration activities under ISA contracts, namely the northern mid Atlantic ridge, the Indian Ocean, the North-West Pacific and the South Atlantic.

The current plan for CCZ provides relevant value-based guidance as foundation for the plan, including common heritage of mankind, precautionary approach, protection and preservation of the marine environment, prior environmental impact assessment, conservation and use of biodiversity and transparency. The plan identifies nine large 'Areas of Particular Environmental Interests' (APEIs), which have been declared by the ISA as off-limits for exploration or exploitation activities. It is also stated that the future exploitation should be sustainable, and impacts needs to be assessed in a holistic way.

The ISA REMP process is due to be formalised by a Council decision, but to date appears to involve: firstly conducting an assessment of the region's environment via existing data (and identifying data gaps), and secondly developing site-specific environmental management measures within the region. This may include temporal or spatial restrictions on mining activities. The REMP may be a tool by which the ISA can manage cumulative environmental impacts from multiple mine sites, as well as compound impacts arising from mining when taken in conjunction with other marine uses or stressors taking place within the same region. However to do so, the data gaps would need to be addressed, and the ISA could take a leadership role in establishing strategic research priorities and encouraging. collaborative research initiatives.

4.2.2 Regulatory Management

For terrestrial mining, a number of international industry standards offer guidance to entities engaged in mining activities and specifically relating to environmental impacts. A high-level list of the concepts and issues that are considered best practice and relevant to regulating the DSM industry is provided below, taking examples or insight from previous marine and terrestrial industries (Gro Sustainability, 2017). It may be prudent to conduct a review of the ISA's guidelines, along with China-specific rules, to ensure the following elements of particular importance are captured in an appropriate manner.

(1) Regulator Planning and Policy Development:

- The use of regional environmental planning or strategic environmental planning tools to allocate areas for resource extraction (and other industry activities) before mining contracts are granted.

(2) Project Permitting and Planning Phase:

- Provision of clear guideline documents for critical aspects of the permitting and operational processes. At a minimum, formal guideline documents should be developed for baseline studies, the process and content of an EIA, the process for stakeholder engagement and the content of an EMMP. Further guidance on these elements is provided in the sections below.
- Formal processes for the assessment and approval of the EIA and EMMP documents, and (in the case of the EMMP) a process for the periodic review and update of the documents by the proponent to reflect the implementation of adaptive management practices in response to monitoring data trends;
- Development and maintenance of a risk management system including identification and management of risks at the EIA stage, and a risk-based approach in the EMMP that assists to focus efforts and financial resources on the highest risks;
- Outcomes-based conditions in environmental contract or permit documents which allow contractors the freedom to implement adaptive management, while prescribing clear compliance limits;
- The use of independent peer reviewers for both EIAs as well as operational environmental monitoring data, in order to build capacity in regulatory organisations and to demonstrate transparency;
- Transparent publishing of all regulatory documents including EIAs, independent reviews, and permit and contract documents;
- Formal stakeholder engagement processes that guide both proponent and stakeholders, and provide specific points for public comment throughout the EIA process, and into operations.

(3) Operations Phase:

- Outcomes based approach to adaptive management, allowing proponents the flexibility to implement various management strategies as long as the agreed outcome (or compliance condition) is met;
- Transparent publishing (and review) of operational environmental data, including annual environmental reports and monitoring reports;
- Guidelines for incident reporting and investigation, and transparent reporting in relation to incidents by both regulator and contractor;
- Regular auditing of operations by experienced, knowledgeable regulatory personnel or third-party experts;
- Use of satellite/AIS tracking and monitoring and other international shipping laws and regulations

- Formal and informal data sharing between industry and regulator, to develop capacity of regulatory bodies; and
- Training and guidelines for regulators to guide policy implementation.

(4) Closure phase:

- Clear closure objectives (as stipulated in the EIA) implemented in a manner that is observable and measurable;
- Closure monitoring and reporting (including three-yearly trend reporting) for the period stipulated in the EIA.

4.2.3 Recommendation for Baseline Studies

The purpose of gathering environmental baseline data for potential seabed mining projects is to define the biological, chemical, geological and physical environment in a resource area, and to enable the environmental baseline data to inform the assessment of impacts for mining projects as well as the determination of appropriate management measures and monitoring strategies to be implemented during operations. This is particularly essential for DSM projects given the lack of biological information available on deep sea ecosystems to date.

A robust environmental baseline allows both contractors and regulators a point of reference from which to monitor impacts, and from which to measure the success of recovery or rehabilitation.

With the purposes described above in mind, baseline data should be collected in a manner which provides:

- Sufficient chemical and physical environmental data to define the environmental conditions, seasonal influences and range of expected conditions to occur over an operational life which may span tens of years;
- Sufficient and adequate ecological data to facilitate a robust identification of key species, ecosystems and habitats in the impact area and more regionally, using a sampling regime appropriate for the scale of the proposed mining activity;
- Adequate regional context on genetic connectivity of, and similarity between, key communities in order to assist with the prediction of the significance of impacts;
- Quantification of ecological and physical parameters to the extent that the knowledge will support a robust impact assessment, including the development of robust and comprehensive predictive models, where relevant;
- Guidance on the spatial and temporal extent of sampling requirements for each environmental aspect relevant to the area and/or resource type.

The ISA (ISA, 2018) has provided some guidance on the baseline data requirements for oceanography, geology and biological communities. The document prepared by the ISA (ISA, 2018) also provides direction on specific baseline information required to be collected for the three main resource types (PMN, PMS and CRC). No guidance is provided for exploration of rare earth muds, although it may be inferred that both these resource types are similar to PMN in their environmental aspects and impacts.

In addition, there remain significant variances in the quality and quantity of baseline study data collected by Contractors in the Area, and presented to the ISA to date. In this respect, the issue of enforcement of a guideline may be equally as important as the development of a more robust guidance document on collection of baseline data.

4.2.4 Recommendations for EIA

The ISA is currently developing Standards and Guidelines for the conduct of an EIA and preparation of an Environmental Impact Statement for exploitation of seabed minerals in the Area. China may also wish to have its own guidelines (for any activities that occur within national jurisdiction, and/or to supplement the ISA's guidelines with China-specific rules for activities in the Area carried out by China's ISA contractors). It may be prudent to conduct a review of the ISA's guidelines, along with China-specific rules, to ensure the following elements of particular importance for DSM EIAs are captured in an appropriate manner.

- Instructions on the level of detail required outlining the activity or activities that are proposed, including sufficient detail of engineering aspects of DSM tools to enable an informed assessment of impacts;
- Detail on the extent and nature of baseline studies that are to be provided in support of the EIA (as described above), as well as the requirements for sampling in support of habitat mapping and genetic connectivity studies;
- An outline of the process of risk assessment required in support of the EIA, with particular regard to the uncertainties associated with DSM projects;
- An outline of the process required to identify impact sources and ecologically sensitive receivers, and an assessment of the extent to which baseline studies have reduced uncertainty in relation to ecologically sensitive receivers in the deep sea;
- An outline on the process to be undertaken in order to determine the extent, duration and significance of environmental impacts (both direct and indirect) that are likely to occur (from each source, and relative to each receiver), taking into account any uncertainties, and using a potential range or zone of impacts to account for uncertainties in predictions;

- Guidance on the development of site-specific trigger values which will provide quantitative management actions as particular environmental thresholds are reached (noting that thresholds for harm may vary between projects and between resources, so it is essential to ensure site-specific thresholds are developed in a robust manner);
- Guidance on the use of predictive modelling to support an assessment of environmental impacts (including hydrodynamic modelling and habitat modelling as described above);
- Guidance on the minimum requirements for elutriate testing and toxicity testing to be included in the EIA (as described above);
- Guidance on the development and description of management activities to be implemented in the event of exceedance of site-specific trigger values (which may also link to the development of compliance conditions as outlined below);
- An outline of the process involved in estimating and quantifying any residual impacts for the deep sea, including deep sea ecosystem services and function;
- Guidance on the development of draft compliance conditions to be included as commitments in the EIA and/or a Contractor's Plan of Work.

4.2.5 Recommendations for Stakeholder Engagement

Stakeholders for DSM projects are likely to include (but may not be limited to) Sponsoring State Government agencies, national non-government organisations, community groups and academic institutions, international organisations with jurisdiction over the high seas, industry groups and other users of the high seas, the ISA, specialist scientific bodies and international non-government organisations. In order for stakeholders to engage effectively throughout the EIA process, clear guidance is required on (Gro Sustainability, 2017):

- The rules relating to the advertising of public review periods and stakeholder engagement meetings, including the method of advertising and the length of time prior to an engagement activity that the advertisement must appear;
- The venues where EIAs must be deposited in hard copy for stakeholder perusal (this usually includes local or regional council offices, libraries, and places where members of the public can freely access hard copy documents, as well as prescribing specific websites where electronic copies must be available);
- The length of public engagement periods (usually proportionate to the level of assessment, so higher levels of assessment will attract longer public engagement periods); and

- The number, nature and location of meetings to be held (particularly useful when stakeholder meetings are required in major centres/capital cities as well as regional or local areas).

The most effective stakeholder processes are those that are guided by formal procedures or process maps, generated by the regulators to ensure the stakeholder engagement process is standardised for all proponents (Gro Sustainability, 2017).

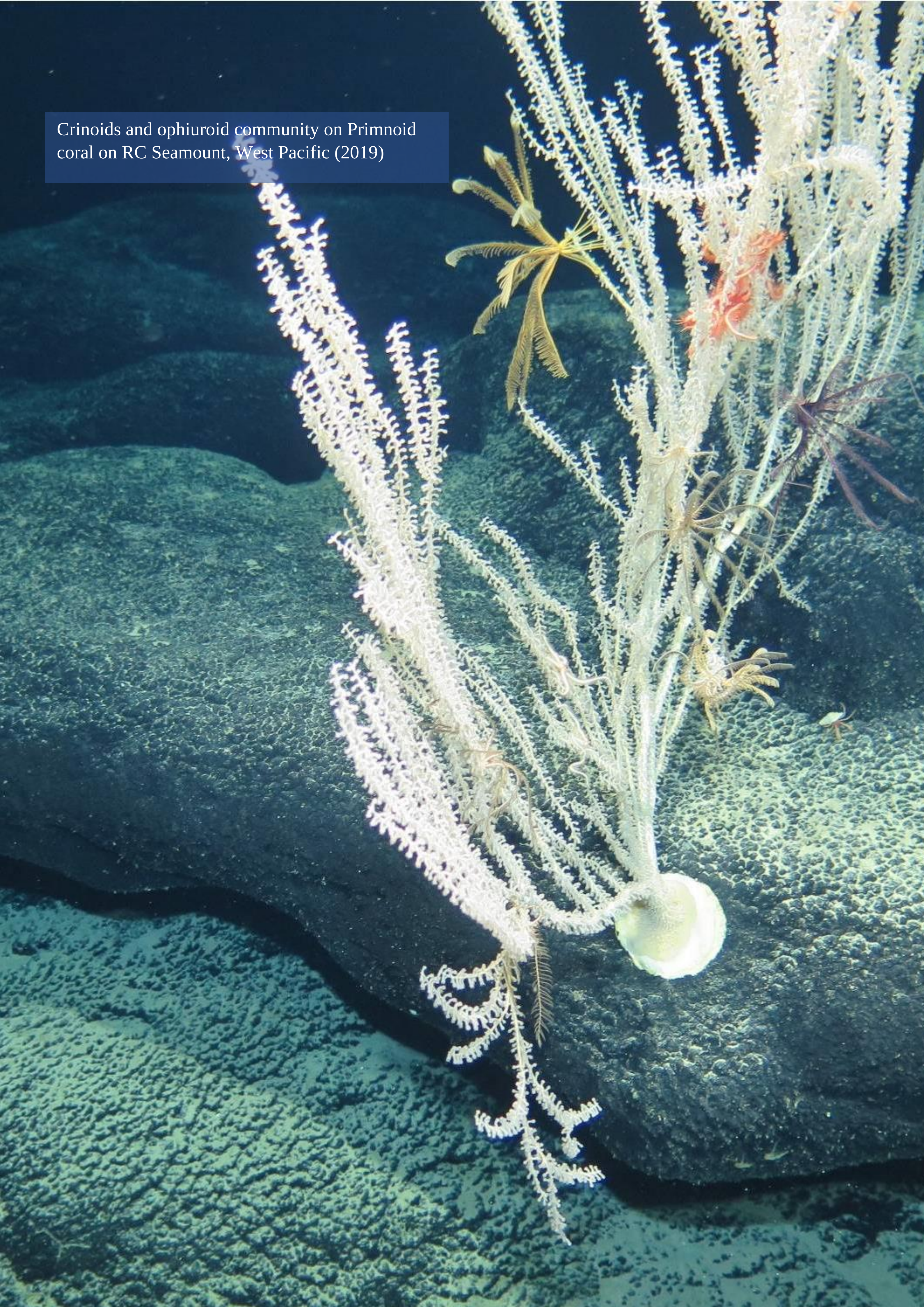
4.2.6 Recommendations for Environmental Monitoring

As with the EIA process, providing proponents with a guideline for the detail and structure of an Environmental Management and Monitoring Plan (EMMP) sets an expectation regarding the scope of these documents to facilitate approval, and enables stakeholders to understand what to expect when reviewing a proponent's management strategies.

It is beneficial for an EMMP guidance document to include direction on:

- Drafting both outcomes-based and management-based provisions. This refers to the requirement to deliver clear goals in relation to outcomes (which may relate to trigger or compliance levels in particular), as well as clear commitments in relation to environment management processes;
- Detailing processes by which adaptive management will be implemented (with reference to management-based conditions), as well as how this will be reported and communicated to ensure continuous improvement is carried out transparently;
- Detailed commitments for monitoring processes to be carried out during operations (either included as part of the EMMP or as a subsidiary plan) including what operational monitoring will be conducted, when, how and to whom it will be reported. Specifically, in relation to monitoring, the plan should:
    - Clearly define two phases of monitoring - firstly a short (e.g. 6 month) period of high intensity monitoring at the commencement of operations to allow fast adaptive management decision making and to gather sufficient data to validate any predictive models relied on in the EIA (known as validation monitoring), and then a more sustainable operational monitoring period once validation of potential impacts has occurred;
    - Incorporate biologically appropriate trigger levels into monitoring and compliance commitments (drawing on baseline environmental data such as genetic connectivity, toxicity and elutriate testing, and life cycle data for critical species);
    - Include near and far-field monitoring of both impact and reference areas;

  - Include annual monitoring commitments, as well as any relevant commitments over periods of longer duration (such as monitoring of regional ecosystem function every three years, etc.);
  - Include monitoring of both environmental aspects (such as benthic fauna biodiversity and abundance, ecosystem function, water quality, etc.) and impacts (such as plume extent and duration, sedimentation rates, bioaccumulation in pelagic fish, etc.);
  - Include a process for the periodic review of monitoring methodology and advancements in technology, to ensure the most appropriate and robust monitoring methods are being utilised;
- Stakeholder engagement associated with the development of EMMPs;
- Outlining of roles and responsibilities within the organisation that will implement the commitments contained in the EMMPs;
- Training requirements;
- Risk management and incident reporting;
- Process for reporting of environmental monitoring data, including details regarding annual environmental reports, and the process for independent review of monitoring results, if relevant;
- Process for review of EMMPs, as well as reporting on the commitments contained therein.



Crinoids and ophiuroid community on Primnoid coral on RC Seamount, West Pacific (2019)

ISA Session (2017)

All rights in the resources of the Area are vested in mankind as a whole, on whose behalf the Authority shall act.

——from Article 137 of the *United Nations Convention on the Law of the Sea*

5 GOVERNANCE

5.1 Governance in International Waters – Overview

5.1.1 Maritime Jurisdictions

The United Nations Convention on the Law of the Sea (UNCLOS) was adopted in 1982 and entered into force on 16 November 1994. UNCLOS divides the ocean space into separate jurisdictional areas and provides a legal framework for activities within those areas.

The ocean space extending from a State’s coastal baseline is divided into different zones of jurisdiction measured from baselines of coastal states, namely: the territorial sea (the first 12 nautical miles) and the Exclusive Economic Zone (EEZ, from 12 up to 200 nm). The seafloor underlying these zones is termed the ‘continental shelf’. The continental shelf may extend beyond 200 nm if certain geological and legal conditions are met. Collectively these zones all lie within the coastal state’s national jurisdiction. Coastal States enjoy sovereignty over resources in their territorial sea, and have sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources in their EEZ and on their continental shelf. These rights are exclusive: if the coastal State does not itself exploit its natural resources, no other party may undertake these activities without the express consent of the coastal State.

UNCLOS also establishes two zones beyond national jurisdiction (which together encompass 60% of the global ocean), namely:

- the ‘High Seas’ (the water column beyond national jurisdiction); and
- ‘the Area’ (the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction).

While the High Seas are open to all States, for the purposes of navigation or fishing for example (UNCLOS, Article 87), UNCLOS sets a more restrictive regime for the Area (UNCLOS Part XI). UNCLOS declares the seabed minerals of the Area to be ‘the common heritage of mankind’ (UNCLOS, Article 136; 1994 Agreement, Preamble, para. 2) and requires that mining in the Area should serve to benefit mankind as a whole, and that any economic benefits from mining in the Area should be shared equitably (UNCLOS, Article 140).

5.1.2 The ISA

An autonomous intergovernmental body, the ISA, is established by UNCLOS to organise and manage the seabed mineral resources of the Area on behalf of mankind as a whole (UNCLOS, Article 137(2)). The ISA also has the responsibility to protect the marine environment, and to protect human life (UNCLOS, Article 145 and 146). The powers of the ISA are conferred by UNCLOS and the authorisation of State Parties. The ISA shall have such incidental powers, consistent with UNCLOS, as are implicit in, and necessary for, the exercise of those powers and functions with respect to activities in the Area (that is: prospecting, exploration or exploitation).

According to UNCLOS, exploration or exploitation of seabed minerals in the Area can only be carried out:

- under a Plan of Work, agreed by way of a contract, with the ISA,
- by States or State-sponsored entities, and
- in compliance with rules set by the ISA.

The ISA comprises 168 members, namely the 167 nation States who are signatory to UNCLOS, and also the European Union. The ISA has so far issued thirty contracts for exploration. Five of those contracts have been issued to Chinese-sponsored entities (Appendix 8.2). Exploration involves scientific studies to assess the geological potential and develop an environmental baseline. It is a precursor to exploitation (seabed mining). No contracts for exploitation have yet been issued by the ISA.

5.1.3 Existing ISA Regulatory Instruments

The whole of the comprehensive set of rules, regulations and procedures of the ISA, sometimes known as the ISA's 'Mining Code', are being elaborated by the ISA progressively. Activities in the Area must be conducted in compliance with this Code. Between 2000 and 2011, the ISA adopted three sets of Regulations on prospecting and exploration, covering three different resource types (PMN, ISBA/6/A/18; PMS, ISBA/16/A/12; and CRC, ISBA/18/A/11). Exploration is conducted subject to the ISA's approval of a plan of work in the form of a contract. An exploration contract confers upon the contractor a 'preference and priority' among future applicants for exploitation (UNCLOS Annex III, Article 10). An exploration contractor's obligations include:

- providing training opportunities for personnel from developing States,
- implementing the exploration plan of work approved by the ISA,
- submitting annual reports to the ISA,
- collecting and submitting to the ISA environmental baseline data so as to enable a future assessment of the impact their activities may have on the marine environment, and
- preventing, reducing and controlling pollution and harm caused by its activities to the marine environment.

5.1.4 ISA Regulatory Instruments under Development

Nowadays, the activities in the Area are facing a crucial juncture of transition from exploration to exploitation. A consultation process on draft Regulations for exploitation commenced in early 2014. The negotiation of this text has featured as a priority item on the agenda of the ISA Council every year since then, and thus far six evolving iterations of the draft instrument have been published for discussion. The Draft Exploitation Regulations encompass: the issue of exploitation contracts by the ISA, rights and duties of contractors, protection and preservation of the marine environment, monitoring and enforcement by the ISA, information-gathering and handling, the payment regime for contractors, and other matters.

Even though the revised Draft Exploitation Regulations have made tangible progress , further improvements such as the balance of rights and obligations of all parties involved in the development of the resources of the Area, payment mechanisms, environmental issues, decision-making and inspection mechanisms, liability, and the development of standards and guidelines, still require study and discussion..

The ISA's Legal and Technical Commission (LTC) in 2017 had proposed a roadmap for adoption of the Regulations that showed a completion date of July 2020however the 2020 deadline was notably not referenced by member States at the most recent Annual Session of the Council, where progress on substantive matters was slow. Indeed, it is hard to envisage the Regulations being finalised and adopted within the early proposed deadline, given the infrequency of Council meetings, and because so many matters remain unresolved. Particularly contentious is the discussion around the royalty rates that would be payable by contractors when mining commences. A new approach to the further development of the Regulations has been established for 2020, via four inter-sessional working groups which are open to all stakeholders.

However, the absence of agreed Exploitation Regulations prevents applications for exploitation contracts. A number of pioneer nodule exploration contracts (including 3 sponsored by China), which have already once been renewed for a 5-year period between 2016 and 2017, are due to expire in 2021 and 2022. It is unclear what options would be available at that point for those contractors. Another exploration contract extension may be most likely.

The draft Exploitation Regulations are being developed concurrently with subsidiary instruments called 'Standards and Guidelines' that will set more detailed requirements for mining operations. The ISA has estimated that fifty such Standards and Guidelines are required. Six – which largely focus on parameters for environmental management

– have been identified as priority documents, which would need to be in place by the time of the adoption of the draft Exploitation Regulations. Expert working groups or consultants have recently been appointed by the ISA's LTC to develop first drafts of these instruments. The Council has also emphasised that these Standards – along with a set of draft over-arching environmental goals, objectives and principles – will require discussion and adoption by the Council; and China will have an opportunity to provide inputs via those discussions.

Phase 1 ISA Standards and Guidelines
The ISA Council in July 2019 requested the Legal and Technical Commission to prioritise development of the following six Standards and Guidelines documents, which it considered essential prerequisites to the adoption of the Exploitation Regulations: (1) Preparation and assessment of an application for the approval of a plan of work for exploitation. (2) Environmental impact assessments (EIA) and the preparation of an environmental impact statement (EIS). (3) Preparation of environmental management and monitoring plans (EMMP). (4) Development and application of environmental management systems (EMS). (5) Tools and techniques for hazard identification and risk assessments. (6) Guidelines for safe management and operation of mining support vessels.

Challenges to the development of these instruments are likely to include: ISA capacity and access to relevant expertise, scientific data gaps, and a need to achieve political consensus across the ISA's membership in order to adopt final drafts.

5.1.5 REMPs

Simultaneously, while working upon the regulatory instruments described above, the ISA is also focussing efforts to produce REMPs for the geographic regions in which there is exploration interest.

Members of the ISA have signalled that the adoption of such REMPs should be a prerequisite to the grant of any contract for Exploitation. The purpose of REMPs is to ensure the effective protection of the marine environment, a duty for the ISA set by Article 145 of UNCLOS. REMPs are likely to have 'policy' status at the ISA, rather than 'rule' or 'regulation' status. But certain aspects of REMPs are likely to be given legally binding force upon ISA organs, contractors and/or member States, for example a prohibition on mining or causing impacts within identified protected areas within the region, referred to by the ISA as 'Areas of Particular Environmental Interest' (APEIs).

5.1.6 ISA Sponsorship

Any contract issued by the ISA must either be held directly by a State agency or held by an entity which is sponsored by the State who effectively controls that entity (UNCLOS, Article 139(1) and 153(2)). This element of sponsorship is fundamental to the international regime, as it is designed to ensure that a State Party to UNCLOS has responsibility to the international community for the activities of any contractor to the ISA.

UNCLOS devised a parallel system of exploitation, allowing developing States special access rights to reserved areas within the Area.

A sponsoring State is required to adopt appropriate measures to exercise control over any seabed mineral activities under its jurisdiction, to secure compliance with international standards. The ITLOS Seabed Disputes Chamber issued an Advisory Opinion in 2011 to assist sponsoring States better understand their obligations. The Opinion indicated that UNCLOS provides for two tiers of legal duties for sponsoring States:

(1) ensure compliance (due diligence) obligations – wherein the sponsoring State must take "reasonably appropriate" measures to ensure its contractor's compliance with UNCLOS the rules of the ISA. This is a duty of conduct, which means that – where the State has taken "reasonably appropriate" measures the duty is discharged (regardless of whether or not the contractor does in fact go on to comply with the relevant rules).

(2) direct obligations arising from international law - which include:

- assisting the ISA set out in article 153, paragraph 4, of the Convention,
- applying the precautionary approach,
- employing best environmental practice,
- conducting an environmental impact assessment, and
- adopting measures to ensure the provision of guarantees in the event of an emergency order by the ISA for protection of the marine environment,
- providing recourse for compensation.

These obligations apply to States regardless of their individual wealth or capacity. If either of these categories of duty are *not* effectively discharged by the sponsoring State, and third-party or environmental harm is caused by the actions of the sponsored contractor, then the sponsoring State is liable for damages, alongside the contractor.

A first step in meeting the 'due diligence' obligation of a sponsoring State is to have domestic law in place that will bind a contractor to follow relevant UNCLOS and ISA standards and rules.

5.1.7 National Legislation on DSM

Around 15 States have adopted national legislation regulating DSM in the Area so far. These legislations can be divided into three "periods" (ISA, 2019). The first period refers to the legislation adopted in 1980s under the reciprocating States regime (RSR), which aimed at ensuring national rights and interests in DSM in the Area before the adoption of the UNCLOS by unilateral legislation. The first instrument of the RSR was the US Deep Seabed Hard Mineral Resource Act of 1980, Similar legislation was adopted by France, Germany, Italy, Japan, United Kingdom and Soviet Union. After the Adoption and entry into force of the UNCLOS, most of these legislations have been revised in order to keep consistency with the provisions of the UNCLOS. The second period refers to legislation adopted after the entry into force of the UNCLOS and before the issue of the advisory opinion of the Seabed Chamber of the ITLOS, including the legislation adopted by Russia, New Zealand and Czech Republic. The third period refers to legislation adopted or amended after the issuance of the Advisory Opinion of the Seabed Chamber of ITLOS in 2011, including the legislation by Belgium, Fiji, United Kingdom, Tonga, Tuvalu, Singapore, Nauru, China, Kiribati and France. These legislations have more or less drew on the Advisory Opinion, which will help State parties sponsoring activities in the Area better fulfil their responsibilities and obligations as sponsoring States.

To implement the national legislation on DSM, some States have also enacted relevant implementing rules and regulations. The United States adopted the DSM Regulations Affecting Pre-Enactment Explorers, DSM Regulations for Exploration Licenses, DSM Regulations for Commercial Recovery Permits and Guidelines for Obtaining Minerals other than Oil, Gas and Sulphur on the Outer Continental Shelf. The United Kingdom adopted the DSM (Exploration Licences) (Applications) Regulations and the DSM (Exploration Licences) Regulations. Japan adopted the Ordinance for Enforcement to implement its DSM Act. As the Comparative Study of the Existing National Legislation on DSM published by the ISA highlighted, "[a]s the roles and responsibilities of the Authority and sponsoring States are more clearly articulated, administrative procedures and measures may require updating to reflect any clarification in these respective roles." (ISA, 2019). Since the ISA continues to develop the exploitation regulations and relevant standards and guidelines, the existing national legislation on DSM may need further updated or revised in the future in order to comply with the exploitation regulatory framework of the ISA (ISA, 2019).

5.1.8 China's Deep Seabed Area Legislation

The Law of the People's Republic of China on Exploration for and Exploitation of

Resources in the Deep Seabed Area (Deep Seabed Area Law) was adopted on 26 February 2016, and entered into force on 1 May 2016. This is the first Chinese law specifically regulating relevant activities conducted in the Area by citizens, legal persons or any other organizations of China.

The Deep Seabed Area has 7 Chapters and 29 Articles, which cover general provisions, exploration and exploitation, environmental protection, scientific and technological research and resource investigation, supervision and inspection, legal liability and supplementary provisions. UNCLOS, rules, regulations and procedures of the ISA are transferred and followed by the Law, and the Advisory Opinion issued by the Seabed Disputes Chamber of the ITLOS is reflected. The law provides for good coordination among the activities of Chinese citizens, legal persons and other organizations, the activities of China as sponsoring State and those of the ISA. The doctrine of the Deep Seabed Area Law is based on personal jurisdiction, and it sets up comprehensive systems and rules concerning activities in the Area, including the development of marine scientific research, resources survey, resources exploration and exploitation as well as the protection of marine environment of the Area. Active supervision and inspection, and enforcement mechanisms, are established by the law.

The Deep Seabed Area Law provides that before filing an application with the ISA for exploration or exploitation, the relevant citizens, legal persons or other organization of China shall apply for permission to the department in charge of ocean affairs under the State Council, who shall review the information submitted by the applicant, and shall grant a permission and issue relevant documents if the application meets the requirements stipulated by the law. The law sets out obligations of a contractor including requirements regarding the protection of environment.

After the adoption of the Deep Seabed Area Law, the department in charge of ocean affairs under the State Council formulated a series of administrative measures in 2017, including Measures for the Administration of Licensing for Exploration and Exploitation of Resources in the Deep Seabed Area, Interim Measures for the Management of Samples for Exploration Exploitation of Resources in the Deep Seabed Area, and Interim Measures for the Management of Data for Exploration Exploitation of Resources in the Deep Seabed Area. Since the Deep Seabed Area Law is general in nature and lacks provision on regulating activities of exploitation, relevant implementation regulations still need to be developed in the future (which complement the ISA's regulations on exploitation), in order to establish fully China's domestic legal systems with respect of the Area.

5.2 Current Main Gaps in Governance

5.2.1 International Level

The ISA is tasked to 'organise and control' contractors to 'ensure compliance' with ISA rules, including those rules designed to deliver on the ISA's mandate to 'to ensure effective protection for the marine environment from harmful effects which may arise' from contracted activities in the Area (UNCLOS, Article 157 and 153(5)), 145. Much of the oversight authority within the ISA rests with the executive body of the ISA: its 'Council' comprising 36 member States. These States are elected in a number of different 'chambers', designed to represent different geographic regions and interests. These chambers include (UNCLOS, 1994 Agreement, Annex, section 3):

- major consumers or importers of metals found in the Area,
- the largest investors in DSM in the Area,
- major exporters of the relevant metals from land-based sources,
- developing countries with special interests (land-locked, geographically disadvantaged, islands)
- five regional geographic groupings (Africa, Asia-Pacific, Eastern Europe, Latin America and Caribbean, and Western Europe and Others).

China currently takes its Council seat as one of the four ISA members identified as major consumers.

The Council reports to the Assembly of all States Parties. Both organs meet annually (or more frequently when necessary: a twice-yearly Council meeting schedule has recently been instigated) at the ISA's headquarters in Kingston, Jamaica.

The ISA is supported by a Secretariat, also based in Jamaica, headed by a Secretary-General who is the chief administrative officer of the ISA, and required to support all ISA meetings in that capacity in all meetings of the Assembly, and to perform such other administrative functions as may be instructed.

Another key organ within the ISA is the LTC: this is a group of 30 experts currently, serving in their individual capacities, who meet bi-annually with responsibility to prepare recommendations and advisory inputs to the Council. The LTC's mandate includes the provision of recommendations on applications for ISA contracts, and preparing drafts of rules, regulations and procedures of the ISA, for Council consideration or adoption. The potential for a mining 'approval bias' at the ISA has been noted (Greenpeace, 2019; Pew, 2019), and the composition, election (due again in 2021), expertise and capacity of the LTC is often under scrutiny.

The fact that only three of the 30 commissioners currently in post have ecological science backgrounds, and the lack of practical offshore regulation experience, has been remarked upon as a particular challenge, given the ISA's environmental protection mandate, and the LTC's immediate task to review EIA reports, to develop environmental management plans, and to draft Regulations, standards, and guidelines pertaining to environmental management and thresholds. Criticisms of the LTC have also extended to a lack of transparency, and potential conflict of interests (Greenpeace, 2019; Ardron, 2018; Seascape, 2016). China currently has a member on the LTC, who is a geologist and engineer.

The ISA is mandated to oversee the development of the mineral resources in the Area while simultaneously ensuring the effective protection of the marine environment and preventing damage to biota: a challenging task. There is no other precedent of an international intergovernmental treaty body (with 168 members, each with their own political priorities and interests) attempting to act as a minerals licensing, environmental permitting, monitoring and enforcement, and revenue collection agency as is required of the ISA (French & Collins 2019). In addition, UNCLOS envisages an in-house mining wing of the ISA called 'The Enterprise' (UNCLOS, Article 170). When the Enterprise comes into existence, the ISA will be required to issue exploration or mining contracts to, and regulate, itself. These are functions that within national governments are usually performed by different agencies operating under separate mandates – often purposefully, to avoid conflict of interest, undue influence, or mission-drift.

The ISA faces constraints from:

- infrequency of meeting: the decision-making body of the ISA, the Council, meets for 1-week once or twice a year,
- lack of funding: the ISA's annual budget for 2017-2018 was in the region of US$17m, derived largely from individual member State contributions. Applicants pay a fee of US$500k designed to cover the costs of the application process, and contractors also pay a small annual fee ($60k). Approximately $2m of the ISA budget is spent annually on conference and interpretation services alone, and
- the fact that the same governments may be represented in the ISA's advisory body, decision-making organ, and mining contractor – presenting conflicts of interest that may be difficult to manage.

Different stakeholders have previously raised concerns about lack of due process and poor governance practice (Seascape, 2016; Ardron, 2018; Belgium, 2018; Germany, 2018). Noting the capacity limitations and other constraints of the existing ISA structures, several parties have called for better incorporation of science and external, independent expertise in the ISA's development of regulations, rules and procedures, and in its regulatory oversight of contracts (Pew, 2019). Indeed the ISA's capacity for monitoring and enforcement of contractor obligations is currently extremely limited.

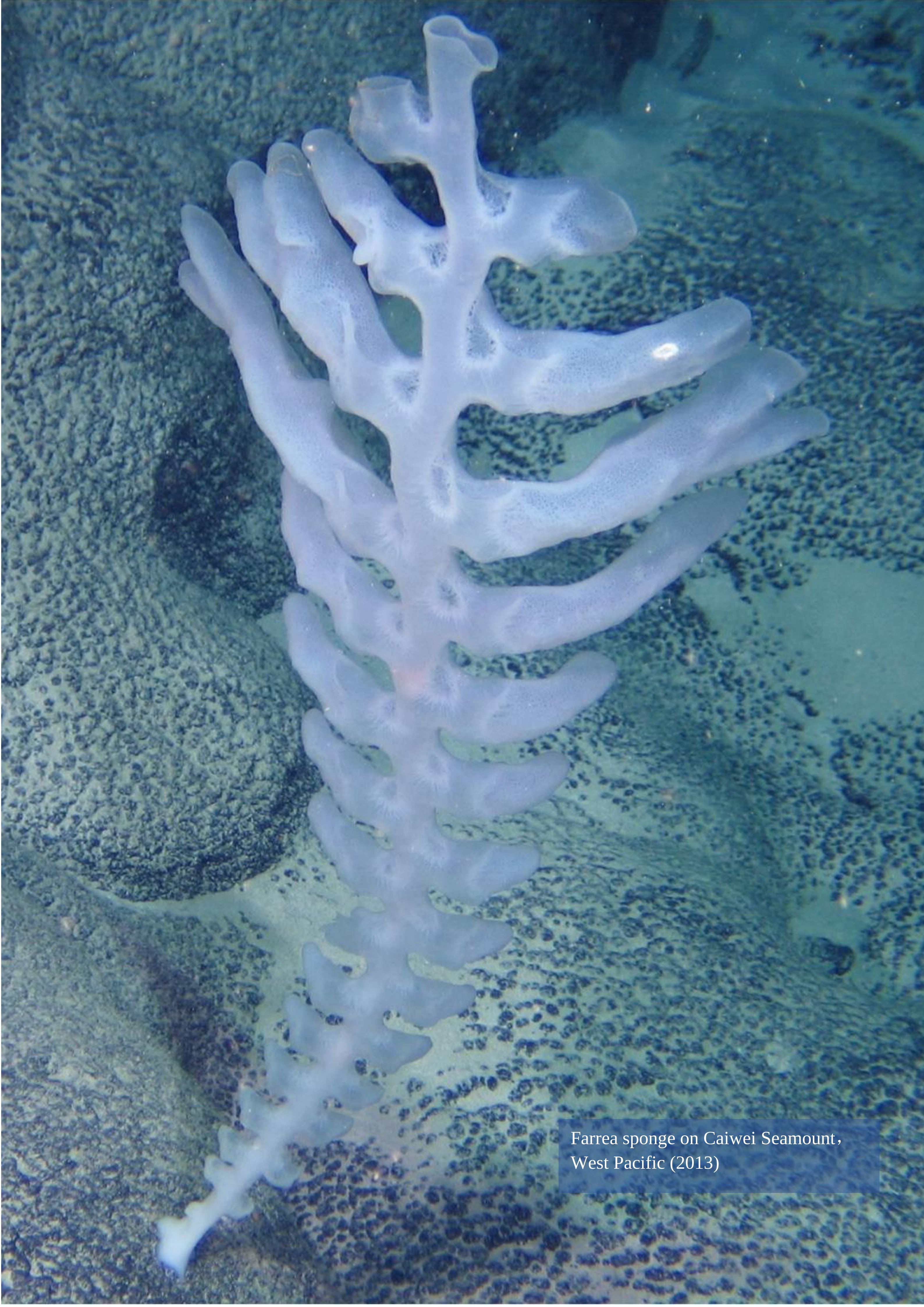
As noted above, the regulations for exploitation within the Area and a series of REMPs are under development at the ISA currently, and while there is a political push for these to be finalised by 2020, there appears to be a large amount of work still required to reach agreement around all necessary elements of the regime. A particular challenge may be the lack of scientific information needed to develop meaningful environmental standards, or to enable robust evidence-based decision-making by the ISA.

5.2.2 National Level

A benefit of the sponsoring State regime is that there will be sanctions and penalties that a State can enforce for non-compliance (e.g. civil and criminal penalties) which are outside of the ISA's mandate. A potential drawback of the sponsoring State regime is that it is currently rather unclear how the ISA's role in regulating activities in the Area fits alongside the sponsoring State's role. In other words, there is a risk of double-regulation, and/or regulatory lacunae between the national and the international regimes. There is also a liability gap, in the event that harm is caused to the environment or a third-party, despite the ISA, contractor and sponsoring State all complying with their respective legal duties (ITLOS Advisory Opinion, Craik et. al., 2018).

The creation of adequate legislative frameworks by States, while essential, is not sufficient in itself: implementation through monitoring and enforcement of the rules created are also crucial (UNCLOS, Article 214 and 215). Strong institutions are particularly important to the oversight of seabed mining activity; legal, fiscal and environmental matters will all require dedicated public administration capacity. Provision should also be made for independent oversight and public notification of, and participation in, decision-making.

China's three sponsored ISA contractors are State-owned enterprises, and so there is no question about the UNCLOS-required relationship of 'effective control' between China and its contractors, though it may be questionable for some of the other sponsoring State – private sector contractor arrangements (Rojas, 2019).



Farrea sponge on Caiwei Seamount，
West Pacific (2013)


SUSTAINABLE DEVELOPMENT GOALS
1 NO POVERTY
2 ZERO HUNGER
3 GOOD HEALTH AND WELL-BEING
4 QUALITY EDUCATION
5 GENDER EQUALITY
6 CLEAN WATER AND SANITATION
8 DECENT WORK AND ECONOMIC GROWTH
SUSTAINABLE DEVELOPMENT GOALS
7 AFFORDABLE AND CLEAN ENERGY
9 INDUSTRY, INNOVATION AND INFRASTRUCTURE
10 REDUCED INEQUALITIES
11 SUSTAINABLE CITIES AND COMMUNITIES
12 RESPONSIBLE CONSUMPTION AND PRODUCTION
13 CLIMATE ACTION
14 LIFE BELOW WATER
15 LIFE ON LAND
16 PEACE, JUSTICE AND STRONG INSTITUTIONS
17 PARTNERSHIPS FOR THE GOALS

6 THE OCEAN AND THE UN SUSTAINABILITY DEVELOPMENT GOALS

In 2015 all member states of UN adopted a plan for achieving a better future for us all, and laying out a path towards 2030, to end extreme poverty, fight inequality and injustice, and protect our planet. At the heart of “Agenda 2030” are the 17 sustainable development goals which clearly defines the world we want and give guidance on also how we need to develop existing and new business to support the development in the right direction. Mining for DSM could affect (either adversely or positively) progress by China towards achievement of a number of the 17 Sustainability Development Goals (SDG) which were adopted by the UN member states in 2015as a central element in the 2030 agenda for Sustainable development (https://sustainabledevelopment.un.org/). The list below is a description on how we see DSM may interact with the SDGs, some of them in a potentially positive way, while others in a potentially negative way.

#5 – Gender equality

DSM is a new business and as it evolves there should be a mandate from the outset to develop equal opportunities for both men and women in all areas of the industry, including research, technology development and future DSM operations. Setting goals for gender equality, and requiring policies for anti-discrimination and anti-harassment should be part of the early development plans for business entities which enter this segment. On-vessel facilities and policies should make relevant accommodation for different genders.

#7 – Affordable and clean energy

Development of, such as, copper, manganese, cobalt, nickel, silver, and zinc and rare earth minerals, could help meet the rising demand for minerals green energy technologies in a low carbon economy.

#9 – Industry, innovation and infrastructure

Similarly, a new metal supply from DSM could assist with infrastructure development -including transport, irrigation, energy and information and communication technology – are crucial to achieving sustainable development and empowering communities across the globe.

The research required for DSM development could also have spill over effects into other areas, e.g. increased understanding of marine ecosystems and ecosystem services, new technology on sub-sea operations and communications systems and marine genetic resources.

#11 - Sustainable cities and communities

Projections point strongly in the direction that more people will live in cities in the future. One important aspect is to fight the increasing air pollution within cities. There is a rapid increase in electric vehicles for city transport, and the demand also for base metals like copper is expected to increase as well. As stated above, metals from DSM can contribute to providing these metals.

#12 - Responsible consumption and production

This SDG focuses on the need to "do more, and better, with less". The world economy needs to develop according to the ideas of a circular economy where less material is added into the economy. Opening a new region of the earth to be exploited to source DSM, appears to run counter to this goal. Opening up a new metal supply chain from the deep-sea may actually disincentivise investment in innovations designed to reduce metal demands (e.g. recycling, product design, consumer behaviour).

#13 – Climate action

Metals supplied from DSM can play an important role in the energy shift, when the world is increasing its effort in increasing its renewable energy supply. However further research is required to understand is the inter-play between deep-sea mining and climate change (e.g. whether there is a risk of disrupting ocean-based carbon sequestration, or other concerns about further impacting an ocean already under climate-induced stresses).

#14 – Life below water

"Every second breath we take comes from the ocean. Connected to all life on this planet, the ocean is our greatest global common, uniting both people and nations. How we protect and manage the ocean will determine much of our success towards delivering the Sustainable Development Goals by 2030, and businesses that are connected to the ocean have a critical role to play." (UNGC, 2019)

Ocean health is facing many challenges, including loss of biodiversity, discharge of chemicals and other types of pollutant, as well as the effects of climate change. According to the Intergovernmental Panel on Climate Change (IPCC) special report "The Ocean and Cryosphere in a Changing Climate" that was presented in September 2019 all people on earth depend directly or indirectly on the ocean and the frozen parts of the planet.

To be able to harvest even more from the Ocean in the future we need to take better care of it than we currently do, and development of sustainable ocean management –

including precautionary governance of DSM activities - is necessary towards reaching the SDGs.

Possible positive contribution from DSM towards the SDG goal #14 could be the increase in global knowledge and scientific understanding of the deep sea environments that will be provided as a result of exploration and exploitation programmes.

#15 – Life on land

Some DSM proponents promote deep-sea mining as means to reduce the pressure on land-based mining. When designing and planning a DSM operation actions to avoid or minimise impact from the land-based process of the operation should be taken.

#17 – Partnerships for the goals

For the world to become successful with the sustainable development agenda it requires partnerships between governments, the private sectors and civil society.

The DSM industry can facilitate such a partnership where private companies cooperate with academic institutions as well as governmental organisations, both at the international (ISA) level and on national levels. A central part of this will be transparency of data and the willingness to share data and knowledge across sectors and national boundaries.

Sponge ground on Caiqi Seamount, the West Pacific (2013)

7 RECOMMENDATIONS

The recommendations presented below comes out of the discussions in the various sections of the document. The recommendations are organised and presented on a higher and more generic level in the Executive summary of this document, while we here present the more detailed description.

7.1 Improvement of Environmental Management System

Recommendation 1 (engage with development of environmental rules): China should actively engage with ISA regarding development of Regulations, Standards and Guidelines, specifically towards environmental baseline, EIA, and EMMP development, in accordance with the specific guidance provided in section 4.2 above.

Recommendation 2 (further improve national legislation): China may review and update the Deep Seabed Area Law in order to comply with the new requirement of the exploitation regulatory framework developed by the ISA within the context of the domestic legal system, to deal more specifically with future exploitation activities, including financial terms, inspection and management, and indemnities to ensure the State is properly protected. Based on the assessment China may seek to develop additional regulations to supplement the ISA requirements, drawing on the concepts of sound environmental management described in section 4.2 above.

7.2 Filling Gaps in Environmental Understanding and Technology

Recommendation 3 (strengthen scientific understanding and grasp key technologies): China should aim to improve the understanding of, and better assess both the risks and opportunities associated with DSM as well as exploitation of NGH. This includes (but is not limited to) (1) strengthening environmental data collection in important marine areas to improve the understanding of deep-sea ecosystems; (2) developing environmentally critical technologies concerning environmental monitoring, EIA, safe operations and environmental restoration; (3) actively promoting the development of environmentally friendly solutions to key technical problems for exploration, exploitation and transportation of deep-sea mineral resources and natural gas hydrates.

Recommendation 4 (improve the understanding for NGH): China should aim to improve the understanding of, and better assess both the risks and opportunities associated with NGH exploitation. China should improve the existing estimate methods of hydrate occurrences, geographical distribution and depth profile, as well as better understanding the dynamics of the hydrate formation inventory and ecosystem dynamics under changing environmental conditions.

7.3 Expanding Value Chain and Promoting Circular Economy

Recommendation 5 (expand value chain): China should seek opportunities for Chinese industry to engage at all levels of the DSM value chain, including research, exploration, exploitation, equipment manufacturing, technology design and mineral processing. This should include emission reduction targets for DSM activities (including noise, CO_2, and pollutants).

Recommendation 6 (promote circular economy): China's DSM policies should proactively support the intentions described in SDG #12, where the ambition of creating a circular economy is embedded in the design from the beginning of the design and concept phase and that "all" collected materials are fully utilized while waste streams are minimised. In addition, should NGH exploitation be deemed environmentally and economically feasible, China should promote the development of carbon capture and storage to accompany the development of hydrate extraction technologies that enable NGH to become a "bridge fuel" towards a low carbon future.

7.4 Creation of Cooperative, Transparent Mechanisms and Platforms

Recommendation 7 (enhance data sharing): Seabed mineral contractors should be encouraged to share widely through globally and publicly accessible databases all environmental data acquired through DSM research programmes. China should play a leading role in establishing good practice for quality control, data sharing and transparency.

Recommendation 8 (conduct collaboration): China should strengthen international cooperation, especially bilateral and multilateral cooperation and exchanges, including jointly contributing to the development of cooperation mechanisms and platforms, jointly building open markets, and jointly promoting marine technology exchanges.

7.5 Enhancement of Leadership Towards the ISA and Active Support of the UN SDGs

Recommendation 9 (support the UN SDGs): China should actively relate to the UN SDGs when further maturing the business case for DSM, such as contribution towards # 14 - life below water and #5 - gender equality in education and training for DSM professionals within geology, engineering and environmental technology, including through mandatory anti-discrimination policies for Chinese seabed mining contractors, including with regards on-vessel conditions.

Recommendation 10 (enhance the leadership towards the ISA): China should continue to initiatives to strengthen ISA as a regulator, and actively engage with ISA. It includes:

- China should consider strategically which Chamber within the ISA's Council it occupies, and take opportunities for convening group discussions as well as take political leadership both within thematic groups and within its geographic group (Asia-Pacific);
- China could showcase at the international level, for example by establishing a working group, its domestic sponsorship law and share information about the relationship between State and contractor in China's example in order to set a precedent for other countries and show leadership around a good model for State sponsorship;
- China could establish a national network of deep-sea scientists, maritime lawyers and other interested stakeholders, drawing from industry, civil society and academia - as well as governmental institutions, and use this group for consultations and to inform its national positions on seabed mining;
- China should advocate at the Annual Sessions of the ISA for a more realistic time frame for development and completion of the 'exploitation regulations', allowing for: an inclusive, collaborative and thoughtful, expert-led and appropriately-paced development of the regulations, standards and guidelines for exploitation; the establishment of strategic research priorities and collaborative research initiatives; and the establishment of a strategy for broader stakeholder input at the domestic and international level;
- China should advocate for building of the regulatory capacity of the ISA – and securing appropriate funding to enable this – including (a) creation of an inspectorate and enforcement function, (b) developing environmental data management capabilities, and (c) properly staffing and resourcing the LTC so that it is competent to provide expert advice on environmental management matters.

Recommendation 11 (support REMP process): China should support a standardised, transparent and consultative REMP process at the ISA. This should include the establishment of a network of biologically representative, fully protected no-mining zones:

- across all ocean regions under the jurisdiction of the ISA;
- for the long term (or in perpetuity);
- prior to any (further) award of exploration or exploitation contracts;
- according to scientific principles, and ecological and social analyses; and
- by way of legally enforceable rules.

Swimming sea cumcumber on slope of north part of the South China Sea (2018)

REFERENCES

Ahlbrandt, T. S., Charpentier, R. R., Klett, T. R., Schmoker, J. W., Schenk, C. J. & Ulmishek, G. F., 2005, Global Resource Estimates from Total Petroleum Systems: AAPG Memoir 86. American Association of Petroleum Geologists, Tulsa

AMC Consultants, 2018, Preliminary Economic Assessment of the Solwara Project, Bismarck Sea, PNG. Technical Report Compiled Under NI-43101 on Behalf of Nautilus Minerals Niugini Ltd.

Amon, D. J., Ziegler, A. F., Dahlgren, T. G., Glover, A. G., Goineau, A., Gooday, A. J., Wiklund, H., & Smith, C. R., 2016, Insights into the Abundance and Diversity of Abyssal Megafauna in a Polymetallic-Nodule Region in the Eastern Clarion-Clipperton Zone. Scientific Reports, 6: 30492.

ANZECC/ARMCANZ, 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Volume 1. The Guidelines, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand

Ardron, J. A., Ruhl, H. A. & Jones, D. O. B., 2018, Incorporating Transparency into the Governance of Deep-Seabed Mining in the Area Beyond National Jurisdiction, Marine Policy, 89: 58 - 66

Baco, A. R., Etter, R. J., Ribeiro, P. A., von der Heyden, S., Beerlie, P. & Kinlan, B. P., 2016, A Synthesis of Genetic Connectivity in Deep-Sea Fauna and Implications for Marine Reserve Design, Molecular Ecology, 25: 3276-3298

Belgium, 2018, Belgian non-paper: Strengthening Environmental Scientific Capacity of the ISA, Document No. J3/AM/04.04.12.05/2018/10380

BGR, 2018, Environmental Impact Assessment for the Testing of a Pre-Prototype Manganese Nodule Collector Vehicle in the East German License Area (Clarion-Clipperton Zone) in the Framework of the European JPI-O Mining impact 2 Research Project

BMWi, 2016, Analysis of the Economic Benefits of Developing Commercial Deep Sea Mining Operations in Regions where Germany has Exploration Licences of the International Seabed Authority, as well as Compilation and Evaluation of Implementation Options with a Focus on the Performance of a Pilot Mining Test

Bors, E. K., Rowden, A. A., Maas, E. W., Clark, M. R., & Shank, T. M., 2012, Patterns of Deep-Sea Genetic Connectivity in the New Zealand Region: Implications for Management of Benthic Ecosystems. Plos ONE, 7(11): e49474

Boswell, R., Collett, T. S., Frye, M., Shedd, W., McConnell, D. R., & Shelander, D., 2012, Subsurface Gas Hydrates in the Northern Gulf of Mexico, Marine and Petroleum Geology, 34(1): 4-30

Boswell, W. R., Watkins, M. B., del Carmen Triana, M., Zardkoohi, A., Ren, R., & Umphress, E. E., 2012, Second-Class Citizen? Contract Workers' Perceived Status, Dual Commitment and Intent to Quit. Journal of Vocational Behavior, 80(2): 454-463

Canadian Environmental Assessment Agency (CEAA), 2013, Environmental Assessment Process Managed by the Agency, Accessed at http: //www. ceaa. gc.ca/Content/B/0/5/B053F859-4895-45A9-8A3A-E74CBE58912A/EA_processes.pdf

Cardno, 2016, An Assessment of the Costs and Benefits of Mining Deep-Sea Minerals in the Pacific Island Region: Deep-Sea Mining Cost-Benefit Analysis / Pacific Community. Suva, Fiji (SPC Technical Report SPC00035). https: //www.sprep.org/attachments/VirLib/Regional/deep-sea-mining-cba-PICs-2016.pdf

Chen, B., Yang, M., Zheng, J., Wang, D., & Song, Y., 2018. Measurement of Water Phase Permeability in the Methane Hydrate Dissociation Process Using a New Method, International Journal of Heat and Mass Transfer, 118: 1316-1324

Circone, S., Kirby, S. H. & Stern, L. A., 2005, Thermal Regulation of Methane Hydrate Dissociation: Implications for Gas Production Models, Energy and Fuels, 19(6): 2357-2363

Coffey Natural Systems Ltd., 2008, Environmental Impact Statement: Solwara 1 Project. Report prepared for Nautilus Minerals Niugini Limited

Commonwealth of Australia, 2013, Matters of National Significance: Significant impact guidelines. Accessed at https://www.environment.gov.au /system /files/ resources/42f84df4-720b-4dcf-b262-48679a3aba58/files/nes-guidelines_1.pdf

Craik, A. N., Ascencio-Herrera, A., Rojas, A., Brown, C., Tladi, D., Charles, E., Jarmache, E., Xue, G., Lily, H., Mackenzie, R., Roady, S. E. & Davenport, T., 2018, Legal Liability for Environmental Harm: Synthesis and Overview., Accessed at https://www.cigionline.org/publications/legal-liability-environmental -harm-synthesis-and-overview

CSIRO, 2008, Water and Sediment Characterisation and Toxicity Assessment for the Solwara 1 Project. Report Prepared for Coffey Natural Systems Pty Ltd. by CSIRO Land and Water Science

Dickens, G. R., ONeil, J. R., Rea, D. K., & Owen, R. M., 1995, Dissociation of Oceanic Methane Hydrate as a Cause of the Carbon Isotope Excursion at the End of the Paleocene, Paleoceanography, 10(6): 965-971

Dobrynin, V. N., Korobko, V. G., Severtsova, I. V., Bystrov, N. S., Chuvpilo, S. A., & Kolosov, M. N., 1980, Synthesis of a Model Promoter for Gene Expression in *Escherichia coli*, Nucleic Acids SymposiumSseries, 7: 365-376

Earth Economics, 2015, Environmental and Social Benchmarking Analysis of Nautilus Minerals Inc. Solwara 1 Project.

Eleanor, M., 1990, Crafting Selves: Power, Gender and Discourses of Identity in a Japanese Workplace, Chicago University

Environmental Protection Authority, Western Australia (EPAWA),2006, Gorgon Gas Development: Barrow Island Nature Reserve. Chevron Australia, Report and Recommendations of the Environmental Protection Authority, Bulletin No. 1221

Environmental Protection Authority, Western Australia (EPAWA), 2011, Environmental Assessment Guideline No. 7: Marine Dredging Proposals.

FAO, 2016, Integrated Ocean Management - Fisheries, Oil, Gas and Seabed Mining, by Melanie Torrie. Globefish Research Programme ,Vol 122, Rome

Fisher, R, Stark, C., Ridd, P. & Jones, R., 2017, Effects of Dredging and Dredging Related Activities on Water Quality: Spatial and Temporal Patterns. Report of Theme 4 – Project 4.2, Prepared for the Dredging Science Node, Western Australian Marine Science Institution, Perth, Australia

Fleming, J., Ford, L. & Hornsby, E., 2018, Facing the Abyss: The Future of Deep Sea Mining, Accessed at https://figshare.com/articles/FacingtheAbyssReport /7564 976 /1

French, D. & Collins, R. A., 2019, Guardian of Universal Interest or Increasingly Out of Its Depth? The International Seabed Authority Turns 25. International Organizations Law Review. Accessed at https://brill.com/view/journals /iolr/aop/ article-10.1163-15723747-2019011.xml

Gardner, J. V., Prior, D. B., & Field, M. E., 1999, Humboldt Slide — a Large Shear-Dominated Retrogressive Slope Failure, Marine Geology, 154(1-4): 323-338

Gerber, L. J. & Grogan, R. L., 2018, Challenges of Operationalising Good Industry Practice and Best Environmental Practice in Deep Seabed Mining Regulation, Marine Policy, doi:10.1016/j.marpol.2018.09.002

Global Sea Mineral Resources (GSR), 2018, Environmental Impact Statement: Small-Scale Testing of Nodule Collector Components on the Seafloor of the Clarion-Clipperton Fracture Zone and Its Environmental Impact.

Golder Associates (NZ) Limited, 2014, Marine Consent Application and Environmental Impact Assessment: Proposed Mining Operation, Chatham Rise. Report prepared for Chatham Rock Phosphate Limited

Gooday, A. J., Holzmann, M., Caulle C., Goineau, A., Kamenskaya, O., E., Alexandra A. -T. Weber, A. A., & Pawlowski, J., 2017, Giant Protists (Xenophyophores, Foraminifera) Are Exceptionally Diverse in Parts of the Abyssal Eastern Pacific Licensed for Polymetallic Nodule Exploration, Biological Conservation, 207: 106–116.

Greenpeace, 2019, In Deep Water: The Emerging Threat of Deep Sea Mining. Accessed at https://www.greenpeace.org/international/publication/22578/ deep-sea-mining-in-deep-water/

Gro Sustainability Pty Ltd., 2017, Regulating Extractive Industries: What Works in Practice? Practitioners' Perspectives on the Effective Implementation of Environmental Legislation. Report Prepared for The Pew Charitable Trusts

Hein, J. R., Morgenson, L. A., Clague, D. & Koski, R. A., 1987, Cobalt-Rich Ferromanganese Crusts from the Exclusive Economic Zone of the United States and Nodules from the Oceanic Pacific, Geology and Resource Potential of the Continental Margin of Western North America and Adjacent Ocean Basins - Beaufort Sea to Baja California, Circum~Pacific Council for Energy and Mineral Resources, Reston, USA

Hein, J. R., 2004, Cobalt-Rich Ferromanganese Crusts: Global Distribution, Composition, Origin and Research Activities, Minerals Other than Polymetallic Nodules of the International Seabed Area, ISA, Jamaica

Hewitt, J. E., 2014, Statement of Evidence of Judith Elaine Hewitt for Chatham Rock Phosphate Limited, Before the EPA: Chatham Rock Phosphate Marine Consent Application: In the Matter of the Exclusive Economic Zone and Continental Shelf (Environmental Effects) Act 2012 and in the Matter of a Decision-Making Committee Appointed to Consider a Marine Consent Application Made by Chatham Rock Phosphate Limited to Undertake Rock Phosphate Extraction on the Chatham Rise

Huang, L., Su, Z. & Wu, N. Y., 2015, Evaluation on the Gas Production Potential of Different Lithological Hydrate Accumulations in Marine Environment, Energy, 91: 782-798

ISA, 2002, Polymetallic Massive Sulphides and Cobalt-Rich Ferromanganese Crusts: Status and Prospects. ISA Technical Study No. 2, ISA, Kingston, Jamaica

ISA, 2012, Environmental Management Needs for Exploration and Exploitation of Deep Sea Minerals: Report of a Workshop Held by the International Seabed Authority in Collaboration with the Government of Fiji and the SOPAC Division of the Secretariat of the Pacific Community (SPC) in Nadi, Fiji, from 29-November to 2 December 2011, ISA Technical Study: No. 10, ISA, Kingston, Jamaica

ISA, 2013, 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, ISA, Kingston, Jamaica

ISA, 2018, Suggestions for Facilitating the Work of the International Seabed Authority, ISBA/24/C/18, ISA, Kingston, Jamaica

ISA, 2018, Suggestions for Facilitating the Work of the International Seabed Authority' Submission by Germany to the Council of the International Seabed Authority, ISBA/24/C/18, ISA, Kingston, Jamaica

ISA, 2019, Comparative Study of the Existing National Legislation on Deep Seabed Mining (Unedited Advance Text), ISA, Kingston, Jamaica

Jones, D. O. B., Kaiser, S., Sweetman, A. K., Smith, C. R, Menot, L., Vink, A., et al., 2017, Biological Responses to Disturbance from Simulated Deep-Sea Polymetallic Nodule Mining, PLoS ONE 12(2): e0171750

Kennett, J. P., & Stott, L. D., 1991, Abrupt Deep-Sea Warming, Palaeoceanographic Changes and Benthic Extinctions at the End of the Palaeocene, Nature, 353(6341): 225-229.

Kirchain, R., Roth, R., Field, F. R., Muñoz-Royo, C. & Peacock T., 2018, Report to the International Seabed Authority on the Development of an Economic Model and System of Payments for the Exploitation of Polymetallic Nodules in the Area.

Klauda, J. B. & Sandler, S. I., 2005, Global Distribution of Methane Hydrate in Ocean Sediment, Energy and Fuels, 19(2): 459-470

Knittel, K. & Boetius, A., 2009, Anaerobic Oxidation of Methane: Progress with an Unknown Process, Annual Review of Microbiology, 63: 311-334

Kvenvolden, K. A., Rapp, J. B. & Hostettler, F. D., 1988, Organic Geothermometry of Petroleum from Escanaba Trough, Offshore Northern California, Organic Geochemistry, 13(1-3): 351-355

Kvenvolden, K. A., 1988, Methane Hydrate - A Major Reservoir of Carbon in the Shallow Geosphere, Chemical Geology, 71(1-3): 41-51

Kvenvolden, K. A., 1993, Gas Hydrates - Geological Perspective and Global Change, Reviews of Geophysics, 31(2), 173-187

Leduc, D., Rowden, A. A., Torres, L. G., Nodder, S. D., & Pallentin, A., 2015, Distribution of Marco-Infaunal Communities in Phosphorite Nodule Deposits on Chatham Rise, Southwest Pacific: Implications for Management of Seabed Mining. Deep Sea Research I, 99, 105-118

Levin, L. A., Mengerink, K., Gjerde, K. M., Rowden, A. A., Van Dover, C. L., Clark, M. R., Ramirez-Llodra, E., Currie, B., Smith, C. R., Sato, C. N., Gallo, N., Sweetman, A. K., Lily, H., Armstrong, C. W. & Brider, J., 2016, Defining “Serious Harm” to the Marine Environment in the Context of Deep-Seabed Mining, Marine Policy, 74: 245-259

Lily, H., 2018, Sponsoring State Approaches to Liability Regimes for Environmental Damage Caused by Seabed Mining. Accessed at https: //www.cigionline.org/publications/sponsoring-state-approaches-liability-regimes-environmental -damage-caused-seabed

Lu, X., Zhang, X. & Wang, S., 2019, Advances on the Safety Related with Natural Gas Hydrate Exploitation, Scientia Sinica Physica, Mechanica & Astronomica, 49(03): 034602

Maaike, K., 2010, Scientific Advice in Integrated Ocean Management: The Process Towards the Barents Sea Plan, Marine Policy, 34(2): 252-260

Malinverno, A. & Pohlman, J. W., 2011, Modeling Sulfate Reduction in Methane Hydrate-Bearing Continental Margin Sediments: Does a Sulfate-Methane Transition Require Anaerobic Oxidation of Methane? Geochemistry, Geophysics, Geosystems, 12(7)

Martens, C. S. & Berner, R. A., 1977, Interstitial Water Chemistry of Anoxic Long Island Sound Sediments. 1. Dissolved gases. Limnology Oceanography, 22(1), 10-25

Maslin, M., Owen, M., Betts, R., Day, S., Dunkley, J. T., & Ridgwell, A., 2010, Gas Hydrates: Past and Future Geohazard? Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences, 368(1919): 2369-2393

Meyer, W. H., 1938, Yield of Even-Aged Stands of Ponderosa Pine. Technical Bulletins, 630

Mienert, J., Vanneste, M., Bünz, S., Andreassen, K., Haflidason, H., & Sejrup, H. P., 2005, Ocean Warming and Gas Hydrate Stability on the Mid-Norwegian Margin at the Storegga Slide. Marine and Petroleum Geology, 22(1-2): 233-244

Ministry for Economy, Trade and Industry (METI), 2017, World's First Success in Continuous Ore Lifting Test for Seafloor Polymetallic Sulphides. Accessed at https://www.meti.go.jp/english/press/2017/0926_004.html

Olsen, E., Holen, S., Hoel, A. F., Buhl-Mortensen, L. & Røttingen, I., 2016, How Integrated Ocean Governance in the Barents Sea was Created by a Drive for increased Oil Production, Marine Policy, 71: 293-300

Pabortsava, K., Purser, A., Wagner, H., & Thomsen, L., 2011, The Influence of Drill Cuttings on the Physical Characteristics of Phytodetritus. Marine Pollution Bulletin, 62(10): 2170-2180

Peacock, S. L., Mciver, C. M., & Monahan, J. J., 1981, Transformation of E. Coli Using Homopolymer-Linked Plasmid Chimeras. Biochimica et Biophysica Acta-Nucleic Acids and Protein Synthesis, 655(2): 243-250

Pew Charitable Trust, 2019, Fourth Report of the Code Project: Summary of Stakeholder Comments on the 2018 ISA Draft Regulations. Accessed at https://www.pewtrusts.org/en/research-and-analysis/white-papers/2019/02/fourth-report-of-the-code-project

Porskamp, P., Rattray, A., Young, M. & Ierodiaconou, D., 2018, Multiscale and Hierarchical Classification for Benthic Habitat Mapping, Geosciences, 8(4) :119

Purser, A., Marcon, Y., Dreutter, S., Hoge, U., Sablotny, B., Hehemann, L., Lemburg, J., Dorschel, B., Biebow, H. & Boetius, A., 2019, Ocean Floor Observation and Bathymetry System (OFOBS): A New Towed Camera/Sonar System for Deep-Sea Habitat Surveys, IEEE Journal of Oceanic Engineering, 44(1): 87-99.

Purser, A., Thomsen, L., 2012, Monitoring Strategies for Drill Cutting Discharge in the Vicinity of Coldwater Coral Ecosystems. Marine Pollution Bulletin 64 (11), 2309-2316

Reynders, D., Peeters, K. & De Backer, P., 2018, Statement by Belgium to the International Seabed Authority 22 June 2018. Accessed at https://www.isa.org.jm/document/statement-belgium-0

Rojas, A. S. & Phillips, F.-K., 2019, Effective Control and Deep Seabed Mining: Toward a Definition. Accessed at https://www.cigionline.org /publications/effective-control-and-deep-seabed-mining-toward-definition-1

RPS Australia West, 2017, A Comprehensive Peer Review of the Existing Modelling Undertaken for Chatham Rock Phosphate. Prepared for Chatham Rock Phosphate Ltd.

Rutqvist, J., Moridis, G. J., Grover, T., Silpngarmlert, S., Collett, T. S., & Holdich, S A., 2012, Coupled Multiphase Fluid Flow and Wellbore Stability Analysis Associated with Gas Production from Oceanic Hydrate-Bearing Sediments. Journal of Petroleum Science and Engineering, 92-93, 65-81

Sassen, R., Milkov, A. V., Roberts, H. H., Sweet, S. T., & DeFreitas, D. A., 2003, Geochemical Evidence of Rapid Hydrocarbon Venting from a Seafloor-Piercing Mud Diapir, Gulf of Mexico Continental Shelf. Marine Geology, 198 (3), 319-329

Seascape Consultant Ltd., 2016, Periodic Review of the International Seabed Authority pursuant to UNCLOS Article 154, ISBA/22/A/CRP.3 (2), ISA, Kingston, Jamaica

Sharma, R., 2017, Deep Sea Mining: Resource Potential, Technical and Environmental Considerations. Springer International Publishing.

Simon-Lledó, E., Bett, B. J., Veerle, A. I. H., Köser, K., Schoening, T., Greinert, J. & Jones, D. O. B., 2019, Biological Effects 26 Years After Simulated Deep-Sea Mining. Scientific Reports, 9: 8040

Spagnoli, G., Miedema, S, A., Herrmann, C., et al., 2016, Preliminary Design of a Trench Cutter System for Deep-Sea Mining Applications Under Hyperbaric Conditions, IEEE Journal of Oceanic Engineering, 41(4): 930-943

SPC, 2013, Deep Sea Minerals: Cobalt-Rich Ferromanganese Crusts, a Physical, Biological, Environmental, and Technical Review. Baker, E. and Beaudoin, Y. (Eds.) Vol. 1C, Secretariat of the Pacific Community

SPC, 2013, Deep Sea Minerals: Manganese Nodules, a Physical, Biological, Environmental, and Technical Review. Baker, E., and Beaudoin, Y. (Eds.) Vol. 1B, Secretariat of the Pacific Community

Spickerman, R. & Lockheed Martin Corporation, 2012, Rare Earth Content of Manganese Nodules in the Lockheed Martin Clarion-Clipperton Zone Exploration Areas. Offshore Technology Conference

Takaya, Y., Yasukawa, K., Kawasaki, T. et al., 2018, The Tremendous Potential of Deep-Sea Mud as a Source of Rare-Earth Elements. Scientific Reports, 8(1): 5763

Thaler, A. D., Plouvier, S., Saleu, W., Alei, F., Jacobson, A., Boyle, E. A., Schultz, T. F., Carlsson, J., & Van Dover, C. L., 2014, Comparative Population Structure of Two Deep Sea Hydrothermal-Vent-Associated Decapods (*Chorocaris* sp. 2 and *Munidopsis lauensis*) from Southwestern Pacific Back-Arc Basins. PloS ONE, 9(7). doi: 10.1371/journal.pone. 0101345

Trofimuk, A. A., Chersky, N. V., & Tsaryov, V. P., 1977, The Role of Continental Glaciation and Hydrate Formation on Petroleum Occurrence. The Future Supply of Nature-Made Petroleum and Gas, pp. 919-926, Pergamon Press, Oxford, UK

United Nations Global Compact (2019). Global Goals, Ocean Opportunities

van Nijen, K., 2018, Towards the Development of a Regulatory Framework for Polymetallic Nodule Exploitation in the Area, Marine Policy, doi:10.1016/j.marpol. 2018.02.027

Vanreusel, A., Hilario, A., Ribeiro, P.A., Menot, L., & Martinez-Arbizu, P., 2016, Threatened by Mining, Polymetallic Nodules are Required to Preserve Abyssal Epifauna. Scientific Reports, 6. doi: 10.1038/srep26808

Vrijenhoek, R. C., 2010, Genetic Diversity and Connectivity of Deep-Sea Hydrothermal Vent Metapopulations, Molecular Ecology, 19, 4391-4411

Wu, N., Huang, L., Hu, G., Li, Y., Chen, Q. & Liu, C., 2017, Geological Controlling Factors and Scientific Challenges for Offshore Gas Hydrate Exploitation, Marine Geology & Quaternary Geology, 37(5), 1-11

Zhang, H., Zhu, B., & Ren J., 2014, Progress in International Exploration of Rare Earth Resources, Mineral Deposits, (33), 1141-1142

DFF3 chimney (>360°C)，Longqi vent field in SWIR (2015)

APPENDIX

9.1 Abbreviations

Abbreviations	Full Names
ACP	African, Caribbean and Pacific
ANS	Alaska North Slope
ANZECC	Australian and New Zealand Environment and Conservation Council
APEI	Areas of Particular Environmental Interest
ARMCANZ	Agriculture and Resource Management Council of Australia and New Zealand
AUV	Autonomous Underwater Vehicle
BGR	German Federal Institute for Geosciences and Natural Resources (Bundesanstalt für Geowissenschaften und Rohstoffe)
BMWi	Federal Ministry of Economics and Technology (Bundesministerium für Wirtschaft und Energie)
CCICED	China Council for International Cooperation on Environment and Development
CCZ	Clarion-Clipperton Zone
CEAA	Canadian Environmental Assessment Act
CRC	Cobalt-rich Ferromanganese Crust
COMRA	China Ocean Mineral Resources Association
DCFM	Discounted Cash Flow Method
DSM	Deep Sea Mining
EEZ	Exclusive Economic Zone
EIA	Environmental Impact Assessment
EMMP	Environmental Management and Monitoring Plan
EPAWA	Environmental Protection Authority in Western Australia
ERR	Economically Recoverable Resource
GSR	Global Sea Mineral Resources
HOV	Human Operated Vehicle
IOM	Integrated Oceans Management
IPCC	Intergovernmental Panel on Climate Change
IRR	Internal Rate of Return
ISA	International Seabed Authority
ITLOS	International Tribunal for the Law of the Sea
JOGMEC	Japan Oil, Gas and Metals National Corporation

LTC	Legal and Technical Commission
MARR	Minimum Attractive Rate of Return
MCS	Monte Carlo Simulation
METI	Ministry of Economy, Trade and Industry
MIT	Massachusetts Institute of Technology
MOR	Mid-Ocean Ridges
NGH	Natural Gas Hydrate
NIOT	National Institute of Marine Technology
NGO	Non-Government Organisation
NPV	Net Present Value
OHI	Ocean Health Index
OMA	Ocean Mining Associates
OMI	Ocean Mining Inc.
PETM	Paleocene–Eocene Thermal Maximum
PMN	Polymetallic Nodule
PMS	Polymetallic Sulphide
REE	Rare Earth Elements
REMP	Regional Environmental Management Plans
ROV	Remotely Operated Vehicle
RPS	Global Professional Services
SDG	Sustainable Development Goals
SPC	Secretariat of the Pacific Community
SPS	Special Policy Study
STP	Standard Temperature and Pressure
TRR	Technically Recoverable Resource
UN	United Nations
UNCLOS	United Nations Convention on the Law of the Sea
UNGC	United Nations Global Compact
USD	US Dollar

9.2 Exploration Contracts

Table 1 Exploration Contracts for PMS

No.	Contractor	Commencement Date	Expiry Date	Sponsoring State	Location of Contract Area
1	COMRA	November 18, 2011	November 17, 2026	China	South-West Indian Ridge
2	Ministry of Natural Resources and Environment of the Russian Federation	October 29, 2012	October 28, 2027	Russian Federation	Mid-Atlantic Ridge
3	Government of the Republic of Korea	June 24, 2014	June 23, 2029	Republic of Korea	Central Indian Ocean
4	IFREMER	November 18, 2014	November 17, 2029	France	Mid-Atlantic Ridge
5	Federal Institute for Geosciences and Natural Resources (BGR)	May 6, 2015	May 5, 2030	Germany	Central Indian Ridge and South-East Indian Ridge
6	Government of India	September 26, 2016	September 25, 2031	India	Indian Ocean Ridge
7	Government of Poland	February 12, 2018	February 11, 2033	Poland	Mid-Atlantic Ridge

Table 2 Exploration Contracts for CRC

No.	Contractor	Commencement Date	Expiry Date	Sponsoring State	Location of Contract Area
1	Japan Oil, Gas and Metals National Corporation	January 27, 2014	January 26, 2029	Japan	Western Pacific Ocean
2	COMRA	April 29, 2014	April 28, 2029	China	Western Pacific Ocean
3	Ministry of Natural Resources and Environment of the Russian Federation	March 10, 2015	March 9, 2030	Russian Federation	Magellan Mountains in the Pacific Ocean
4	Companhia de Pesquisa de Recursos Minerais S.A	November 9, 2015	November 8, 2030	Brazil	Rio Grande Rise in the South Atlantic Ocean
5	Government of the Republic of Korea	March 27, 2018	March 26, 2033	Republic of Korea	East of the Northern Mariana Islands in the Pacific Ocean

Table 3 Exploration Contracts for PMN

No.	Contractor	Commencement Date	Expiry Data	Sponsoring State(s)	Location of Contract Area
1	Interocean Metal Joint Organization	March 29, 2001	March 28, 2021	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia	CCZ
2	JSC Yuzhmorgeologiya	March 29, 2001	March 28, 2021	Russian Federation	CCZ
3	Government of the Republic of Korea	April 27, 2001	April 26, 2021	Republic of Korea	CCZ
4	COMRA	May 22, 2001	May 21, 2021	China	CCZ
5	Deep Sea Resources Development Co., Ltd.	June 20, 2001	June 19, 2021	Japan	CCZ
6	IFREMER	June 20, 2001	June 19, 2021	France	CCZ
7	Government of India	March 25, 2002	March 24, 2022	India	Central Indian Ocean Basin
8	Federal Institute for Geosciences and Natural Research	July 19, 2006	July 18, 2021	Germany	CCZ
9	Nauru Ocean Resources Inc.	July 22, 2011	July 21, 2027	Nauru	CCZ (reservation)
10	Tonga Offshore Mining Limited	January 11, 2012	January 10, 2027	Tonga	CCZ (reservation)
11	UK Seabed Resources Ltd.	February 8, 2013	February 7, 2028	United Kingdom	CCZ
12	Global Sea Mineral Resources NV	January 14, 2013	January 13, 2028	Belgium	CCZ
13	Ocean Mineral Singapore Pte. Ltd.	January 22, 2015	January 21, 2030	Singapore	CCZ
14	Marawa Research and Exploration Ltd.	January 19, 2015	January 18, 2030	Kiribati	CCZ (reservation)
15	UK Seabed Resources Ltd.	March 29, 2016	March 28, 2031	United Kingdom	CCZ
16	Cook Islands Investment Corporation	July 15, 2016	July 14, 2031	Cook Islands	CCZ (reservation)
17	China Minmetals Corporation	May 12, 2017	May 11, 2032	China	CCZ (reservation)
18	Beijing Pioneer Hi-Tech Development Corporation	October 18, 2019	October 17, 2034	China	Western Pacific Basin