CBD

UNEP

Convention on Biological Diversity

Distr.
GENERAL

UNEP/CBD/SBSTTA/20/INF/69
14 April 2016

ENGLISH ONLY

Subsidiary Body on Scientific, Technical and Technological Advice
Twentieth meeting
Montreal, Canada, 25-30 April 2016
Items 4.3 and 4.4 of the provisional agenda*

DRAFT REPORT ON BIODIVERSITY IMPLICATIONS OF DEEP-SEA MINING ACTIVITIES

Note by the Executive Secretary

1. In decision X/29, the Conference of the Parties to the Convention noted an urgent need to further assess and monitor the impacts and risks of human activities on marine and coastal biodiversity, building upon the existing knowledge (para. 68) and requested the Executive Secretary to work with competent organizations which conduct marine assessments, including the United Nations General Assembly Regular Process for Global Reporting and Assessment of the State of Marine Environment including Socioeconomic Aspects, the Food and Agriculture Organization of the United Nations, the United Nations Environment Programme, the United Nations Educational, Scientific and Cultural Organization (UNESCO) -Intergovernmental Oceanographic Commission (IOC), the International Maritime Organization (IMO) and International Seabed Authority (ISA), and other relevant organizations and scientific groups, to ensure their assessments adequately address biodiversity concerns in marine and coastal commercial activities and management, and, as necessary, where gaps are found, work with these agencies to improve the consideration of biodiversity in assessments (para. 69). In the same decision, COP 10further requested Parties, other Governments, and other relevant organizations, to mitigate the negative impacts and risk of human activities to the marine and coastal biodiversity.

2. Pursuant to the above request, the Executive Secretary is circulating herewith, for the information of participants in the twentieth meeting of the Subsidiary Body on Scientific, Technical and Technological Advice, a report on biodiversity implications and deep-sea mining activities, prepared in partnerships with the Global Ocean Biodiversity Initiative through commissioning a consultancy, with financial resources from the Government of the Republic of Korea, as an information for participants at the Sustainable Ocean Initiative (SOI) National Capacity Development Workshop for Namibia (see the report in document UNEP/CBD/SBSTTA/20/INF/18). Since the workshop, the draft report has been further revised incorporating peer-review comments from the resource speakers who attended the Namibia workshop, as well as other relevant experts.

3. The information is provided in the form and language in which it was received by the Secretariat.

* UNEP/CBD/SBSTTA/20/1/Rev1.

Biodiversity implications of deep-sea mining activities

Prepared by

Philip Weaver, Seascape Consultants Ltd

For the Secretariat of the Convention on Biological Diversity

In partnership with the Secretariat of the Global Ocean Biodiversity Initiative

with contributions from:

Ashley Rowden, NIWA
David Johnson, Seascape Consultants Ltd
David Billett, Deep Sea Environmental Solutions Ltd
Kristina Gjerde, Wycliffe Management
Lisa Levin, Scripps Institution of Oceanography
Hannah Lily, Commonwealth Secretariat
Gordon Paterson, Natural History Museum, UK
Alison Swaddling, Pacific Community

April 2016

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Introduction

Seabed mining covers a variety of activities ranging from sand and gravel extraction in shallow and coastal waters, to the mining of diamonds, iron sands and phosphates in shallow and shelf areas, and the mining of base and precious metals in deep waters. This report focuses on the latter: deep-sea mining for polymetallic nodules, cobalt-rich crusts, polymetallic sulphides and phosphorite nodules. Deep-sea mining has become a prominent area of focus in recent years, but it has yet to take place on a commercial scale.

Base and precious metals are found both within and beyond areas of national jurisdiction, while phosphorite deposits are limited to deeper parts of continental shelves and upper slopes (Figure 1). It is important to note that States have exclusive rights to the resources up to 200 nautical miles from their coasts (also called the exclusive economic zone or "EEZ"), as provided under the UN Convention on the Law of the Sea (UNCLOS). Rights to the resources of the seabed may extend beyond the EEZ where an extended continental shelf has been agreed, but exploitation in this case is subject to revenue-sharing provisions under UNCLOS. The seabed beyond the extended continental shelf (i.e. the area beyond national jurisdiction) is known as "the Area" and is administered by the International Seabed Authority (ISA) and also subject to revenue-sharing under the principle of the Common Heritage of Mankind (Figure 2).

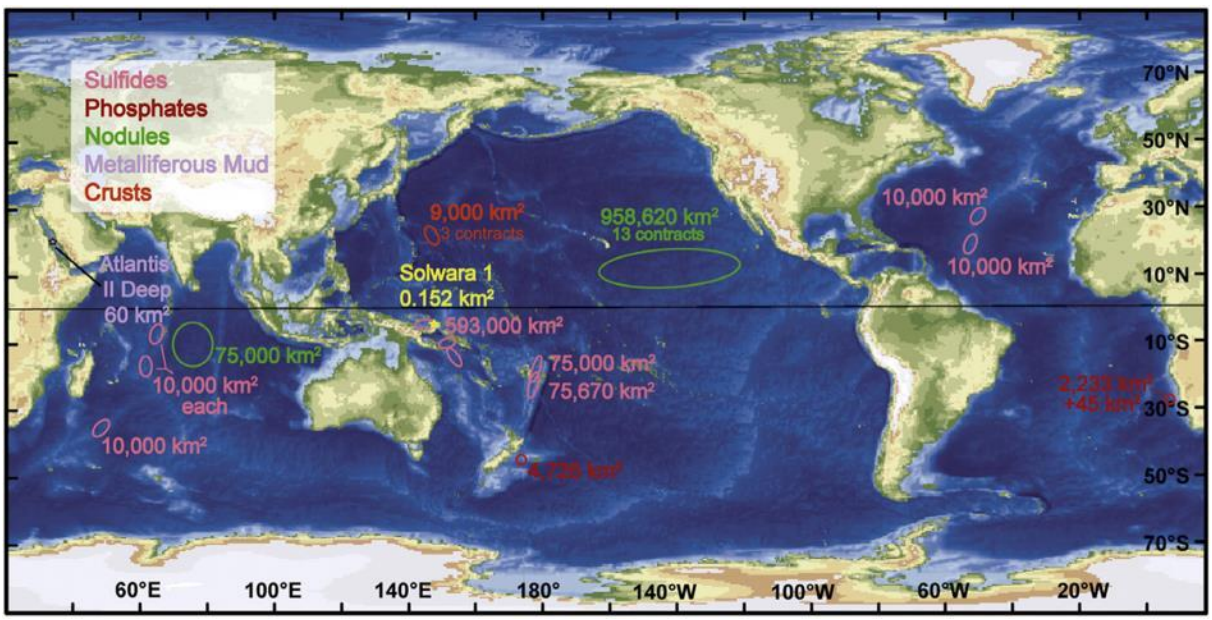

Figure 1: Map of current deep-sea exploration and mining contracts. Note that some marked areas comprise contracts for multiple countries/agencies; size of ovals not to scale. About half of the 1,843,354 km^2 of contracted areas are in exclusive economic zones and the other half are in the deep seabed beyond national jurisdiction. Yellow marks the only mining contract for seafloor massive sulphides (SMS) (from Hein et al., 2013).

Mining activities can be divided into prospecting, exploration and exploitation/mining, each of which may need a separate licence. The International Seabed Authority defines each activity as follows:

1. Prospecting: the search for deposits, including estimation of the composition, size and distribution of deposits and their economic values, without any exclusive rights.

2. Exploration: the search for deposits with exclusive rights, the analysis of such deposits, the use and testing of recovery systems and equipment, processing facilities and transportation systems, and the carrying out of studies of the environmental, technical, economic, commercial and other appropriate factors that must be taken into account in exploitation.

3. Exploitation: the recovery for commercial purposes of deposits and the extraction of minerals there from, including the construction and operation of mining, processing and transportation systems, for the production and marketing of metals.

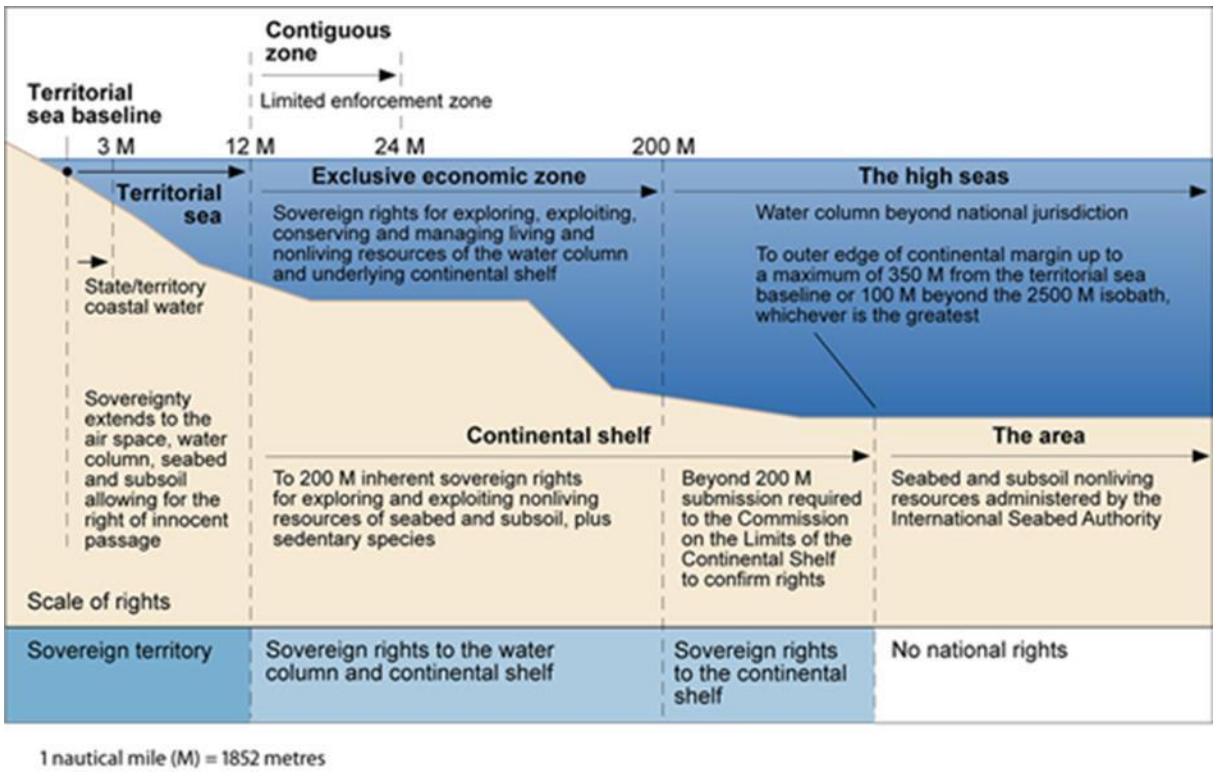

Figure 2: National and international areas of jurisdiction.
From http://laptop.deh.gov.au/soe/2011/report/marine-environment/1-1-jurisdictions.html

The ISA issued its first exploration licences in 2001 and between then and 2010 eight licences were approved. Since then fourteen more licences have been approved with five more waiting to be signed (Figure 3; Table 2). Of these 22 approved projects,, 14 concern the exploration of polymetallic nodules, five concern polymetallic sulphides and three the exploration of cobalt-rich polymetallic crusts; 13 of the exploration projects are located in the Clarion-Clipperton Zone (CCZ). The remaining projects are located in the Indian Ocean (4), the Atlantic Ocean (2) and the north-western Pacific Ocean (3). These 22 approved projects cover an area of more than 1 million km^2.

Each licence runs for 15 years, so the first licences are due for renewal in 2016. There have been no applications to the ISA for exploitation licences to date.

Within national jurisdiction, Papua New Guinea was the first country to issue an exploration licence in 1998 for polymetallic sulphides. Since then, many exploration licences have been issued by other

countries, such as: Solomon Islands, Vanuatu, Fiji, Tonga, Japan, and New Zealand. Further exploration licences remain under application. Currently there are only two granted exploitation licences world-wide: one issued in 2011 for a site under that first exploration licence in Papua New Guinea, and another in 2010 by the joint Saudi–Sudanese Red Sea Commission for a site in the Red Sea (for metalliferous mud). Exploitation at the Papua New Guinea site is expected to start in 2018, however development of the Red Sea site has been put on hold with no expected start date announced.

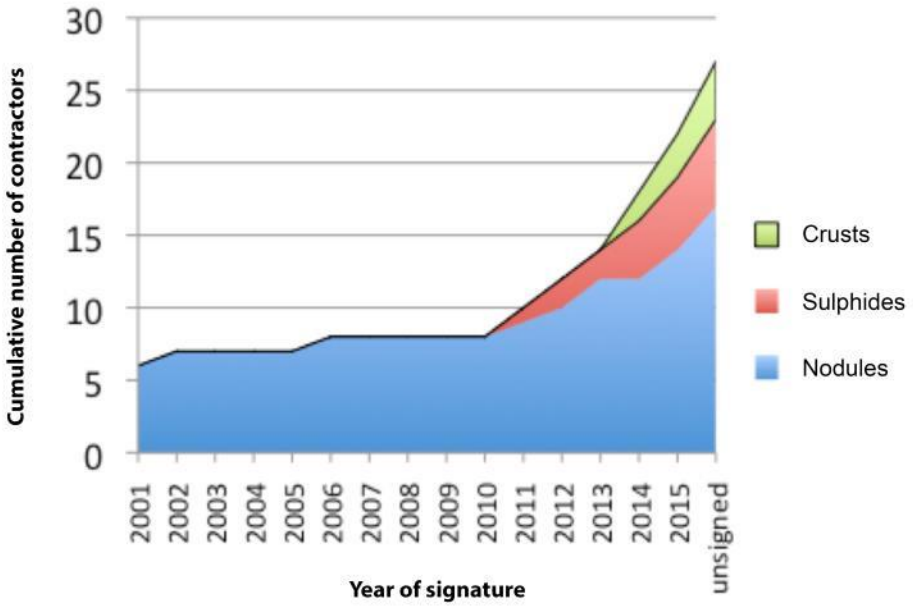

Figure 3: Cumulative number of contractors holding signed exploration licences with the International Seabed Authority. Figures correct as of July 2015 (ISA, 2015a).

Deep-sea mining is appealing to many countries, including small island developing States, as a means of economic development and revenue generation. This is particularly the case for States located in the south-west Pacific Ocean, which are particularly rich in deep-sea minerals. Many Pacific States are extremely interested in their deep-sea mineral potential and developing a deep-sea mining industry as they see this as a unique opportunity to, amongst other things, reduce reliance on international aid and alleviate poverty. There are some States who have adopted the ”watch and wait” approach to gain more information before deciding whether or when to engage with this new industry. The Pacific Community in collaboration with the European Union have established a project to help Pacific Island countries to improve the governance and management of their deep-sea minerals resources in accordance with international law. This project pays particular attention to the protection of the marine environment and securing equitable financial arrangements for Pacific Island countries and their people. Details of the project can be found at http://gsd.spc.int/dsm/

Deep-sea mining has been identified as one of the potential new sectors of blue growth by the European Union (ECORYS, 2012), driven by increasing demand for raw materials. This demand has arisen through a combination of factors, including increasing consumer demand in emerging economies, the development of new technologies that require increased supply of metals such as copper (e.g. much of the renewable energy sector) and issues related to security of supply (ECORYS, 2014; UNEP, 2014). At the same time, the grade of ore from land-based mines continues to decline with some of the largest mines such as the Chuquicamata mine in Chile having grades of 0.7 per cent copper, compared to more than 1.3 per cent in polymetallic nodules and potentially several per cent in polymetallic sulphide deposits. The prospect of working in deep water is also less of a challenge, as

potential crossovers with the hydrocarbon industry (which now routinely work in waters up to 3000 metres deep) could reduce technology development costs (e.g., for riser systems and pumps that are required to pump the ores from the seabed).

It has been claimed that deep-sea mining will have a lesser environmental impact than land-based mining. The reasons for this include: comparatively less new infrastructure is needed, such as road and rail links and the creation of mining villages in remote areas; there are no acid mine drainage problems; there are fewer layers of rock to remove and dispose of, and the ore is of a higher grade, requiring less mining per tonne of product. However, some types of deep-sea mining will impact large areas since many deposits form very thin surface layers. Many of the ecosystems that will be impacted are poorly known, often fragile or vulnerable, and many will be very slow to recover. Apart from the direct impact of the mining, sediment-laden and potentially toxic plumes will be generated that will extend the impact beyond the mined area. In addition, coastal processing plants may be built that could potentially release harmful materials into near-shore and coastal areas.

A large amount of literature has accumulated relating to mining for base and precious metals in the ocean, though there is very little related to phosphate mining. Recently there have been a number of reports summarising the economic and environmental aspects of deep-sea mining. The European Union-funded ECORYS report (ECORYS, 2014 – available at https://webgate.ec.europa.eu/maritimeforum/en/node/3732) gives an overview on the current and latest state of knowledge of deep-sea mining, with a focus on the potential from a geological perspective, the relevant technologies, the economic viability, environmental implications, the legal regime under which seabed mining operates, and an inventory of ongoing exploration and exploitation projects. In a separate exercise, the Pacific Community contracted UNEP/GRID-Arendal to conduct a state of knowledge assessment of the Pacific marine minerals. The results were compiled into five reports published in 2013 (available at http://gsd.spc.int/dsm/index.php/publications-and-reports), which cover geology, biology, environmental management, technological development and socio-economic aspects. Finally, Nautilus Minerals have made available through their website a large amount of information related to their progress towards mining base and precious metals in the Bismarck Sea off Papua New Guinea (http://cares.nautilusminerals.com/IRM/content/default.aspx). All these sources have been used extensively in this report.

Main deposit types

2.1 Polymetallic nodules

Polymetallic nodules are concretions formed on the seabed by precipitation of concentric layers of iron and manganese hydroxides around a core. They vary in size from microscopic to some tens of centimetres across, although most are between 5-10 cm in diameter, and they grow extremely slowly at rates of 5-10 mm/million years. Commonly they sit on the seabed, half buried in sediment, though they can also be found buried in the upper sediment layers. They vary in abundance and distribution, being limited to areas with very low sedimentation — typically deep seafloors between 4000 and 6500 metres water depth, and they are more common in the Pacific than other oceans where, exceptionally, they can cover up to 70 per cent of the seabed. The composition of nodules varies with their environment of formation, and in addition to manganese and iron, they can contain nickel, copper and cobalt in commercially attractive concentrations as well as traces of other valuable metals such as molybdenum, zirconium and rare earth elements. To be economically viable, nodules need to have an abundance of more than 15 kg/m^2 over areas of more than several tenths of a square kilometre.

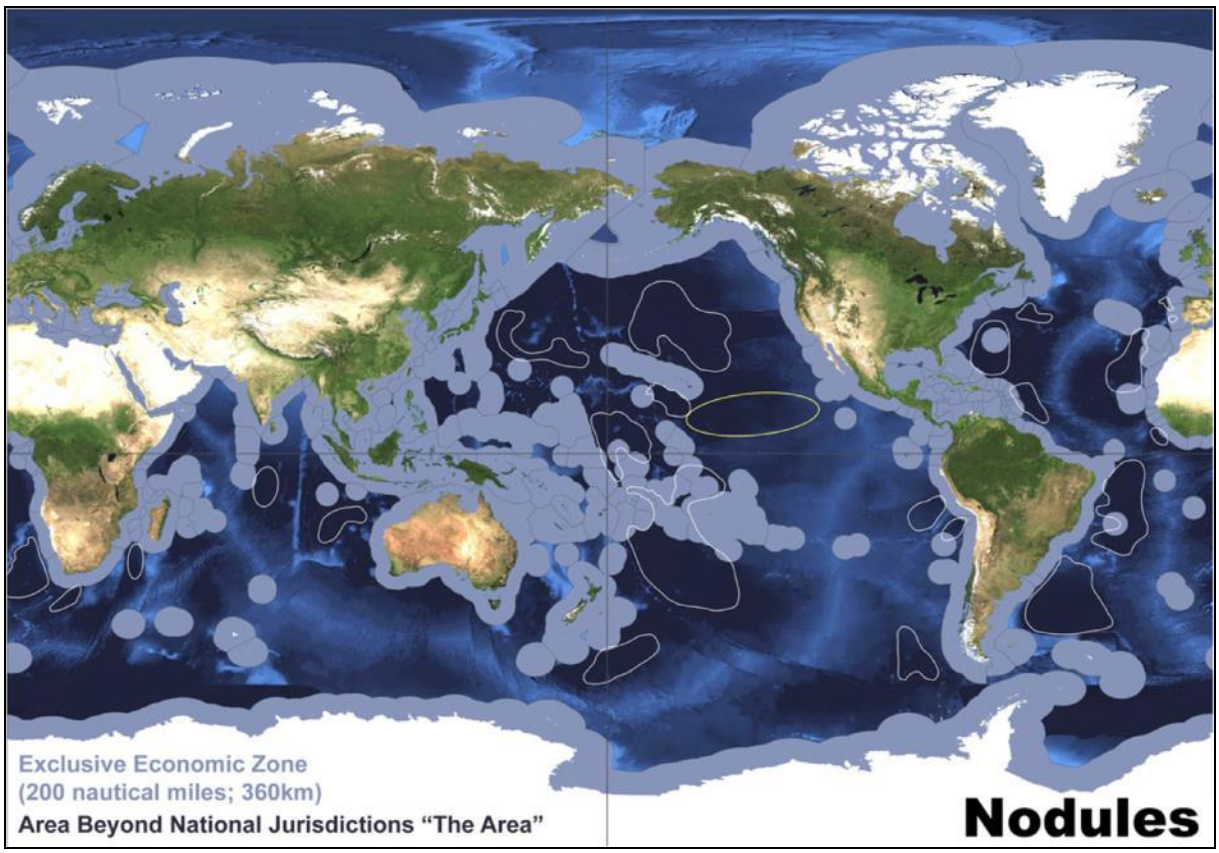

Figure 4: Map of global distribution of Exclusive Economic Zones (gray shading), areas beyond national jurisdictions (dark black-blue to pale gray-blue), and global permissive areas for development of abyssal plain polymetallic nodules; the Clarion–Clipperton Zone (CCZ) is the zone of greatest economic interest and is marked by a yellow line; all other areas are marked with a white line; a permissive area does not mean that economic nodule deposits will be found in that area. Small patches of scattered nodules will occur in other areas (from Hein et al., 2013).

Areas with commercial potential have been identified in the Pacific — the Clarion Clipperton Zone (CCZ), Penrhyn Basin near the Cook Islands and the Peru Basin (Figure 4) — and the Central Indian Ocean Basin. The CCZ has an area of approximately 12.1 million km^2, of which 1.39 million km^2 is within the EEZs of various nations (Morgan, 2012). The ISA have estimated that the CCZ contains a potential (inferred) resource of 62 billion tonnes of nodules, comprising 17,500 million tonnes of manganese, 761 million tonnes of nickel, 669 million tonnes of copper and 134 million tonnes of cobalt (ISA 2010a). The amount of copper contained in the CCZ nodules is estimated to be about 20 per cent of that held in global land-based reserves.

1.1.1. Current mining activity and prospects

The ISA regulations allow for claim areas to measure up to 150,000 km^2, although half of this area must be relinquished back to the Area within eight years. Alternatively, claims may be made for up to 75,000 km^2 with no relinquishment. Exploration contracts are awarded for a period of 15 years.

The ISA has signed 14 contracts for exploration of polymetallic nodules (Table 2) – 13 in the CCZ and one in the Central Indian Ocean (Figures 5 and 6) (information correct on 1 September 2015: also see ISA, 2015a). Most contractors have applied for close to the maximum area allowed, which is 75,000 km^2 (the UK Seabed Resources area occupies 58,000 km^2), giving a total of approximately 1,030,000 km^2 licensed for exploration. In addition, two further applications for exploration areas in the CCZ have been approved but not signed (information correct on 1 September 2015). No applications have been made to carry out exploitation of polymetallic nodules within the Area to date.

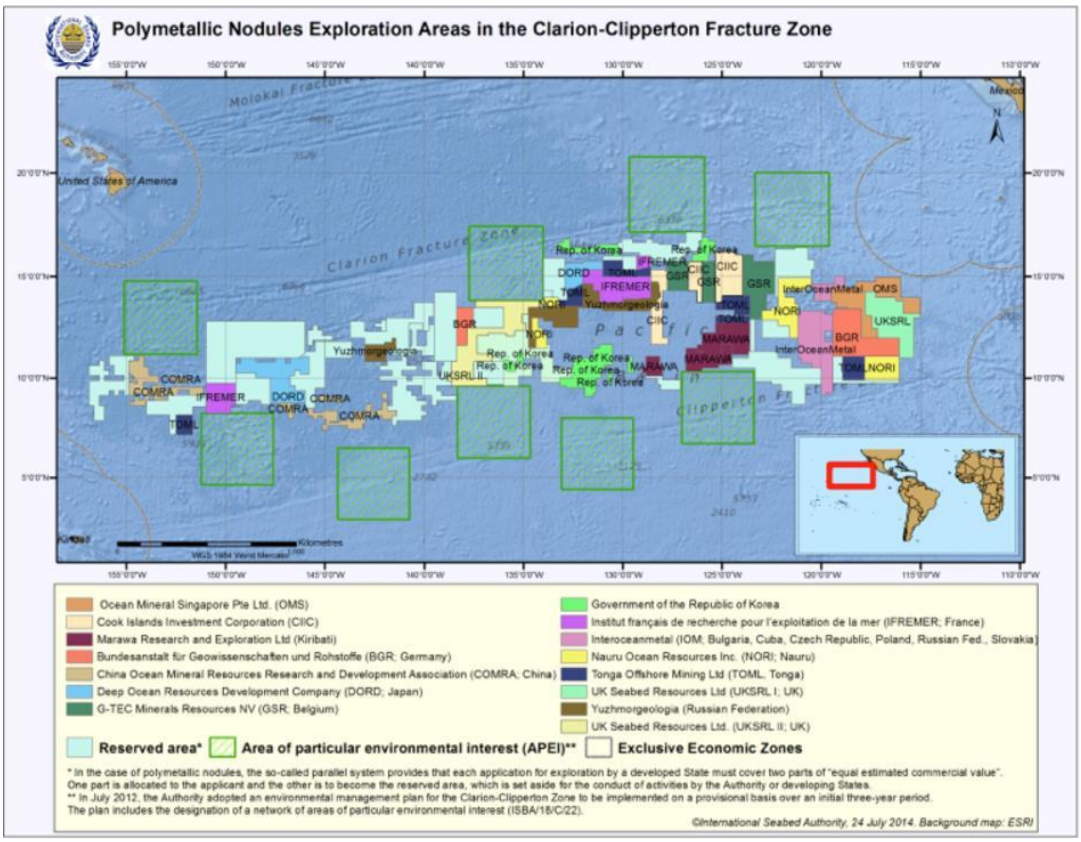

Figure 5: Areas licensed by the ISA for exploration of polymetallic nodules in the Clarion Clipperton Zone of the Pacific Ocean (From ISA).

There are no known areas that have been licensed for exploration or exploitation of polymetallic nodules within national jurisdiction. However, the Cook Islands initiated a tendering process for the exploration of polymetallic nodules within its EEZ on 10 August 2015, with a closing date for applications of 11 January 2016. Other potential areas in the Pacific are the two eastern island groups of Kiribati (Phoenix and Line) and to a lesser extent the Gilbert Islands (Kiribati) and also within the EEZ of Tuvalu and Niue (SPC, 2011).

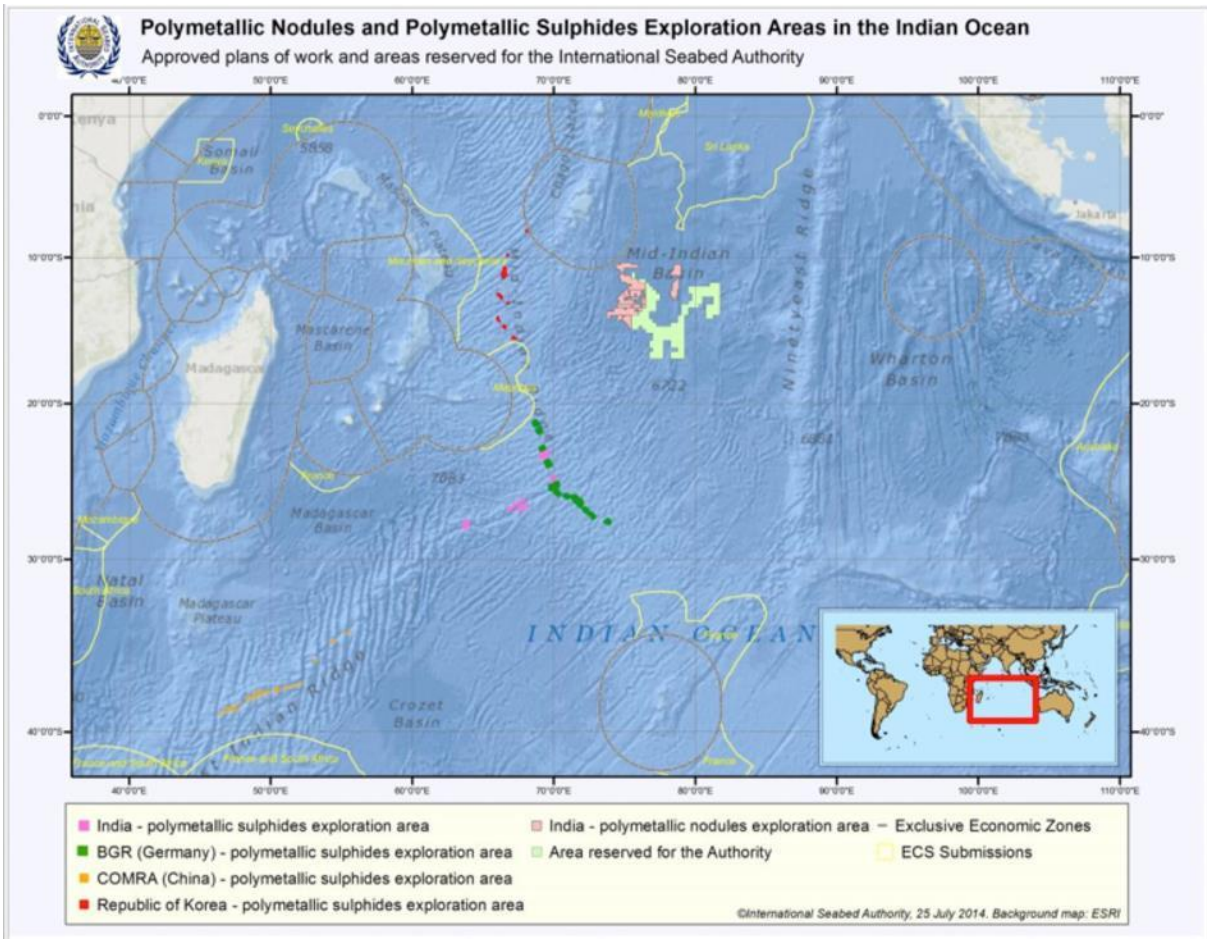

Figure 6: Areas licensed by the ISA for exploration of polymetallic nodules in the Indian Ocean (rrom ISA).

2.2 Cobalt-rich crusts

Cobalt-rich crusts (Figure 7) are formed on bare rock surfaces in the ocean by the precipitation of minerals from seawater at a rate of 1-5 mm per million years. Crusts form layers up to 25 cm thick and can extend for many square kilometres in water depths ranging from 400 to 4,000 metres. The thickest and most economically viable crusts form on the outer rims of the summits of seamounts and on saddles on their summits, in water depths ranging from 800 - 2,500 metres (Hein and Koschinsky, 2014). Other areas of any given seamount may have sediment cover and have no economic value. Cobalt-rich crusts of commercial interest are found predominantly in the Pacific (Figure 8) where there are an estimated 11,000 seamounts (57 per cent of the global total) and 41,000 knolls (Yesson et al. 2011, estimated from the latest global bathymetry).

The crusts are composed predominantly of iron and manganese oxides and hydroxides, but can contain commercially significant quantities of other metals such as cobalt, nickel, copper and platinum, plus rare metals such as tellurium, zirconium, bismuth, tungsten, niobium and some rare-earth elements. Cobalt-rich crusts in the central Pacific have been estimated to contain up to four times more cobalt, nine times more tellurium and 3.5 times more yttrium than the current land-based reserves of these metals (Hein and Koschinsky, 2014). The main minerals of interest are cobalt, copper and nickel, though rare-earth elements may also be recovered.

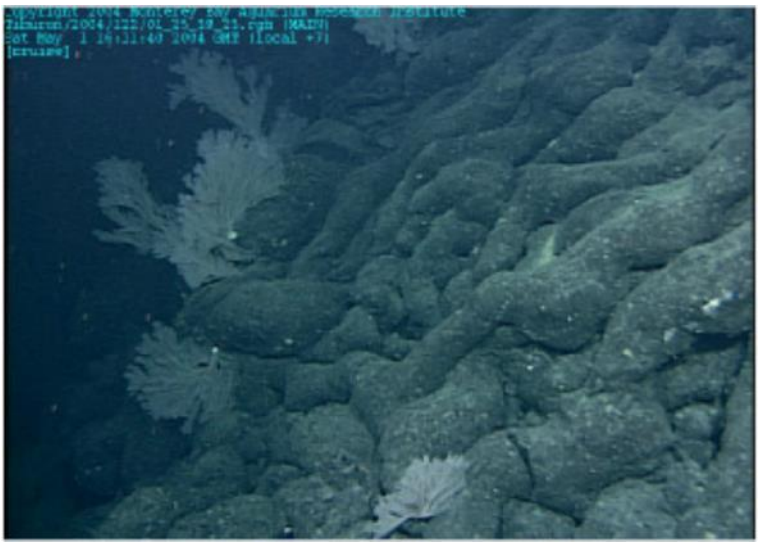

Figure 7: Manganese crust coating seafloor basalt. Image courtesy MBARI.

2.2.1 Current mining activity and prospects

The ISA regulations stipulate that contractors may claim a total exploration area of 3,000 km^2. This, however, must be reduced to 1000 km^2 over time. Each exploration block may measure no more than 20 km^2, but may be square or rectangular. A maximum of 150 blocks may form the claim, arranged in clusters of at least five contiguous blocks. The ISA regulations are based on a mining model analysis by Hein et al. (2009), who estimated that a total area of about 260 km^2 over a 20-year mining life span would yield 1 million wet tonnes per year of crust. Subsequently, He et al. (2011) suggested that a mine site would need to cover a total area of 1,214 km^2 to be profitable over the same period for the same yield.

The ISA has signed three contracts for exploration of cobalt-rich crusts all within the western Pacific (Figure 9; Table 2). One further application for exploration on the Rio Grande Rise, in the South Atlantic (Figure 10), has been approved but not signed (data correct 1 September 2015; also see ISA, 2015a).

As far as is known no licences have been granted for exploration in areas of national jurisdiction for cobalt-rich crusts, although the Republic of the Marshall Islands has significant prospects and is currently developing legislation with the expectation of issuing exploration licences in the future.

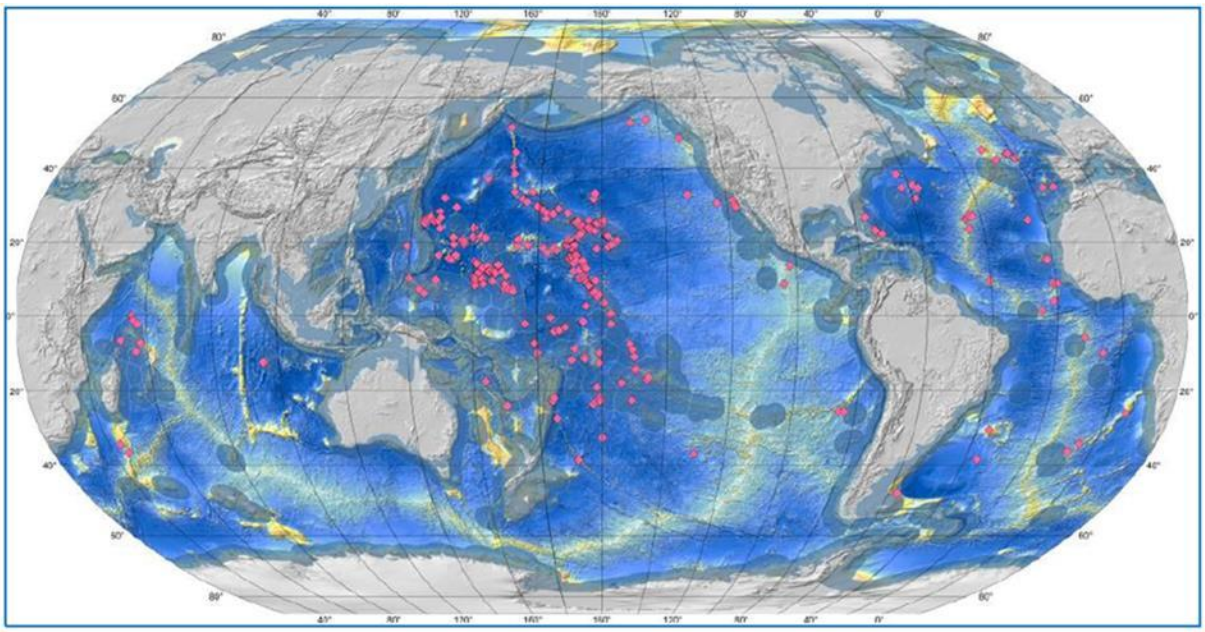

Figure 8: Location of polymetallic crust samples in the ISA database with Co concentrations above 0.5 wt. % (N=465) (from ECORYS 2014).

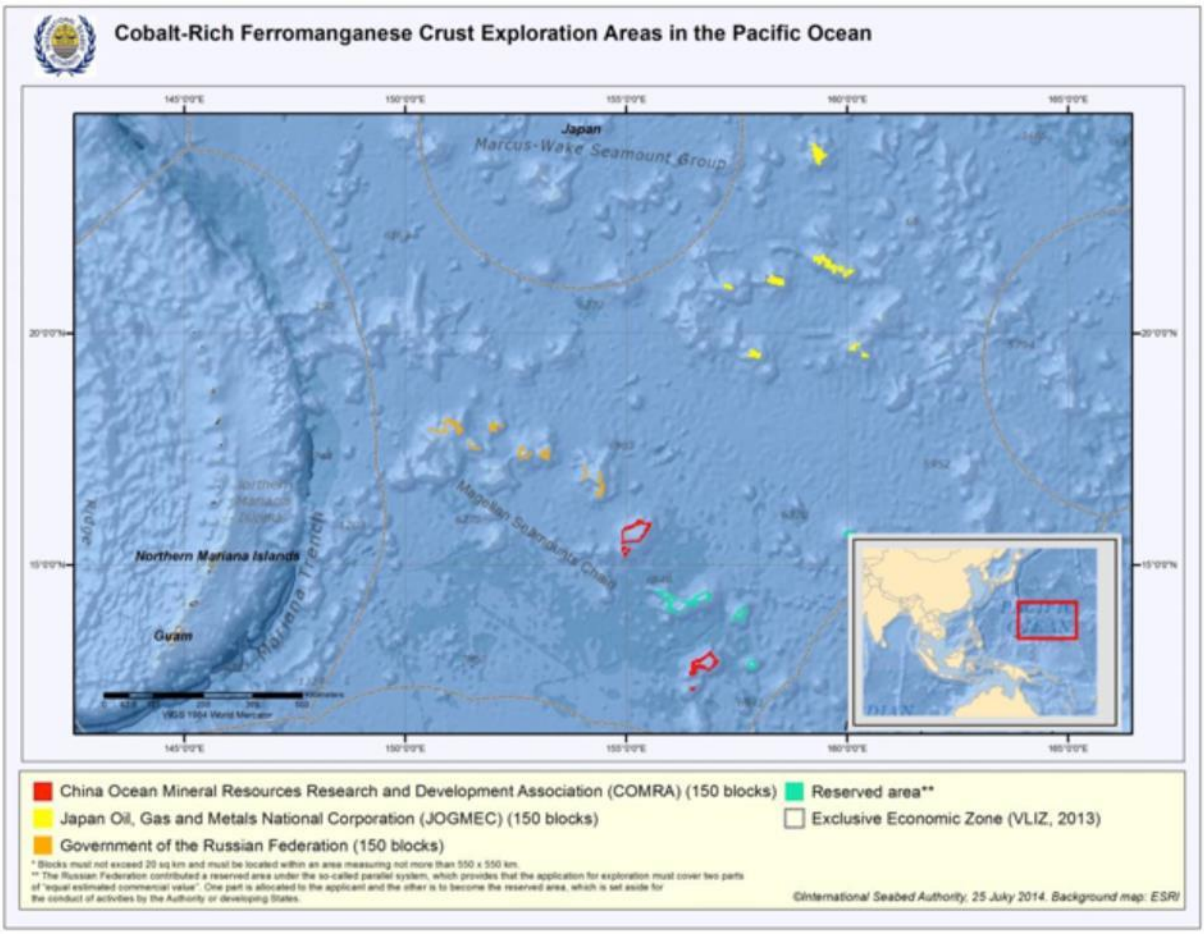

Figure 9: Areas licensed by the ISA for exploration of cobalt-rich crusts in the Pacific Ocean (From ISA)

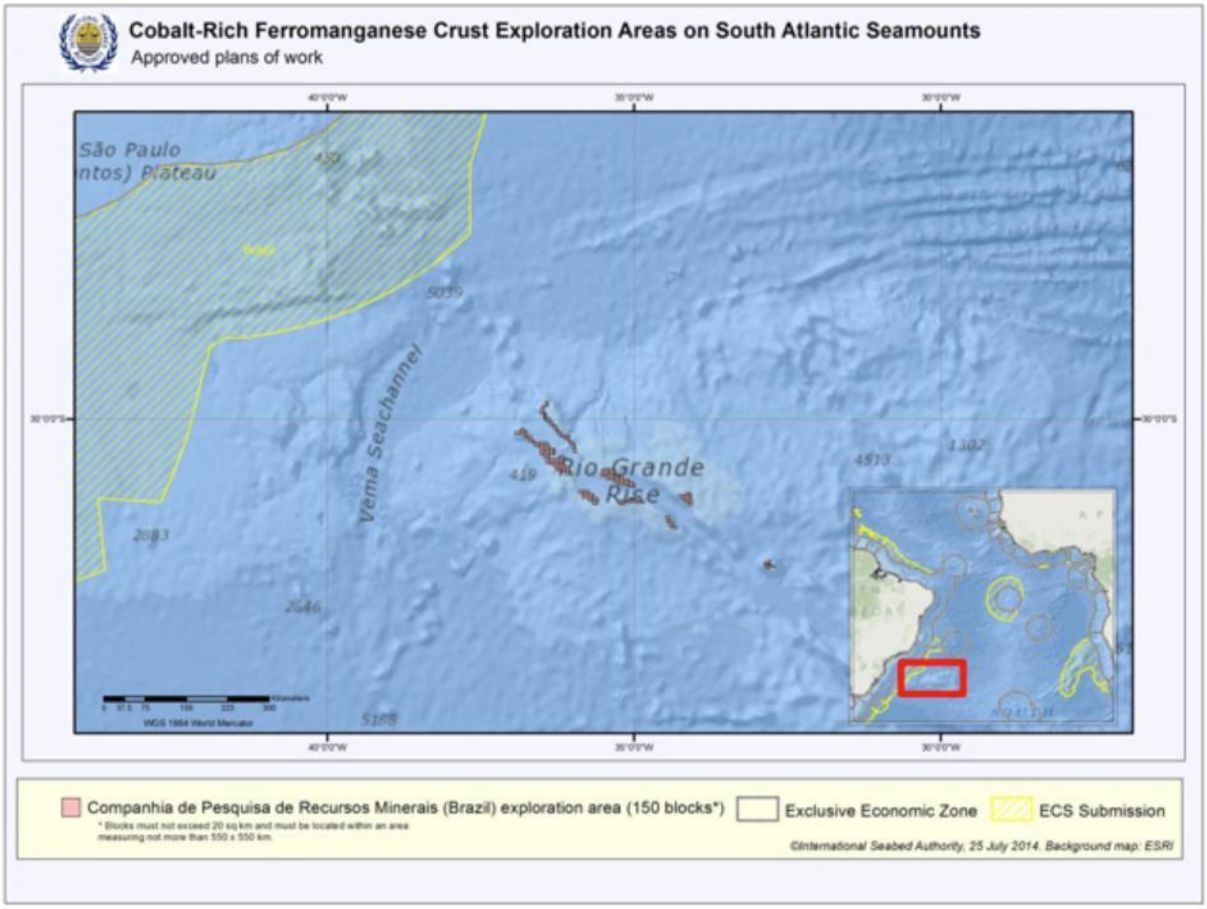

Figure 10: Areas licensed by the ISA for exploration of cobalt-rich crusts in the South Atlantic (From ISA)

2.3 Polymetallic sulphides

Polymetallic sulphides (or seafloor massive sulphides, SMS) are formed at oceanic plate boundaries in water depths from 500 to 5,000 metres by the action of hydrothermal fluids that pass through the crust becoming heated and dissolving metals from the fissured rocks. Metal sulphides precipitate when these fluids are cooled as they pass up towards the seabed, or by seawater when they are expelled from the seabed where they often form hydrothermal chimneys (Figure 11). Over time, the build-up of particulate sulphides, collapsed chimneys and other vent debris can form a mound of metal sulphide-rich material. Deposits of this type can range in size from several thousand to several million tonnes, and it is estimated that around 600 million tonnes of massive sulphide deposits occur within the easily accessible neovolcanic zone of mid-ocean ridges (Hannington et al., 2011) (Figure 12). These deposits can contain copper, zinc, lead, gold, silver, but the metal compositions vary considerably from one deposit to the next and only a few have commercially interesting compositions (Figure 13). In the Red Sea the hydrothermal fluids that are ejected from the seafloor mix with a dense brine-rich layer of seawater, causing the metalliferous deposits to precipitate over a wide area of seafloor (Bäcker and Schoell, 1972) (see Case Study 2 in annex to this report).

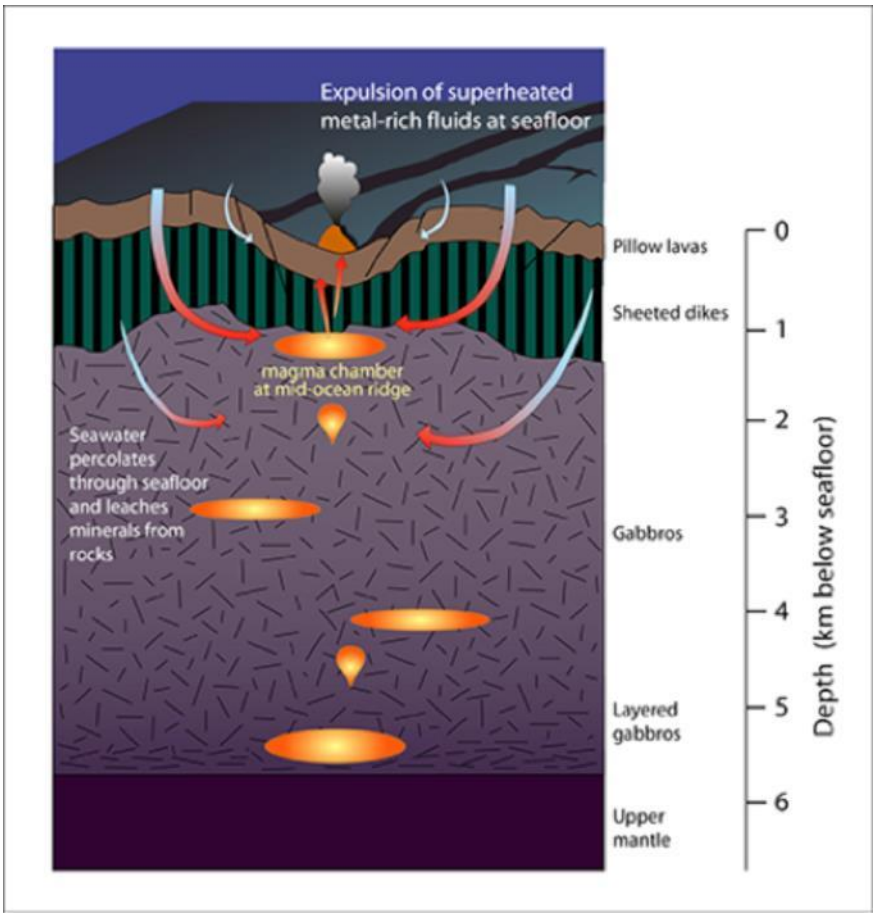

Figure 11: Graphic representation of hydrothermal mineral deposit formation at a mid-ocean ridge (Image: Seascape Consultants Ltd)

The ore bodies produced along oceanic plate boundaries will eventually be transported away from the ridge axis by the movement of the tectonic plates and become progressively buried by sediments. These older ore bodies contain potentially more and larger SMS deposits but cannot be easily located by current technology. However, work is ongoing to develop more suitable technology to prospect for such deposits, which offer the possibility of large three-dimensional ore bodies similar to those that are exploited on land.

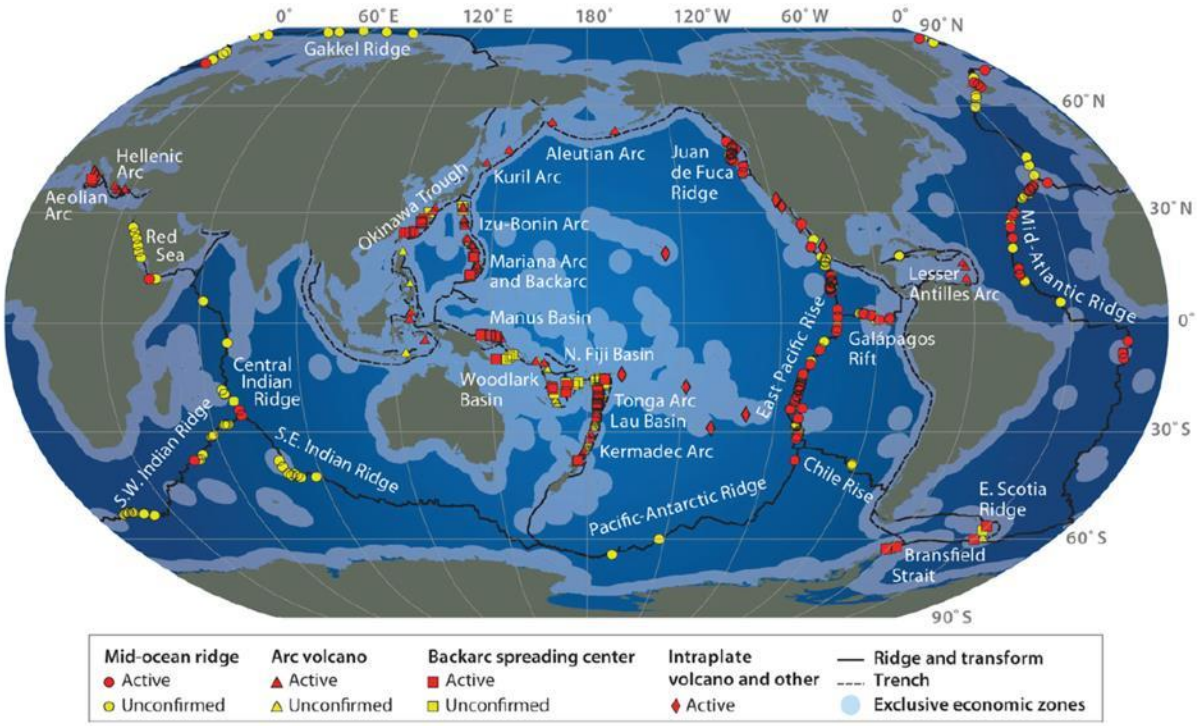

Figure 12: Global distribution of seafloor hydrothermal systems and related mineral deposits. Version 2.0 of the InterRidge Global Database (Beaulieu, 2010) used in this study contains information on 554 sites of seafloor hydrothermal activity (confirmed and unconfirmed) and inactive deposits. About 300 are sites of high-temperature hydrothermal venting; 165 are confirmed sites of massive sulfide accumulation. Credits: S. Beaulieu, K. Joyce, and S.A. Soule (Woods Hole Oceanographic Institution). (From Hannington et al., 2011)

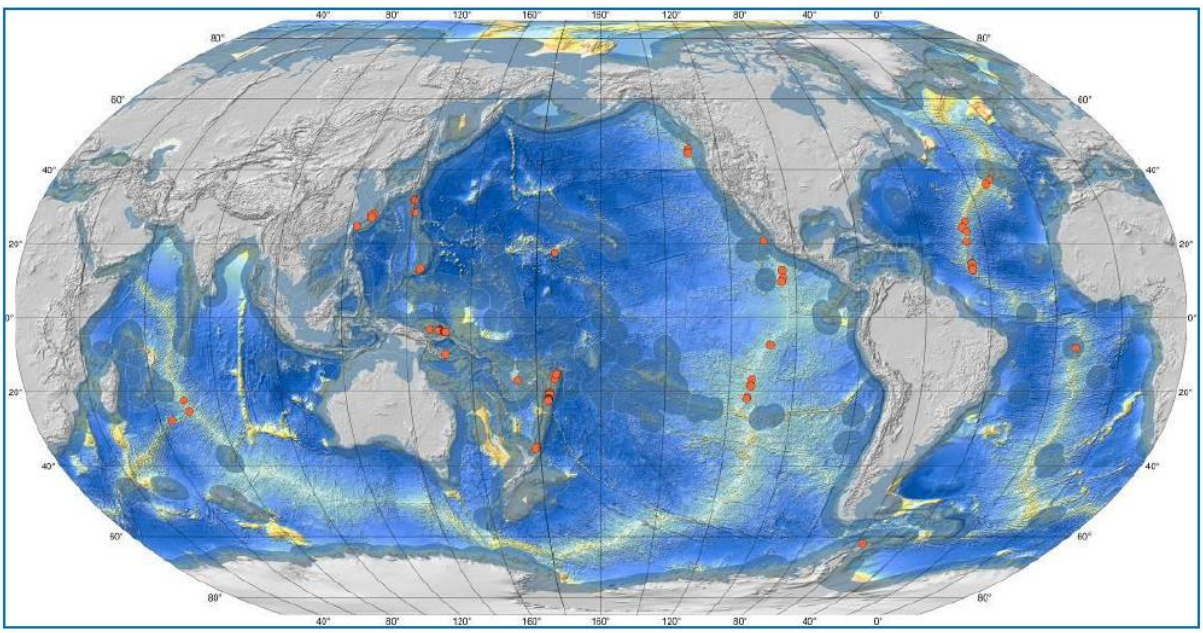

Figure 13: Location of seafloor massive sulphide occurrences with base and/or precious metal enrichment (source GEOMAR; N=82) (from ECORYS 2014).

2.3.1 Current mining activity and prospects

Only one prospecting license has been issued in the Area. This licence was issued to the Federal Institute for Geosciences and Natural Resources of Germany (BGR) in 2011 for polymetallic sulphides in the southern central Indian Ridge and the northern south-east Indian Ridge. The granting of this prospecting licence subsequently resulted in an application in 2013 for an exploration license in the same area.

The ISA regulations stipulate that contractors can claim a total exploration area of not more than 100 blocks each of 10x10 km in size, within an overall constraint area of 300,000 km² with the longest side not exceeding 1,000 km in length.

The ISA has approved five contracts for exploration of polymetallic sulphides on the mid-Atlantic Ridge (Figure 14), on the SW Indian Ridge and in the central Indian Ocean; a further contract for an exploration licence on the Indian Ocean ridge is awaiting signature (ISA, 2015a; Table 2).

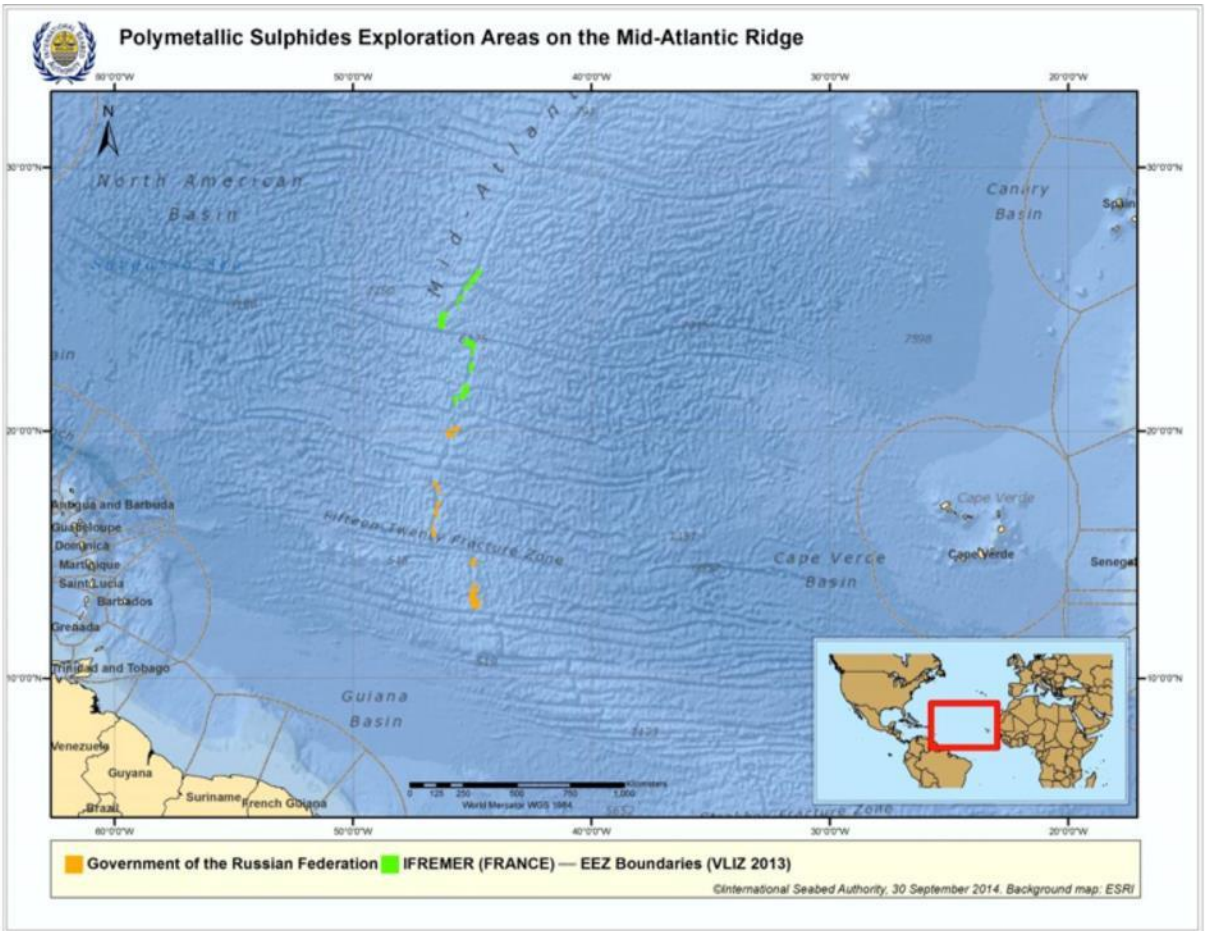

Figure 14: Areas licensed by the ISA for exploration of polymetallic sulphides on the mid-Atlantic Ridge (Map from ISA)

The ISA has not so far issued any licences for exploitation of polymetallic sulphides in the Area.

The ECORYS report (ECORYS, 2014 Annex 5) includes a major review of licensed mining activities in areas of national jurisdiction, though this was limited to activities in waters deeper than 500m. The

report states that this was a difficult task as there is no single source or database of information and so the list is not necessarily complete. Their identified activities are listed in Table 3. Most of the activities listed relate to polymetallic sulphides. The table shows that two companies — Nautilus Minerals and Neptune Minerals — hold the majority of the licences.

The total area licensed or under application for mineral exploration in States' EEZs is difficult to calculate, but ECORYS (2014) estimate a figure of 800,000 to 900,000 km^2, all for polymetallic sulphides. Neptune Minerals state on their website (http://www.neptuneminerals.com/our-business/tenements/#, accessed 12 August 2015) that they hold 175,000 km^2 of tenements in seven countries in the western Pacific, namely Japan, Papua New Guinea, Solomon Islands, Vanuatu, Fiji, Tonga and New Zealand. Nautilus Minerals state in their 2014 annual report that they have an exploration portfolio of 423,000 km^2 of granted and applied for tenements in the territorial waters and EEZs of Papua New Guinea, Tonga, Solomon Islands, Fiji, and New Zealand (see Figure 15).

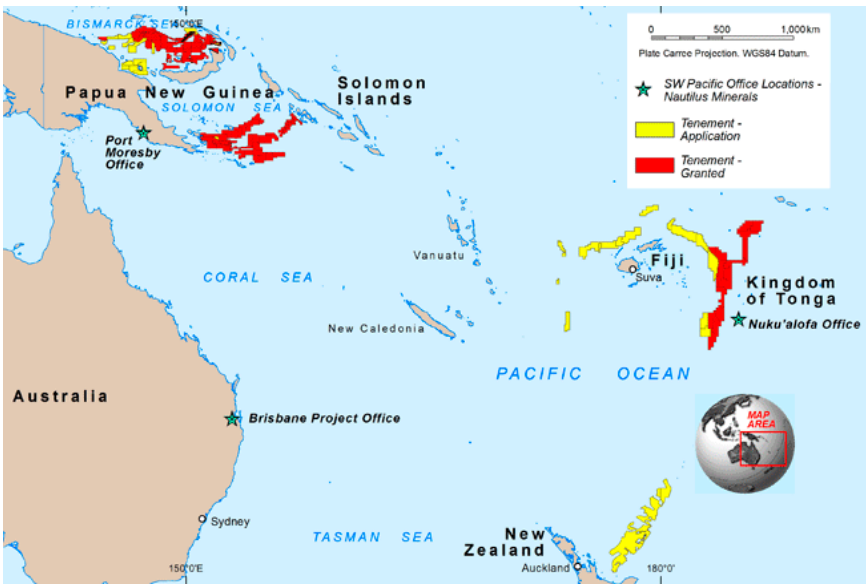

Figure15: Areas licensed/ under application by Nautilus Minerals for exploration of polymetallic sulphides in the national jurisdictions of Papua New Guinea, Fiji, Tonga and New Zealand (From Nautilus Minerals)

The two granted mining licences within national jurisdiction are held by Nautilus Minerals for mining polymetallic sulphides at the 'Solwara 1' site in the Bismarck Sea off Papua New Guinea (figure 16) (see Case Study 1 in annex to this report), and Diamond Fields International for mining polymetallic muds at the 'Atlantis II' site in the Red Sea (see Case Study 2 in annex to this report).

The Nautilus Minerals licence area includes the Solwara 1 and Solwara 12 areas and includes the following resources (Lipton, 2012) at a copper equivalent cut-off grade of 2.6%:

1. Indicated Mineral Resource: 1,030kt @ 7.2% Cu, 5.0 g/t Au, 23 g/t Ag, 0.4 % Zn
2. Inferred Mineral Resource: 1,540kt @ 8.1 % Cu, 6.4 g/t Au, 34 g/t Ag, 0.9% Zn

Nautilus Minerals has nearly completed the construction of its three mining vehicles and is progressing with the build of its Riser and Lifting System. The construction of the mining vessel is also underway. Nautilus Minerals predicts that mining will begin at Solwara 1 in 2018 (Nautilus Minerals, 2015). The Solwara 1 and 12 sites are, however, very small and will be in operation for just 30 months (Coffey Natural Systems, 2008). Other sites could be identified in the next few years so that the mining operation can move from site to site either in the Bismarck Sea or elsewhere.

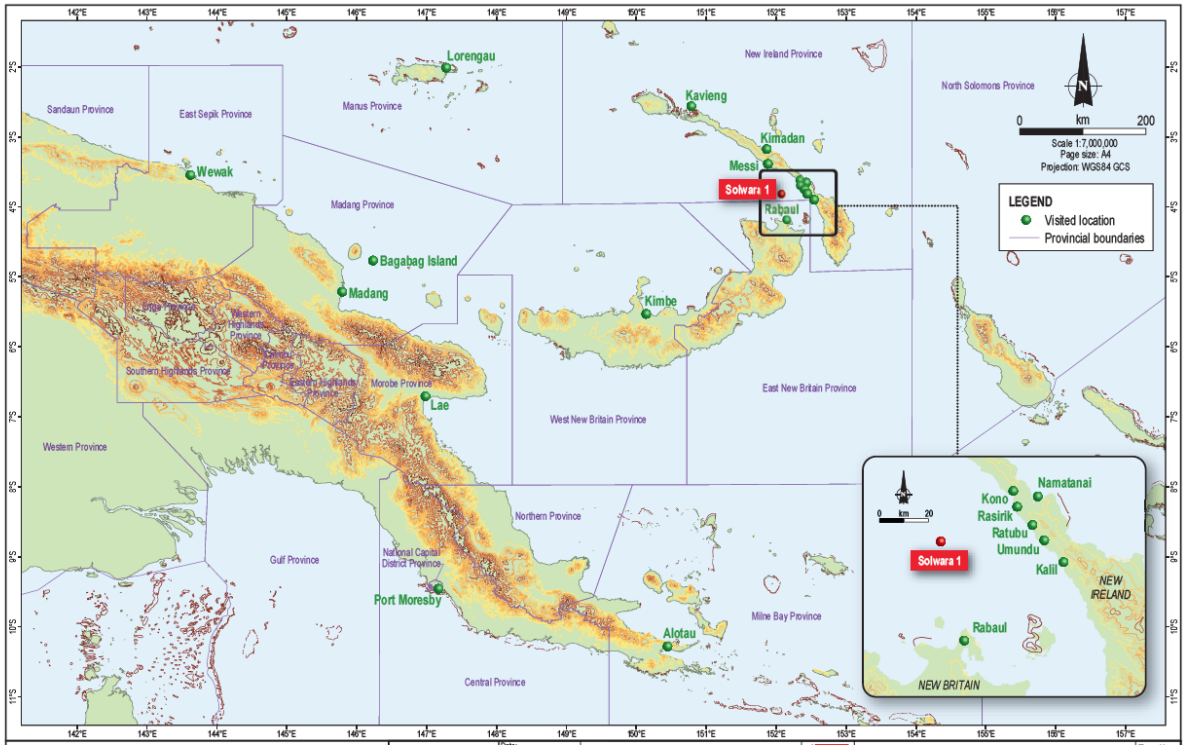

Figure 16: Location of licence area for Nautilus Minerals Solwara 1 offshore Papua New Guinea (Coffey Natural Systems, 2008)

2.4 Phosphorite nodules

Phosphorites are sediments that include significant portions of authigenic and diagenetic phosphate minerals, mainly apatite (calcium phosphorite) and francolite (carbonate flourapatite). A threshold of 18 per cent P_2O_5 is commonly used for their definition. Phosphorite deposits have formed numerous times throughout geological history, and diverse theories regarding the genesis of their formation have been published. Recent publications stress that bacteria, under low oxygen conditions, are thought to play a role in the formation of modern and ancient phosphorite deposits (e.g., Crosby & Bailey 2012), Phosphorite deposits are restricted to the continental margins and are often associated with present-day high productivity upwelling systems with low oxygen availability at the sediment-water interface, e.g., off Baja California/Mexico, Peru, Chile, Namibia and the margins of the Arabian Sea (Kudrass 2014) (see Figure 17). Other phosphorite deposits not linked to present-day upwelling (but maybe areas of high productivity) are found off the east coast of North America, off Australia and New Zealand (Föllmi 1996). Phosphorite deposits vary in form with locality, from small granules <500 µm (so-called pelletal deposits), to lamellae, crusts and larger nodules of several cm in diameter, and the resource can be concentrated at varying depths within the sediments, from the sediment surface to metres within sediments. Concentration of the deposits can occur through a variety of reworking processes, such as slumping, bioturbation, iceberg scour, and winnowing and erosion from currents. Most marine phosphorite deposits of interest for commercial mining are ancient (e.g., deposits off New Zealand were formed in the Miocene; Cullen 1987).

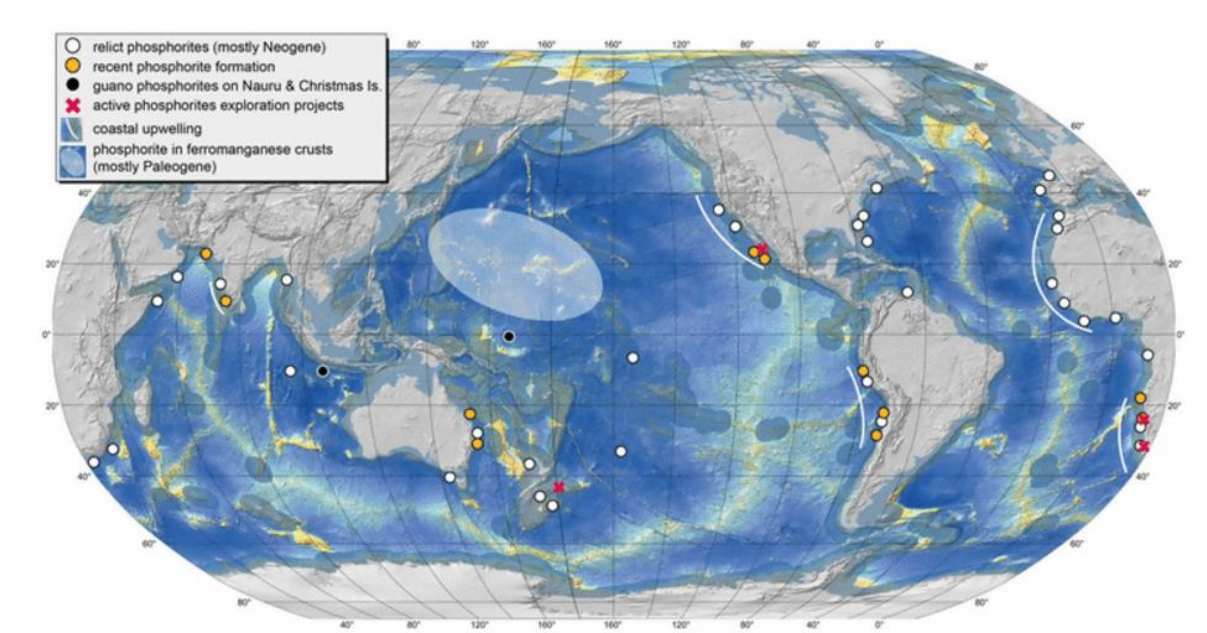

Figure 17: Distribution of upwelling areas and occurrences of relict and recent phosphorites (Kudrass, 2014)

2.4.1 Current mining activity and prospects

There are two main areas of current interest for phosphorite mining in the deep sea: on the continental margin off Namibia at depths of 180-300 m, and off New Zealand at depths of 250-450 m. For example, Namibian Marine Phosphate Ltd (NMP) holds tenements covering an area of approximately 7000 km^2, 60 km off Walvis Bay (the Sandpiper Project). The company's feasibility study estimated 3.0 Mtpa of phosphate concentrate product (27.5 - 28.0% P_2O_5) could be produced over an initial mine life of 20 years (http://namphos.com/project/sandpiper.html). In March 2012, NMP submitted an environmental impact assessment and environmental management programme report to government bodies in order to obtain permission to begin mining. Following concerns about the impact of phosphorite mining on the local fishery, a moratorium on mining (including exploration) was put in place in September 2013. The moratorium, initially imposed for 18 months, could be in place for three years, with the possibility of an extension not excluded. Off New Zealand, phosphorite deposits mainly occur on the Chatham Rise. Where the resource is concentrated on the central crest of the rise, nodules at 66 kg m^{-2} have been estimated to represent 25 million tonnes of phosphorite averaging 22% P_2O_5 (Kudrass & Von Rad 1984a). Chatham Rock Phosphate Ltd (CRP) has mining/prospecting permits and licences covering a total area of approximately 10,000 km^2 on the rise. CRP proposed to initially mine 30 km^2 of seabed per annum to meet its annual minimum production target of 1.5 million tonnes of phosphorite nodules (http://www.epa.govt.nz/EEZ/chatham_rock_phosphate/the_application/Pages/default.aspx). In May 2014, CRP submitted an environmental impact assessment to the New Zealand Environmental Protection Authority as part of its application for a marine consent to begin mining an area of approximately 800 km^2. In February 2015, CRP was refused consent for a variety of reasons, and the company is currently considering whether to reapply.

Mining technology

The technology required to identify potential mineral reserves and mine them successfully is partly developed and partly under development. The key tasks have been broken down into a value chain as can be seen in a recent report commissioned by the European Commission (ECORYS, 2014) (Figure 18).

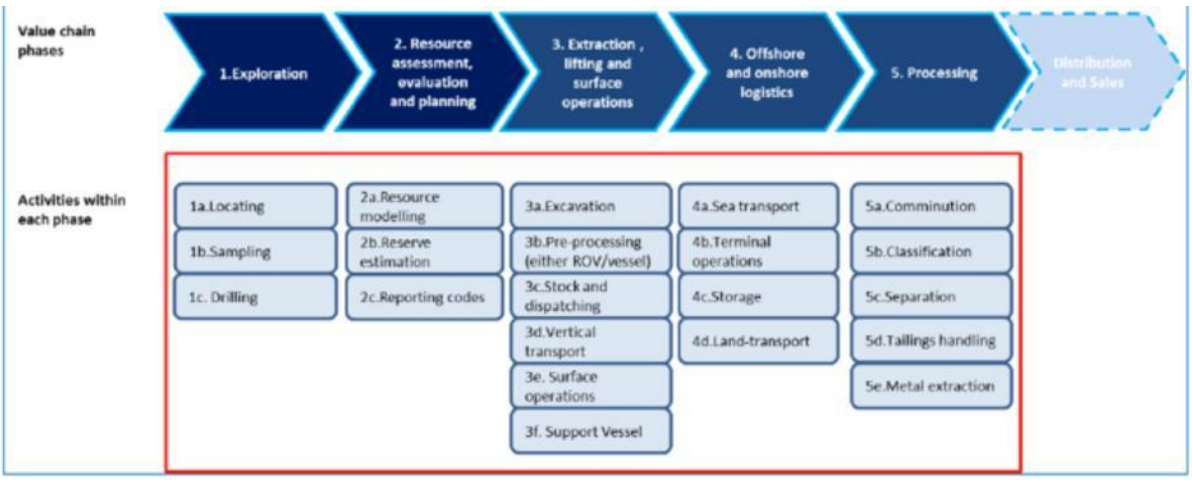

Figure 18: Schematic overview of deep-sea mining value chain showing phases and activities (ECORYS, 2014)

3.1 Exploration

In order to assess the potential of mining resources on the seabed, it is necessary to identify, test and delineate the deep-sea mineral deposits. This requires a wide range of instruments ranging from electromagnetic, seismic and sidescan sonar surveys, to sampling devices such as corers, drills and dredges and chemical sniffers. For environmental assessment the equipment includes sampling devices, camera surveys, water sampling devices and ocean current measurement equipment. Use of this equipment requires considerable infrastructure, including ships and remotely operated and autonomous vehicles. Some of this equipment is shown in Figure 19. In the laboratory a wide range of equipment and techniques is used for resource assessment and identification of biological species.

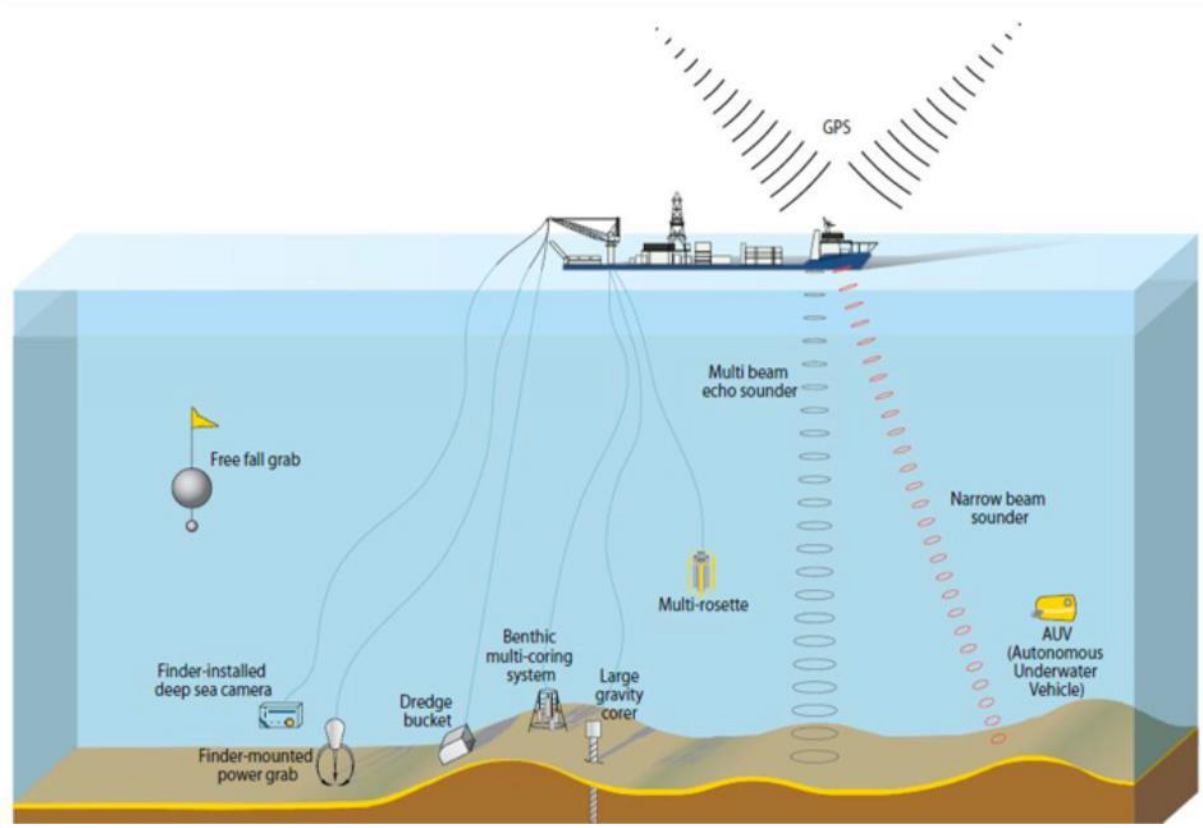

Figure 19: Examples of exploration techniques and tools. Source: Smith and Heydon (2013).

The ECORYS (2014) report includes a review of the technology readiness level (TRL) for deep-sea mining through the whole value chain (Table 1). It concluded that exploration tools were reasonably well developed for all three mineral types, although autonomous vehicles, which provide high-resolution data, are undergoing rapid development, particularly for long-range and deep-water capability and for integration with newly developed sensors.

Table 1: Level of advancement per value chain stage and deposit type (from ECORYS, 2014)

Value change stage		**SMS**	**Nodules**	**Crusts**	**Notes**
Exploration		moderate	high	moderate	Challenge esp. related to drilling (high costs/high intensity vis-a-vis current findings). In addition, gravity gradiometer is needed for SMS exploration.
Resource estimation		moderate	moderate	low	2D modelling fairly developed, 3D modelling poses requirements
Extraction and materials handling	Excavation	low	low to moderate	very low	Hardly any experience for crusts, only exploratory level for the others
	Vertical transport	low	low	very low	No longer term higher capacity testing
	Surface operations	moderate	moderate	moderate	Similar development stage/requirements for each deposit type
Logistics		high	high	high	Technologies mature; ship-to-ship transhipment may pose challenges still on vessel-to-vessel operations.
Processing		moderate	low	low	Depend on metal composition and extraction aims (which metals to take out from the ores)

3.2 Resource assessment, reserve evaluation and mine planning

Resource assessment, reserve evaluation and mine planning are essential steps in the project-planning phase, where exploration data are synthesised in a numerical 3D resource model and its uncertainty is assessed. Intermediate results lead to an estimate of in-place resources (ECORYS, 2014). The techniques are well developed for land-based mining but need to be refined for deep-sea mining as and when mining begins. Some of the uncertainties will be reduced for nodule and crust mining since these are essentially two-dimensional deposits (relatively thin surface layers on the seabed) and increased for sulphide mining where the deposits are three-dimensional and require considerable drilling information to prove the dimensions of the ore body.

3.3 Extraction, lifting and surface operations

This phase covers the excavation or collection of the minerals from the seafloor, pre-processing of the ore on the seafloor, dispatching and vertical transportation to surface and any surface operations prior to shipping of the material to shore (ECORYS, 2014). Since no deep-sea mining has taken place to date (except in the 1970s when manganese nodules were briefly mined by a consortium of western mining companies – see Scott, 2001), much of the equipment is either in the concept stage, under development or awaiting testing. The seabed mining machines will be very different for each of the resource types, though the lifting and surface operations will have much in common.

Nautilus Minerals has already developed three seafloor instruments for mining polymetallic sulphides: bulk cutter, auxiliary cutter and collecting machine. These instruments are modifications of mining tools used elsewhere in the mining industry, for example in land-based coal mines and offshore dredging and diamond mining (Coffey Natural Systems, 2008).

The mining process will involve the auxiliary cutter levelling the seabed in preparation for the bulk cutter that will mine in a similar way to coal cutting machines. Each cutting machine will disaggregate the rock, leaving it for the collecting machine that will draw it in as a slurry and pass it to the riser system (Figure 20). Ultimately a hole will be created in the seabed, similar to land-based mines, which, in the case of Solwara 1, could be 18-30 metres deep and cover 0.11 km^2. In addition the overburden will need to be removed, which consists of an estimated 130,000 tonnes of unconsolidated sediment plus 115,000 tonnes of waste rock (Coffey Natural Systems, 2008). This will be pumped to an area of seabed outside the mined area, which may lead to additional environmental impacts. The plume generated by these operations is expected to deposit 0.18 to 500 mm over an area of 2.3 $km^{2.}$

Another example of test mining machines for SMS deposits has been developed by a joint venture of Mitsubishi Heavy Industry and Sumitomo Metal Mining Co (Ishiguro et al., 2013). They also developed a drum cutter and an auxiliary, or multi-axis, cutter. These devices both feed the crushed rocks and mud directly to the slurry pump thus removing the need for a collector vehicle.

A number of machines are under development by different organisations to collect polymetallic nodules on the seabed (Agarwal, 2012; Chung 1996). These machines will crawl across the seabed removing the upper few centimetres to tens of centimetres of the surface sediment and sift out the nodules, which will then be passed to a riser either in a crushed or uncrushed form. The sediment will be left on the seabed but the weight of the machine will compact the surface layers, which may make it harder for organisms to recolonise once mining has ceased.

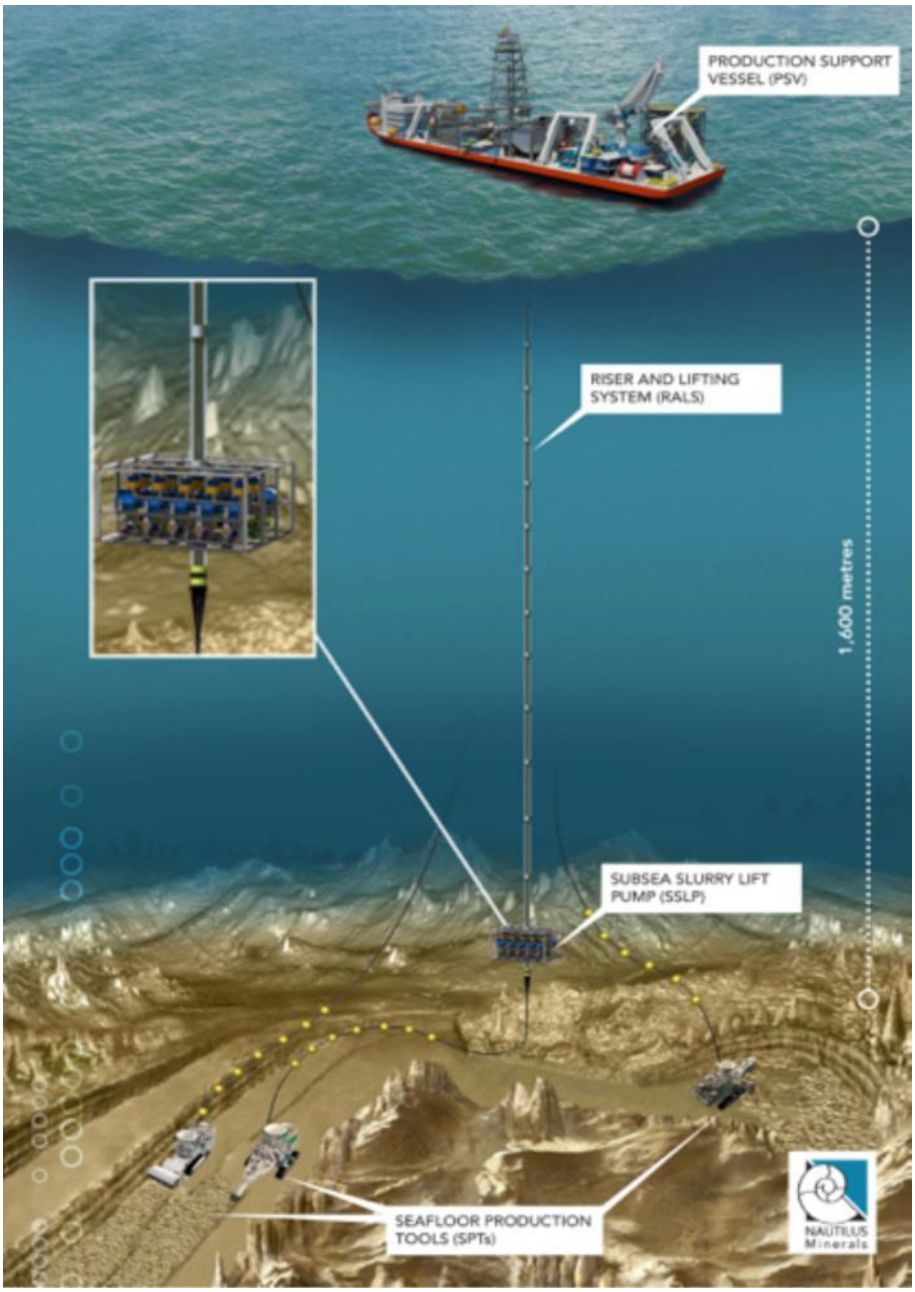

Figure 20: Example of seabed mining operations planned for the Solwara 1 mine off Papua New Guinea (Source: Nautilus Minerals).

Most of the engineering data related to crust mining in China, Russia and Japan are proprietary and therefore the extent to which the relevant technology currently exists is not publicly known (Smith and Heydon, 2013). Crust mining machines present a technological challenge since the ore is bound to the underlying rock surface, which may be very irregular. Thus the mining machine needs to determine the crust thickness just ahead of the cutters and adjust the depth of cut continuously to match the thickness. Any inclusion of underlying rock will diminish the grade of the ore. This presents a major technological challenge (Hein et al., 2013).

For all types of mining, ores are likely to be crushed at the seabed, perhaps removing the non-ore components, and in some cases they will also be concentrated into piles ready for transport to the surface.

A mining concept has been developed by the Dutch dredging company Boskalis for the proposed mining by CRP of phosphorite nodules on the Chatham Rise off New Zealand (http://www.epa.govt.nz/eez/EEZ000006/EEZ000006_CRP_Marine_Consent_Application_EIA.pdf). Their concept consists of a dredge pump and pump drive on a frame near the seabed, collectively known as a drag-head and weighing 30 to 50 tonnes. High pressure water jets (possibly assisted by cutting teeth incorporated into the drag-head) loosen the seabed sediment, which is collected by the dredge pump as the drag-head is pulled over the bed by hoisting wires. A screen on the drag-head prevents material greater than 150 mm from entering the pump. The drag-head is designed to collect phosphorite nodules from a layer that varies in thickness from 0 to 50 cm, and to avoid dredging the underlying chalk/ooze layer.

Once excavated the ores need to be transported to the ship, where they can be offloaded onto barges. Early methods of bringing nodules to the surface used mechanical transport systems, but the development of slurry pumps in the hydrocarbon industry has opened the possibility of using riser and lift systems (RALS) to great depths for all mineral types. A number of companies are designing and using such systems (e.g. Nautilus Minerals, 2010). So far these systems have not been tested with the transport of ores, though this will be carried out at Solwara 1 where the water depth is 1,600 metres. Developing systems that can work in the Clarion Clipperton Zone with water depths up to 6,000 metres will be much more challenging.

The ores will arrive at the ship in a wet state and will need to be dewatered on board with the discharge water being returned to the sea. This particle-laden discharge plume will form a turbid plume rich in small particles and potentially containing toxic material. For Solwara 1 the particles in the plume will be less than 8 microns in size (Coffey Natural Systems, 2008). Nautilus Minerals plan to return this water through the riser pipes to near the seabed where it will be used to drive the RALS pump (Coffey Natural Systems, 2008).

Metallurgical processing is not expected to take place at sea (ECORYS, 2014).

The handling of mining equipment on the seabed and receiving of ores will require a specialist Production Support Vessel (PSV) that will be similar to those used in the hydrocarbon industry (Smith and Heydon, 2013). Nautilus Minerals has entered into a hire arrangement for such a vessel that will be owned by Marine Assets Corporation and built by the Fujian Mawei Shipbuilding company in China (http://www.nautilusminerals.com/s/Media-NewsReleases.asp?ReportID=682236&_Type=News-Releases&_Title=Nautilus-enters-into-Vessel-Charter , accessed 12 August 2015).

Ecosystem characteristics and potential impacts

The four deep-sea mineral types considered here are located in very different environments, each with unique ecosystems. The consequences of mining could therefore have different impacts on each resource and are discussed individually below. For all deposit types there is a lack of scientific information (Baker et al., 2013), especially information on taxonomy, species distributions and life cycles, ecosystem function, susceptibility to toxic substances and physical disturbance as well as recovery potential. To encourage dialogue between taxonomists, the ISA has sponsored a number of standardisation workshops. The first was held in June 2013 in Wilhelmshaven, Germany, to standardise megafaunal taxonomy for exploration contract areas in the CCZ. The second was held In November 2014, in Uljin, Republic of Korea to standardise macrofaunal taxonomy in the CCZ. A third workshop, to be held in Ghent, Belgium in December 2015, will focus on taxonomic methods and standardization of meiofauna in the CCZ.

4.1 Polymetallic nodules

4.1.1 Habitats and biodiversity

Nodules can only be formed where net sedimentation is very low. Such conditions exist in the abyssal plains of the Pacific Ocean and in smaller areas of the Indian Ocean. Many of the abyssal plains in the Atlantic are filled by sediments redeposited from the continental margins and hence are not suitable for nodule formation. A review of the habitats and biodiversity of manganese nodule regions was recently provided by Smith (2013) on which the following account is based.

Nodule provinces typically provide hard substrates in the form of the nodules and soft substrates in the red clays that surround them. Thus there are organisms that live in the sediment, on the sediment surface, attached to the nodules and those that are free swimming. The great depths produce low water temperatures, and currents are generally very weak, leading to high physical stability. In the CCZ organic flux to the seabed is generally low though there are variations with the flux being higher in the east. Species diversity is often high in abyssal habitats (Snelgrove and Smith, 2002). For example, hundreds of species of polychaete worms and isopod crustaceans are typically found at single abyssal sampling sites (Glover et al. 2002; Brandt et al. 2005; Ebbe et al. 2010). High diversity is also common among relatively large animals, especially echinoderms such as sea stars and sea cucumbers, and among much smaller animals, including nematode worms and foraminiferans. For example, more than 500 species of nematodes and more than 200 species of foraminiferans have been found in single study areas of about 20 x 20 km (Nozawa et al. 2006; Smith et al. 2008a; Miljutina et al. 2010). At regional scales, diversity is less well quantified but is thought to be high, with many thousands of species inhabiting abyssal basins (Snelgrove and Smith 2002; Ebbe et al. 2010). Use of molecular methods such as DNA analysis is becoming more common in defining taxonomic groups in the CCZ, and a detailed methodology has been described by Glover et al., (2016). Using DNA barcoding Janssen et al. (2015) assessed samples from two sites in the CCZ separated by 1300 km. Their results showed high local and regional diversity mostly because of large numbers of singletons in the samples. A higher proportion of wide-ranging species in polychaetes was contrasted with mostly restricted distributions in isopods.

Some of these abyssal species – especially fish, sea cucumbers and some foraminiferans – are widely distributed. However, many species have been collected, sometimes in very high abundance, in single localities only (Mullineaux 1987; Glover et al. 2002; Brandt et al. 2005; Nozawa et al. 2006; Smith et al. 2008a; Ebbe et al. 2010). At present there is no consensus on whether there is a

characteristic scale of distribution for abyssal species and whether this might be dependent on the taxon, or size of organism. This is related to the paucity of sampling in the deep sea and in achieving consistency in taxonomy between different studies, particularly as most species collected are new to science. Some species may be very widely distributed at abyssal depths across ocean basins, while others appear to have very restricted ranges spanning only 100 to 1,000 km.

Nodule regions sustaining different levels of particulate organic carbon flux appear to have different levels of species diversity and substantially different faunal communities, both in the soft sediments and on the nodules themselves. (Mullineaux, 1987; Veillette et al., 2007a; UNESCO, 2009; Ebbe et al., 2010). The CCZ, the area of most intense interest for manganese nodule mining in the Pacific, experiences substantial east-west and south-north gradients in overlying primary production and the flux of food to the abyssal seafloor (UNESCO et al., 2009; Watling et al., 2013). Based on these gradients, as well as on patterns of faunal turnover, the CCZ is expected to harbour distinct faunas and levels of biodiversity in different subregions. The CCZ is also thought to straddle a major biogeographic provincial boundary in the abyssal Pacific (UNESCO 2009; Watling et al. 2013).

In the CCZ, the polymetallic nodules themselves harbour a biota distinct from the surrounding sediments. In one CCZ locality, roughly 10 per cent of exposed nodule surfaces were recorded as being covered by sessile, eukaryotic organisms. Of these, foraminiferan protozoans accounted for more than 98 per cent of both the surface cover and number of individuals (Mullineaux 1987), although this may not necessarily be representative of the entire CCZ. Animals found attached to nodules include small sponges, molluscs, polychaetes, encrusting bryozoans and xenophyophores, with the vast majority of the nodule species not found in surrounding sediments (Mullineaux 1987; Veillette et al. 2007a; Kamenskaya et al. 2015). The nodule fauna varies with the surface texture of nodules, as well as with regional variability in the flux of particulate organic carbon to the seafloor (Veillette et al. 2007a and b).

Studies of sea-floor communities in the CCZ and other abyssal Pacific regions suggest that there is a characteristic fauna of the abyss, distinct from populations at the ocean margins. This relates not only to the different geomorphological settings but also to changes in depth and its effects on the physiology of organisms. Changes across the CCZ may also be related to depth gradients. Rates of change will vary with dispersal abilities and life histories of the fauna, which are generally very poorly known.

4.1.2 Potential impacts

There are three major types of impacts of deep-sea mining, associated with: loss of substrate, direct effects of mining the seabed (operational plume and re-sedimentation, light and noise pollution) and the discharge plume and its effects on pelagic and/or benthic organisms depending on the depth of discharge (ECORYS, 2014). The severity of these impacts will depend on the duration of the impact, the size of the area impacted, the nature of the impact and the potential for recovery. In addition, there may be impacts related to pollution from vessels, including light pollution.

Polymetallic nodules are essentially a two-dimensional deposit, lying in the top few centimetres to tens of centimetres of the surface sediments. In order to achieve mining targets of one to two million tonnes of ore per year, areas of around 100 km^2 will need to be mined per year, per operator. The ECORYS report (ECORYS, 2014) suggests 300 km^2 will be mined per operator per year. It is possible that an equivalent area of seabed will be covered by sediment generated by the operational plume. The removal of nodules will obviously destroy all those organisms living attached to nodules such as sponges, sea anemones, komokiaceans and xenophyophores. These taxa will not be able to

recolonise because it will take millions of years for the nodules to re-grow, and other hard substrates are not available in the mined areas. However, in each mining area about 40 per cent of the seabed may not be impacted and while nodules in these areas may occur in lower abundance, suitable substrate will remain across the CCZ. The mining process will destroy many organisms living in the sediments, though it is possible that portions of the microbial fauna and meiofauna (e.g., nematode worms, foraminiferans) may survive. Recolonisation of the sediment by infauna may be made more difficult due to compaction of the sediments caused by the weight of the mining machines.

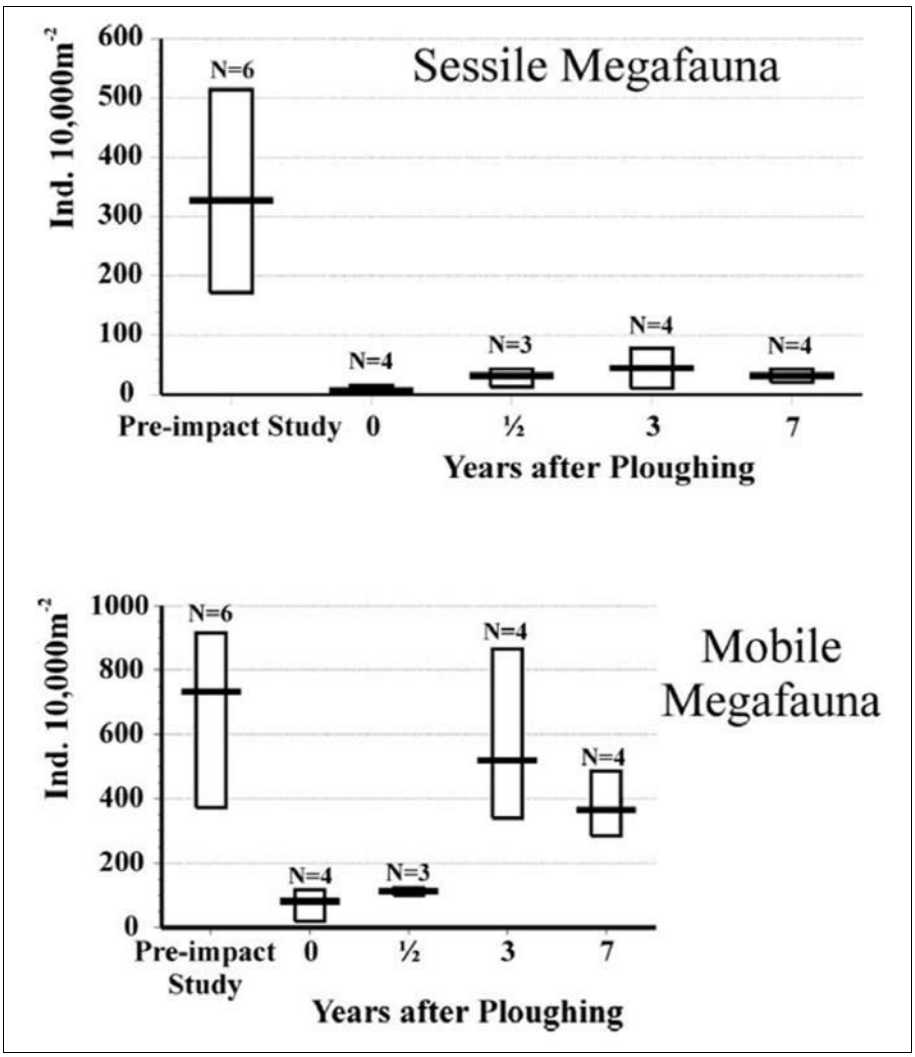

Figure 21: Animal densities in DISCOL disturbed area, Peru Basin, Pacific Ocean. Densities (Individuals 10,000m^2): arithmetic mean, minimum–maximum range and N, the number of records used (from Bluhm, 2001).

A number of experiments have been set up to investigate the rate of recolonization in areas of the CCZ (Thiel et al., 2001; Sharma, 2001; Miljutin et al., 2011). The DISCOL recolonization experiment was set up in 1989 when an area of nodules in the Peru Basin was ploughed. The site was revisited aftersix months, three years and seven years (Bluhm, 2001). The results show that the variety of higher taxa and the total numbers of individuals were severely reduced by the disturbance with virtually no recovery of sessile megafauna even after seven years. Mobile megafauna show a small increase in the variety of taxa after seven years and a larger increase in numbers of individuals after three years. (Figure 21). The DISCOL site was revisited in 2015, 26 years after the initial disturbance,

but results are not yet available. A second study assessing recolonization in a nodule area was carried out by Miljutin et al., (2011) in the CCZ who examined a 26 year-old disturbance track. They found that even after this length of time the total nematode density and biomass within the dredging track were significantly lower than outside the track.

The mining process may create a turbid plume of water with particulates generated as the nodules are lifted and cleaned before being passed to the riser. The magnitude of this benthic plume will depend on the design of the equipment, but there are no published test results to show how voluminous it might be. How far it will spread will depend on its density and volume and any prevailing current. Some estimates suggest that more than 99 per cent of the mass of the near-bottom sediment plumes will settle within one month and within 100 km of the point of origin (Rolinski et al., 2001). Plume monitoring may need to extend outside of the licence block of the contractor, and thresholds will need to be established to determine the effective boundary of the plume for monitoring purposes (Figure 22). The cumulative effect of repeated plume deposition will also need to be taken into account (Figure 22).

A second turbid plume will be created by the dewatering of the slurry that is transferred up the riser pipe. This will take place on the ship, and the water will be returned to the water column at an unknown depth. The ECORYS report analysed some of the implications of this plume (ECORYS, 2014). If the discharge plume is released at the sea surface, ecosystem effects can be expected as a result of introducing cold, nutrient rich and particle-laden water into surface waters. Strict control of water brought to the surface will have to be maintained, and the integrity of riser pipes and discharge pipes will require continuous monitoring. In nodule areas the depth of the ocean will be great (4,000 to 6,000m), increasing options for where a discharge plume might be released. Oxygen Minimum Zones (OMZ) between c. 100 and 1,000m are often associated with polymetallic nodule areas, such as the CCZne. While these areas are generally lower in biomass than in more productive parts of the ocean, they may contain many species with very poorly known levels of endemism. Metals in a discharge plume in OMZs may go through phase changes. Discharge in the mesopelagic zone (at depths down to c. 1,500m) may affect some species that undertake diurnal vertical migrations into surface waters. Pelagic biomass typically decreases with increasing depth before increasing in the benthic boundary layer. Options for discharge in the bathypelagic and abyssopelagic zones may need to be considered, although these zones also have characteristic fauna. However, the pelagic species are likely to have wider geographic distributions, at least on the regional scale. There may be a requirement for efficient heat exchangers within the discharge pipeline in order to cool the discharge water to the exceptionally low ambient temperatures (1-2ºC) found in the deep sea. Deep-sea organisms are sensitive to small changes in temperature. In addition, the benthopelagic fauna living within the Benthic Boundary Layer (c. the 100m overlying the seabed) may have unique and poorly known species.

Any plumes discharged in mid-water will potentially travel very long distances and impact not only mid-water organisms but also any benthic communities if they impinge on the seabed (for example if the plumes are intersected by seamounts or when they finally settle). Oebius et al. (2001) suggest such plumes can travel for at least 100 km. However, the finer particles could remain in the water column for 3-14 years depending on environmental conditions, the volume of particles produced and the speed with which they become dispersed (Rolinski, 2001). Particle tracking models will be required to estimate the trajectories of particles and their duration in the water column across a range of particle sizes.

An assessment of the potential impacts of both mid-water and benthic plumes was fundamental in the design of the protected area network proposed for the CCZ (Smith et al., 2008b; Wedding et al., 2013). The protected areas, known as Areas of Particular Environmental Interest (APEIs), have each been designed with a buffer zone 100 km wide on all sides to prevent impacts from plumes in the central protected area.

A potential third particle laden plume could be generated by the ship to barge offloading process if the ore is moved in a wet state. Any waste water produced by this transfer could possibly be added to the dewatering plume though there is no legislation in place to control this process at present.

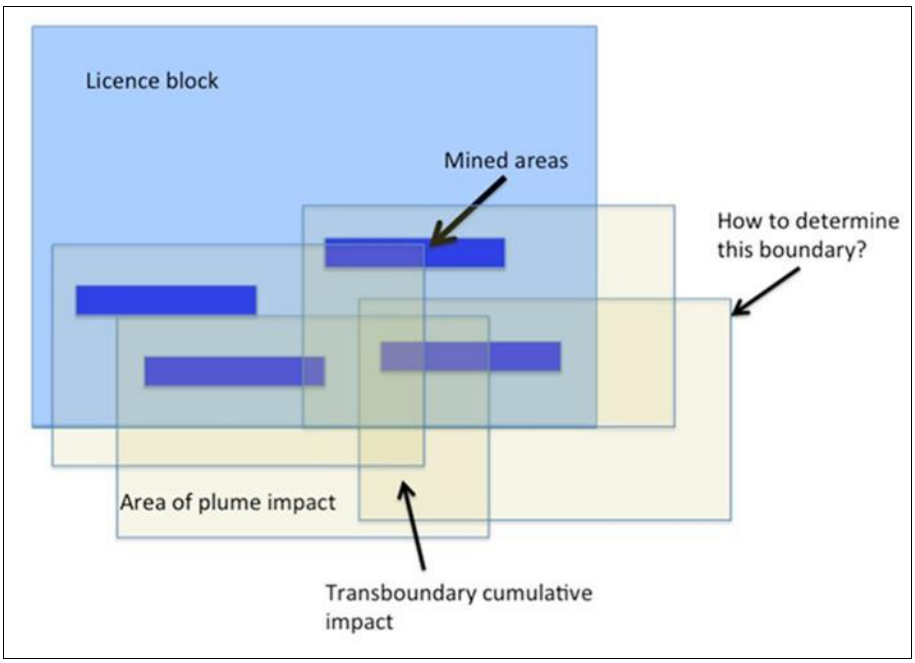

Figure 22: Potential impact of plumes in and adjacent to mined areas.

4.2 Cobalt Crusts

4.2.1 Habitats and biodiversity

The most economically interesting crusts are found at water depths between 800 and 2,000 metres on the flanks and summits of seamounts and plateaux where currents are sufficiently strong to prevent sediment from depositing. The geologically oldest seafloor features have had time to develop the thickest crusts and these are located in the western Pacific. A review of the habitats and biodiversity associated with cobalt crust was recently provided by Clarke (2013), on which the following account is based.

A biogeographic classification for bathyal zones (depths of 800 to 3,500 metres) grouped the entire south-west Pacific into four large biogeographic provinces (UNESCO 2009). However, an environmental classification done specifically for seamounts showed that considerable variation might be expected within the larger provinces, based on depth, organic carbon flux to the seafloor, oxygen level and proximity to neighbouring seamounts (Clark et al. 2011a). Cobalt-rich crust habitat is characterised by rocky substrate, reasonably swift current flows and a wide depth range (Figure 8). The rocky substrate makes the habitat suitable for sessile animals, such as corals and sponges that require hard surfaces on which to attach, but generally unsuitable for burrowing animals, which require soft muddy sediments (although soft sediment will occur in small patches). Swift currents that occur around seamounts or steeply sloping topography can limit the type or shape of animal that can live in such a dynamic environment and not be swept away. However, filter feeders that require good current

flow to bring food particles to them without excessive sediment can find such conditions advantageous. The flanks of seamounts span a wide depth and temperature range, meaning that a large variety of animals can find suitable conditions to live.

Seamounts can have highly variable substrate composition (Wright, 2001) and accordingly host a wide variety of fauna (Clark et al., 2010). Typically, however, the large biogenic-forming corals and sponges dominate the megafauna (Rowden et al., 2010). An initial comparison of seamounts off Hawaii revealed no significant difference between the mega-faunal composition of ferromanganese crust and non-ferromanganese crust features, with similar numbers and composition of the main groups – sponges, corals, anemones, crabs, sea stars, sea urchins, brittle stars, sea cucumbers, feather stars (Clark et al., 2011b). Increasing depth was the main driver of change in faunal composition. There were, however, differences in distribution (and likely abundance) between seamounts, with a number of species being recorded much more frequently on cobalt-rich crust. In a later analysis that include some additional data, Schlacher et al. (2014) report that the structure of mega-faunal assemblages is different in areas with cobalt-rich crusts compared to those outside the cobalt-rich crust region. This difference resulted from variations in species composition and generally lower abundance on cobalt-rich crust seamounts, rather than differences in species richness. Cross Seamount, south of Hawaii, has relatively thick crust on its flanks that has been described as “sparse and barren” (Grigg et al. 1987). However, isolation from other seamounts or shallow waters can restrict successful recruitment, so the scarcity of biota might not be related to the chemical composition of the crust. Foraminifera have been shown to settle at higher densities on crust than on basalt substrate (Verlaan, 1992). More research is required to improve our understanding of the relationship between faunal community structure and crust composition. However, recent studies are at least beginning to improve our understanding of benthic community structure on cobalt-rich crusts. For example, Morgan et al. 2015 have identified north-south differences in mega-fauna community structure along the Necker Ridge (Central Pacific Ocean).

Many of the potential seamounts with commercially important crusts in the south-west Pacific region extend to within 800 to 1,000 metres of the surface, which is within the depth range of the deep scattering layer (DSL). This is a mix of zooplankton (such as shrimps, euphausiids, and copepods) and mesopelagic fish (such as lantern fish and small squid) that migrate vertically upwards at night and down during the day. Where the DSL makes contact with the seamount summit and upper flanks, there is a zone of interaction between pelagic and benthic ecosystems. These seamounts are too deep to be associated with high concentrations of fish and higher predators that are associated with shallow seamounts (Clark et al., 2010). Kvile et al. (2012) point out that there are practically no data on seamounts with a summit depth below a few hundreds of metres from the sea surface.

4.2.2 Potential impacts

The mining of cobalt-rich crust will involve grinding or scraping the surface of the seamounts or other topographic features to a depth of about 25 centimetres (see https://www.isa.org.jm/sites/default/files/files/documents/eng9.pdf). As with polymetallic nodules, crusts are essentially a two-dimensional feature and therefore large areas would need to be mined per year. Assuming a crust thickness of 30-60 mm, Hein et al. (2009) estimated that approximately 9 - 17 km^2 will be mined per million tons of ore extracted. He et al. (2011), using a different mining model, estimated that up to 60 km^2 would need to be mined per year for the same yield. . Each operator is likely to mine between one and two million tons of ore per year over a 20-year mining operation. Apart from the loss of this area of habitat, benthic plumes created by the mining process will likely travel downslope on the flanks of the seamount or other feature. As the habitats and organisms change with depth then a range of different habitats may be impacted. The extent of the impact of the benthic

plume will depend on its volume and composition, which will be dependent on the mining process and equipment design. The plume will affect organisms by clogging the filter feeding mechanisms of many animals, which rely upon clean current flow containing small animals and particles that are their food. Plume deposits may overwhelm organisms and prevent juveniles from settling (Rogers, 1999).

A number of abundant taxa found on deep-sea seamounts are slow-growing and long-lived. Cold-water corals, in particular, live for hundreds to thousands of years (Roarck et al., 2006; Rogers et al., 2007; Carreiro-Silva et al., 2013)). These slow growth rates, together with variable recruitment due to intermittent dispersal between seamount populations (Shank, 2010), mean that recovery of vulnerable species (and the assemblages they form) from human impacts, such as fishing or mining, is predicted to be very slow (Probert et al., 2007). Studies on seamounts off New Zealand and Australia have shown few signs of recolonisation or recovery after 10 years of closure to bottom-trawling operations (Williams et al., 2010), and signs of dredging on the Corner Rise seamounts were still clearly visible after a period of up to 30 years (Waller et al., 2007). Schlacher et al. (2014) considered that the life history characteristics and morphological traits of the fauna they observed on cobalt-rich crusts imply that recovery from the mechanical impacts of mining is likely to be very slow. Several implications for the design of spatial management and conservation tools with respect to cobalt-crust mining emerge from the study of Schlacher et al. (2014). These authors concluded that: conservation of seamounts outside of the cobalt-rich region is unlikely to capture the full range of assemblage features found inside the region; conservation areas need to encompass a broad bathymetric gradient; and ideally mining blocks should not exceed 2 km in length.

The operation of seafloor production tools will increase levels of introduced noise, vibration, and light Clark and Smith (2013). Noise and vibration together can affect the auditory senses and systems of some animals. There can be direct damage to other animals, discomfort that might cause avoidance reactions, or an increase in background noise that can interfere with communication between animals or limit their ability to detect prey (Popper et al., 2003). Light can repel or attract some animals. For example, many fish display attraction or avoidance responses to light, varying by species. Bright lights can blind some species, and this has been a concern with research operations around hydrothermal vents (InterRidge, 2006). These types of indirect effects are not well understood and will need monitoring from the outset. Animals that can be affected include benthic invertebrates, fishes, and deep-diving marine mammals.

The potential impact from mid-water discharge plumes will be similar to those described for polymetallic nodules. However, the expected water depth of cobalt-rich crust mining will be considerably less than for nodule mining and the riser system being developed by Nautilus Minerals for depths of 1,600 metres in Solwara 1 involves the retuned water being discharged near the seabed where it can be used to drive the slurry pump. Hence it may not be necessary to carry out mid-water release of waste water.

4.3 Polymetallic sulphides

4.3.1 Habitats and biodiversity

Polymetallic sulphides are found at oceanic plate boundaries where hydrothermal fluids are expelled at the seafloor. These fluids are rich in reduced chemicals that are used as an energy source by chemoautotrophic bacteria, which in turn form the base of a food chain that is independent of photosynthesis. A review of the biology associated with seafloor massive sulphide deposits was recently provided by Fisher et al. (2013), on which the following account is based.

The toxic nature of many of the hydrothermal fluids and the extreme conditions with widely varying temperatures has led to the evolution of many specialised species that are vent-endemic. Species also need to be able to respond to the ephemeral and patchy nature of hydrothermal vents. Hydrothermal vents are not continuous along the plate margins, ranging from a few kilometres to hundreds of kilometres apart and within any one location, sources of venting fluid might be anywhere from a metre to hundreds of metres apart (Ferrini et al., 2008; Baker, 2009). Volcanic and tectonic activity are both common on active spreading centres, and both affect the point sources of hydrothermal fluid emission and the longevity of individual sites. Tectonic activity can alter the hydrothermal plumbing at a site, blocking or redirecting hydrothermal venting. Volcanic activity can result in sites being partly or completely repaved with hot lava. Either type of activity can partially or completely wipe out the site's endemic communities.

The frequency at which hydrothermal venting stops and starts, at any particular location, is dependent of the spreading rate of the tectonic plates (see van Dover, 2014a for a review). On fast-spreading centres, such as the East Pacific Rise, where the plates move apart at a rate of more than 10 centimetres a year and large volumes of magma erupt, venting is likely to be more ephemeral. On the Mid-Atlantic Ridge, which is a slow-spreading centre where plates separate at approximately 2.5 centimetres a year, this kind of activity is much less frequent (Rubin, 2012). One well-studied site on this ridge, the TAG site (Rona, 1973) is thought to have been active for tens of thousands of years, although individual chimneys and sources of diffuse flow within the TAG mound are active for much shorter periods (White et al., 1998). Because of the patchy and ephemeral nature of hydrothermal venting, endemic faunal populations must have dispersal and recruitment capabilities that allow them to recolonise new sites regularly. However, the dispersal capabilities and resultant genetic connectivity among sites in an area varies by species and region (Vrijenhoek, 2010). Vent community structure will reflect adaptations to the natural frequency and intensity of disturbance (Miller et al., 2011).

At hydrothermal vents, both lava flows and seafloor mineral deposition result in creation of hard substrate that rises above the surrounding sea floor. These structures can provide habitat for other groups of animals that are not directly tied to active hydrothermal flow and, in fact, are unlikely to tolerate exposure to hydrothermal fluid. Inactive (old) hydrothermal vent sites and inactive hydrothermal chimneys at active sites can both provide prime substrate for rich suspension-feeding assemblages dominated by corals and echinoids not normally found on the deep seafloor (Van Dover, 2011). These animals are often slow growing and long lived (Probert et al., 2007). In addition to exposure to food broadly found in the benthic water, these communities may also benefit from primary production at nearby active vents (Erickson et al., 2009). The animals living on inactive vent sulphide structures and the infauna of inactive sediments in the vicinity of venting are not well studied, although the indications are that these communities may also depend to some extent on production from vents (Levin et al. 2009). Recently, inactive vents at the Rumble West seamount on the Kermadec Arc north of New Zealand were found to support unique groupings of species, even though these species are found elsewhere as part of other assemblages (Boschen et el., 2015).

Hydrothermal vents with generally similar chemical/thermal habitats exist in all of the world's oceans. However, there are significant differences among vent communities in different regions of the world. For example, the giant tubeworms that dominate many vent habitats in the eastern Pacific have never been seen at Atlantic, Indian Ocean, or south-west Pacific vent sites. On the Mid-Atlantic Ridge, swarms of endemic vent shrimp with chemoautotrophic symbionts cover many hydrothermal chimneys. In the Indian Ocean, shrimp, anemones, and big, symbiont-containing snails constitute the largest portion of the biomass. Analysis of the composition of vent communities suggests at least five biogeographic provinces for vent fauna, although the number and boundaries of these provinces have yet to be resolved with any certainty (Bachraty et al., 2009; Moalic et al., 2011; Rogers et al., 2012) (Figure 23).

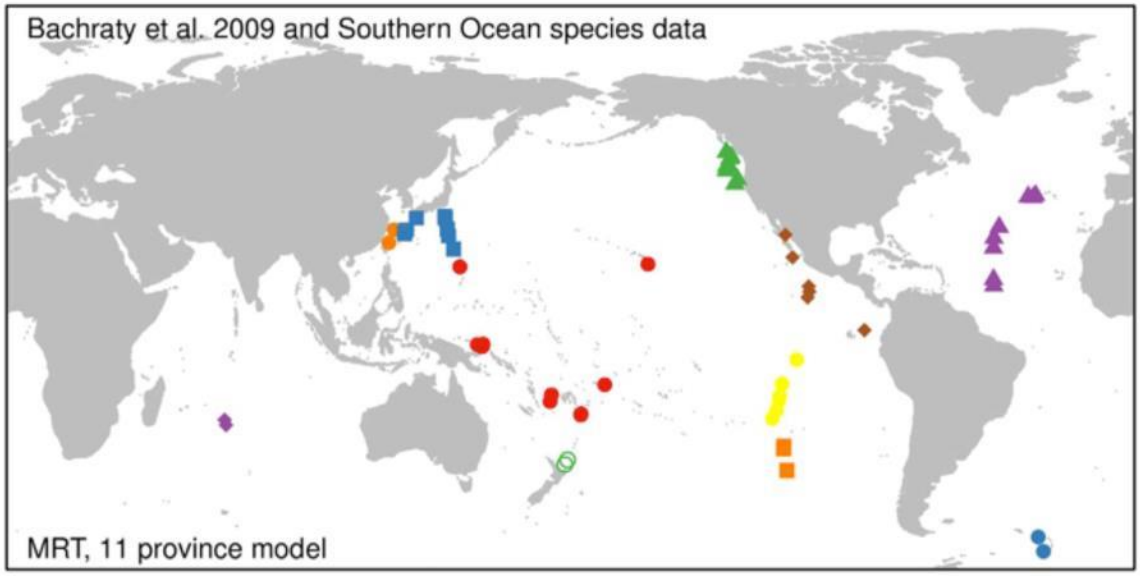

Figure 23: Results of geographically constrained clustering using multivariate regression trees. An 11-province model based on the combined dataset was the most frequent optimal model when using multiple cross-validations. Vent provinces are resolved comprising the Mid- Atlantic Ridge, the ESR, the northern, central, and southern East Pacific Rise, a further province located south of the Easter Microplate, four provinces in the western Pacific, and a further Indian Ocean province. (Rogers et al., 2012)

4.3.2 Potential impacts

Polymetallic sulphides form three-dimensional ore bodies and thus the area impacted per million tons of ore extracted is much smaller than for nodule or crust mining. Unlike sulphide deposits on land, deposits identified so far at sea have limited overburden. Nautilus Minerals estimate that 280,000 tonnes of rock and sediment will be removed and pumped away from the mined area (Batker and Schmidt, 2015), a process that may itself cause additional sediment plumes. Although the loss of habitat may be relatively small it can still have a major impact on hydrothermal vent habitats since these are rare in occurrence. Ocean ridges make up just 9.2 per cent of the global seafloor (Ramirez Llodra et al., 2010), and hydrothermal vents are located on just a small proportion of the ridges.

It is unlikely that mining can be carried out on active vents since these will be too hot, but Nautilus Minerals propose to mine very close to the active vents at Solwara 1 (Coffey Natural Systems, 2008). So close in fact that it is expected that hydrothermal vent faunas will be impacted. Both active vent faunas and adjacent non-active vent faunas will be destroyed by the mining. Hydrothermal vents, however, occur in dynamic environments where the hydrothermal activity can turn off periodically, and frequent volcanic activity can destroy the vents. Thus vent organisms are relatively well adapted to recover from disturbance, and new hydrothermal chimneys will grow rapidly to replace those lost to mining. Shank et al. (1998) and Gollner et al. (2015) describe a hydrothermal system on the East Pacific Rise that was destroyed by volcanism and recolonised within five years. However, the East Pacific Rise is a fast spreading centre where the lifecycle of venting systems is likely to be short. At slow spreading ridges, such as the Mid Atlantic Ridge, and ultra-slow spreading ridges such as the Gakkel Ridge in the Arctic Ocean, vent systems may persist for extended periods, perhaps up to tens of thousands of years. These slow spreading centres may contain more massive sulphide resources because they have more time to accumulate. It is not known how fast ecosystems can recover in slow spreading locations. However, vent communities are regarded as some of the most resilient marine

ecosystems by Van Dover et al. (2014a) (Figure 24). What may be of high importance is the intensity and extent of mining activity. If single mines are widely spaced along ridges, located at a small proportion of the active vent sites, then ecosystems may be able to recover relatively quickly, recolonising from adjacent locations. However, if mining is more extensive with a high proportion of active vents being mined, then the ability of organisms to recolonise may be severely reduced (Van Dover et al., 2014a).

The mining of sulphide deposits will cause oxidation and the creation and release of a number of toxic compounds including sulphides and heavy metals. Whilst some vent faunas may have increased tolerance to such compounds there has been very little research on impacts to the non-vent faunas and to organisms in the water column that could be affected by toxic plumes (ECORYS, 2014).

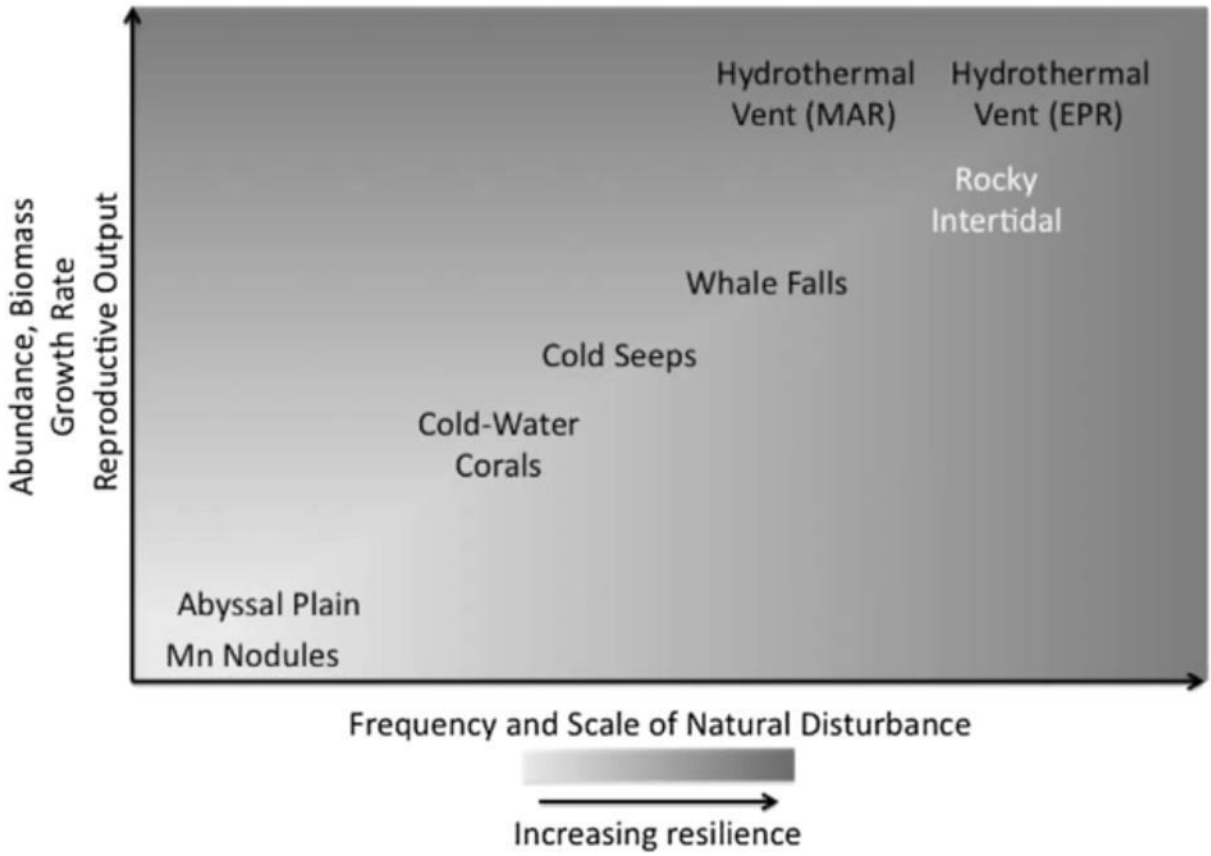

Figure 24: Resilience of deep-sea faunas to environmental impact (from van Dover et al., 2014a)

Sediment-laden plumes both from the mining machines and the particle-laden discharge plume could impact benthic habitats some distance away from the mined areas. It has been pointed out that hydrothermal venting and volcanic activity at ridges both create natural plumes that are themselves both toxic and particle laden (Batker and Schmidt, 2015). Hence it might be expected that fauna living in the vicinity of oceanic plate boundaries should be able to withstand such impacts, though this has not been proven by toxicity experiments.

Very little is known about the speed with which the non-active vent faunas will recover. The faunas can be very similar to those found on seamounts. For example, filter feeding sponges and corals can dominate in high abundance, and these organisms and the assemblages they support may take a long time to recover from disturbance (Williams et al. 2010). In addition, vent faunas and non-vent faunas

4.4 Phosphorite nodules

4.4.1 Habitats and biodiversity

Marine phosphorite deposits are found in unconsolidated seabed sediments. These so-called 'soft' sediments of mainly mud and sand-sized particles provide significant habitat for infaunal animals. Among these largely soft sediment habitats can be found occasional 'hard' substrate such as rock outcrops, boulders and gravels as well as large phosphorite nodules where they occur exposed on the seabed surface. All these hard substrates provide habitat for epifaunal animals. Epifaunal animals can also be found on the soft seabed surface. The pelagic environment above these benthic habitats varies from location to location, but where upwelling occurs there may be consistent oxygen, nutrient and temperature characteristics that result in enhanced surface water productivity. This productivity can ultimately result in relatively high fluxes of organic matter to the seafloor, and provide feeding locations for fish, seabirds and marine mammals. The two main areas of interest for phosphorite mining are on the continental margin off Namibia, and the crest of a topographic rise off New Zealand, the Chatham Rise. The deep-sea habitats and biodiversity of the Chatham Rise are reasonably well known, and the mega-/macro-epifauna and infaunal communities are described below as an example of the 'receiving environment' for phosphorite mining. First for the Chatham Rise as a whole (because a regional context is important to understand), and thereafter for the area on the central crest of the rise when mining has been proposed. Studies have also been published on the supra- or hyper-benthos (Lörz, 2010; Knox et al., 2012), and meiofauna of the Chatham Rise (e.g., Grove et al., 2006; Leduc et al., 2012), but these are not elaborated upon here.

McKnight & Probert (1997) identified three macro-epifauna "community groups"; the shallowest community was characterised mainly by crustaceans and two deeper water communities characterised mainly by echinoderms. Group A was found on mainly sandy sediments on the crest and shallower flanks of the rise at 237-602 m; Group B at 462-1693 m was associated with muddy sediments; Group C on muddy sediments at 799-2039 m. They noted that the bathymetric range of assemblages on the north and south flanks of the Chatham Rise appeared to be asymmetric, presumably because of temperature differences caused by the vertical displacement of the Antarctic Intermediate water on the north flank (McKnight & Probert, 1997). Floerl et al. (2012) identified 9 main epifaunal "biological groups" (represented by >2 sites) from a survey of the Chatham Rise and the Challenger Plateau, of which 8 were observed on the Chatham Rise, and three of them only on the rise. The distribution of these groups showed a marked across-rise pattern, that these authors presumed to be driven by depth, slope and productivity (Floerl et al., 2012).

Probert and McKnight (1993) reported that the infauna of the rise was dominated numerically by polychaetes and peracarid crustaceans. Probert et al., (1996) described the polychaete fauna in greater detail, and identified two main polychaete communities, one occurring mainly on the crest of the rise (244-663 m) and a deeper one (802-1394 m) on the slopes of the rise. Community composition also differed between the north and south of the rise. Probert et al. (1996) considered the faunal differences to reflect differences in the quantity and quality of the food supplied to the seabed controlled by the spatial and temporal dynamics of the overlying sub-tropical front. In a subsequent study, Probert et al. (2009) examined the polychaete fauna from sites along a north-south transect across the central Chatham Rise from water depths of c. 2300 to 350 m. Analysis grouped the shallowest sites, at c.350–453 m, and samples from sites at c. 1000 m and 2300 m north and south of the Rise which were more disparate in their faunal composition. A distinct assemblage was recorded from a site at c. 750 m on the southern flank of the rise. As in the earlier study (Probert et al., 1996), faunal composition differed between the northern and southern flanks of the rise, and faunal density again appeared to be highest on the southern side of the rise.

Dawson (1984) summarised the taxon-focused studies which were published in the 1960s and 1970s, as well as geologically-focused sampling (grabs and photo/video images) undertaken by New Zealand-German collaborative studies (in 1978 and 1981), when qualitatively describing the benthic fauna and assessing possible effects of phosphorite nodule mining on the rise. He noted that in the area where phosphorite resources were concentrated there was hard substratum suitable for colonisation by sessile fauna, and that a "quite extensive epifauna" of corals (such as *Goniocoralla dumosa*), bryozoans, cnidarians, bivalves and brachiopods developed. Dawson considered the "*Goniocorella* clumps" as "epifaunal oases" which "undoubtedly attract small fish as feeding areas and may well be more the centre of energy dispersal than the smoother parts of the Rise". Dawson's (1984) summary was in part based on the observations recorded by Kudrass & von Rad (1984b) from underwater imagery taken during the 1981 survey. Analysis of this imagery led these authors to note a series of correlations between the distribution of phosphorite nodules and macrobenthic fauna. In particular they noted that "colonies of branching corals (e.g., *Goniocorella dumosa*) and gorgonian corals form patches of dense growth, especially in areas where large phosphorite nodules cover the seafloor in Area 4 [eastern part of their study area]". They also remarked that "those corals are much less frequent in Areas 1 and 2 [western part of their study area] where phosphorite nodules are smaller.".Other positive correlations with nodules were noted for small burrowing crabs, molluscs, brachiopods, asteroids, and cidarid echinoids. Other types of echinoid were observed to show a negative correlation with visible phosphorite nodules (Kudrass & von Rad, 1984b).

The most recent studies of infauna and epifauna communities of the central crest of the Chatham Rise resulted in part from a survey undertaken in 2012 by Chatham Rock Phosphate Ltd to characterise the benthic habitats and fauna of the area they proposed to mine. Two other surveys in 2007 and 2013 funded by New Zealand government also contributed to a fuller description of the epifaunal communities. The results of these studies confirmed the general findings described by Dawson (1984) and Kudrass & von Rad (1984b), but also quantitatively described and identified the infaunal and epifaunal communities, and related their distribution to a suite of environmental variables (Leduc et al. 2015, Rowden et al., 2014). Of particular interest, was: (1) the identification of an infaunal community dominated by lysianassid and phoxocephalid amphipods which was strongly associated with the presence of high-density phosphorite nodules and may represent a nodule-specific community; (2) infaunal diversity was significantly correlated with topographic variables, and was greatest in areas with uneven topography and inside depressions; (3) the overall structure of the epifaunal communities is mostly relatable to the presence of mud/sand and phosphorite nodules; (4) two of the epifauna communities dominated by the stony coral *Goniocorella dumosa* show a patchy distribution and are associated directly with the presence of large phosphorite nodules that are concentrated in the proposed mining area, and a gradient in sea surface temperature that is indicative of a front that could be a site of enhanced productivity and flux of organic matter to the seabed; and (5) the aforementioned communities have not been observed elsewhere on the Chatham Rise, or in the waters around New Zealand.

4.4.2 Potential impacts

There have been few studies of the impacts or consider the potential impacts of phosphorite mining and processing on the marine environment published in the scientific literature (but see Dawson, 1984; Kudrass & von Rad, 1984b; Gnandi et al., 2006; Leduc et al., 2015). However, recent interest in phosphorite deposits off Namibia and New Zealand has resulted in a large number of studies assessing the various potential impacts resulting from phosphorite mining which are published as reports, most of which are available from the internet (e.g., http://www.epa.govt.nz/EEZ/chatham_rock_phosphate). The potential impacts are synthesised below, some of which may site-specific or might not be realized at all. However, until more studies have been

completed, particularly *insitu* disturbance-recovery experiments and potentially monitored trial mining, it is difficult to predict the full extent of the potential impacts from phosphorite mining.

The most significant impacts from phosphate mining are likely those associated with: (1) long-term persistence of sediment plumes, both from mining excavation and processing, that could adversely affect ecosystem functioning of benthic and pelagic components; (2) disruption of areas important for fish, not only where commercial fishing takes place but those areas significant for breeding and spawning of both commercial and non-commercial species; (3) contamination of waters (potentially coastal waters) from (a) exposure of deep anoxic sediments (particularly in upwelling areas) to the overlying water column and (b) processing effluent returned to the sea that could contain contaminants; (4) large-scale excavation and removal of soft sediment and hard substrates (e.g. large nodules on sediment surface that support coral dominated communities) which will affect sediment stratification and biogeochemistry, and rates of faunal repopulation; and (5) the possibility that large-scale sediment removal and dispersal will lead to tipping points regarding tolerances of benthic and pelagic life to changes in physical and chemical parameters such as dissolved oxygen, turbidity, and organic matter content of the sediment which could lead to ecosystem regime shifts. On land there are concerns about impacts on food-safety levels (e.g. in consumed fish) resulting from release of contaminants (e.g. cadmium, uranium) from sediments and disposal of processing waste.

Baseline Assessment and Monitoring

The assessment of impacts of marine mining will need to be completed in three phases: i) baseline information, ii) monitoring during mining, and iii) monitoring recovery.

5.1 Baseline assessment

Baseline assessments are required to determine the characteristics of the marine environment before any activity takes place. They need to be comprehensive so that the degree of disturbance can be assessed and recovery can be measured towards the pre-disturbance conditions.

The ISA requires its contractors to gather environmental baseline data and to establish environmental baselines against which to assess the likely effects of the Contractor's activities on the marine environment (ISA, 2013b). The regulations stipulate a robust statistical design in preparing the sampling strategy and the collection of physical, chemical, biological and other parameters that characterise the systems likely to be impacted by exploration and possible test mining activities. These data, in conjunction with any recommendations from the Legal and Technical Commission of the ISA, will be used to establish environmental baselines against which to assess the likely effects of the Contractor's program of activities. The environmental baseline in the exploration area incorporates seven groups of data: physical oceanography, chemical oceanography, sediment properties, biological communities, bioturbation, sedimentation, and geological properties (Figure 25).

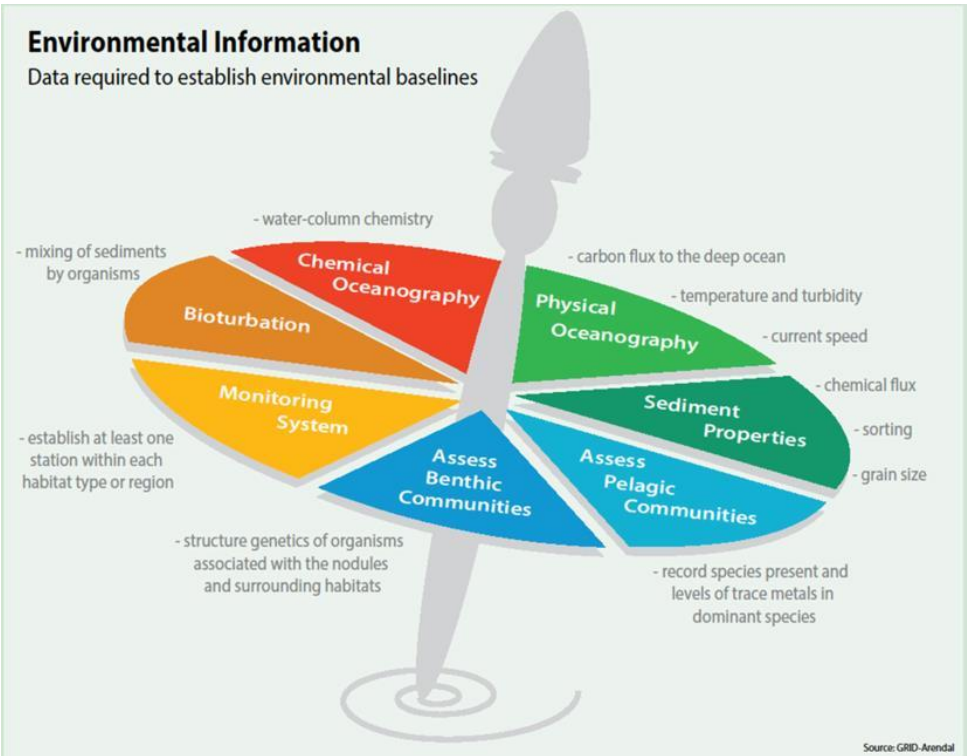

Figure 25: Environmental information required by the ISA to establish environmental baselines (from Lodge et al. 2013).

The types of data to be collected, the frequency of collection, and the analytical techniques used must follow the best available methodology and employ an international quality system and certified laboratories (Lodge, 2013).

Existing ISA regulations relate only to exploration and test mining. Regulations by the ISA related to exploitation are being discussed as part of the stakeholder engagement process that was begun in March 2015 (ISA, 2015b). Regulations that have been, or will be, developed by the nation states that are signatories to the UNCLOS must not be of a lower standard than those set by the ISA.

5.2 Monitoring during mining

The ISA has not developed regulations for monitoring during the mining activity. Measurements will need to be made to test predictions on a variety of parameters such as extent of excavation, generation or release of toxic chemicals, sound/light penetration, components of plumes including particle size, density and chemical nature, spread of plumes in three dimensions, integrity of riser and discharge pipes. Since deep-sea mining is a new activity it will be important to test all predictive models to ensure that impacts remain within agreed limits and to enable adaptive management by building on best practice. This testing will be particularly important for plume dispersion models and models of habitat impact.

The criteria have not been established for monitoring plume dispersion or habitat impact. For plumes it will be necessary to set appropriate thresholds to be measured, since the plume will extend almost infinitely becoming more and more dilute. Thresholds may take into account particle count and some measures of toxicity dependent on the material being mined. For habitat impact one commonly used standard in the laboratory is the LD_{50}, or the point at which 50% of individuals of a particular species are killed within a specified time. It is not clear if this could be used in mining areas but some measure of the impact of plumes on benthic organisms and over wide areas will need to be devised. In some areas where toxins as well as particulates are an issue it may be necessary to carry out bioaccumulation measurements on a range of key species. If the impacts extend beyond the licensed area, e.g. due to plumes, then rules will need to be put in place to establish who is responsible for the monitoring. This allocation of responsibility will become complex if the impacts extend into other licence blocks.

The appropriate timing of measurements will also be a factor to consider. For example, in nodule mining the collector will be constantly moving across the seafloor but the benthic plume may persist for days, months or years and may be reinvigorated when the collector passes on a new swath. Thus both the immediate impact and the cumulative impact over the duration of mining within the licence block will be important.

5.3 Monitoring after mining

The monitoring of recovery of ecosystems will be a major requirement of exploration mining licences. Some ecosystems, such as those in polymetallic sulphide mines may be able to recover to a pre-mined situation. This recovery may occur over a few years for vent faunas but is likely to take longer for the non-vent faunas that are located nearby. Full recovery will not be possible for the abyssal plain ecosystems affected by polymetallic nodule mining or phosphorite mining, since the nodule substrate will no longer be available (although a small number of nodules may remain, since collectors will not

be 100% efficient). It is assumed that the rest of the fauna will recover but this may be over very long timescales – e.g. tens to hundreds of years for polymetallic nodule mining on abyssal plains. In crust mining areas, recovery may also be very slow and the structure of the ecosystem may be different to the pre-mining state if the crusts themselves support a unique ecosystem as suggested by Schlacher et al. (2014).

The long recovery times will make it difficult to mount an effective monitoring programme and use this to guide adaptive management of mining activity, since an effective monitoring strategy could take 100 years. Nevertheless monitoring will be necessary so that we can learn more about impacts in the deep sea and take whatever steps necessary. Other issues will arise because the impacts may extend beyond the licence block (potentially into other licence blocks) due to the spread of plumes (Figure 22). Wedding et al. (2013) indicate that impacts of plumes could extend 100 km from the source. Rules will need to be put in place about the responsibilities of contractors to monitor beyond their licence block and to determine the extent of plume spread, and to continue long-term monitoring beyond the economic life of the mine site and in the event of a company's fiscal failure.

Monitoring ecosystem recovery in the deep sea over such vast areas is a completely new field with no established guidelines. The EU-funded MIDAS project (www.eu-midas.net) will address this issue, but it will be the responsibility of the ISA to put a set of regulations together for the Area, and nation states for mining within EEZs. Monitoring activities could involve photographic and video surveys in areas that have been mined and areas impacted by plumes. The percentage of impacted area to be covered, resolution, and frequency of survey will all need to be determined and may be different for each resource type. In addition seabed sampling will be required with a variety of measurements especially counts of biodiversity and biomass. The results will be compared to the baseline survey data to assess the speed of recovery.

5.4 Restoration and rehabilitation

Restoration refers to rebuilding the ecosystem that existed at the mine site before it was disturbed. Rehabilitation refers to the establishment of a stable and self-sustaining ecosystem, but not necessarily the one that existed before mining began. Neither process has been developed in the deep sea, and it may prove to be impossible due to the large pressure changes that would occur between the laboratory where organisms could be grown and the seabed where they would be introduced. Nevertheless, calls for a restoration fund to be set up to enable conservation and restoration research have been made (Barbier et al., 2014). The concept of restoration in the deep sea was addressed by van Dover et al. (2014b) who considered that some level of restoration or rehabilitation would be feasible, at least at relatively shallow water sites such as Solwara 1. For areas mined for crusts this would be difficult because of the complexity of the ecosystems and the large areas mined. For nodule-mined areas it would be impossible because of the extreme depths, large areas and very large numbers of species involved. However, even here it may be possible to improve the possibility of recolonisation through environmental engineering approaches.

Interaction of deep-sea mining with other activities

The interaction of deep-sea mining with other human activities will depend very much on different situations. In the central Pacific, for example, the CCZ is far away from almost all other human activities. In the Atlantic however, the Mid-Atlantic Ridge is crossed by commercial shipping routes, many trans-Atlantic cables and significant fisheries interests. A conclusion of the SEMPIA workshop (see Case Study 3 in annex to this report) was that these other human activities and established scientific research programmes all had a vested interest in the Atlantic part of the Area where mining may be considered. This potential interaction between mining and other interests is even more evident in national waters, for example Portuguese waters adjacent to the Azores. Studies to map pressures, undertaken by the University of Azores, illustrate potential conflicts and possible impacts of plumes from mining on established uses including fisheries, conservation and tourism.

Any list of possible activities that may interact with deep-sea mining may include fisheries, shipping, oil and gas, cables and pipelines, tourism and artificial reefs, sand and gravel extraction, mariculture, wind farms and other marine renewables, navigational dredging, waste dump areas including munitions etc. Each of these activities exhibit pressures (means by which they 'disturb' the environment such as siltation rate changes or habitat damage and habitat loss) but their specific status and trend is regionally or locally specific. Matrix methodologies have been used to inventory activity mixes as a basis upon which to analyse regional pressure trends.

Conflict is most likely when other activities may be displaced by deep-sea mining. For example, off Namibia, the phosphorite nodule resource is found within the same part of the outer continental shelf that supports fisheries and may be spatially incompatible in some ways. Off New Zealand, phosphorite nodule resources overlap in distribution with a Benthic Protected Area that is part of a network of protected areas designed to mitigate the effect of fishing. Thus the fishery's interest in offsetting its impact would be compromised should mining for phosphorite nodules be allowed to take place in this area.

Issues associated with multiple uses of ocean areas will be exacerbated by the environmental impacts of mining, such as smothering caused by plumes and remobilisation of toxic compounds that can affect neighbouring areas. Cumulative impacts on the natural ecosystems are likely to occur from many and/or repeated activities. Methodologies to account for cumulative impacts in the marine environment have proved difficult to establish and work in OSPAR and HELCOM over a sustained period has concluded this to be a "*complex and often nebulous concept unless targeted goals have been defined*" (OSPAR, EIHA 15/6/2). However, a summary of deliberations within OSPAR is considered useful and is presented in Case Study 5 in annex to this report.

Deep-sea mining also has a terrestrial component. Minerals resources extracted from the ocean will be brought ashore for processing. Interaction with other activities here on land could be positive or negative or both. For example, maritime activity to service vessels and mining operations could strengthen homeport business and support infrastructure improvements. But processing plants may also compete with other coastal interests, generate polluting wastes and reduce the aesthetic value of the land thereby reducing future residential usage or tourism potential.

Licensed exploration activity

Currently 19 countries are sponsoring States to licences in the Area (Table 2), with other countries such as Fiji, and Tuvalu also interested in future engagement. Eight countries have issued exploration licences in national jurisdiction, with other countries currently considering applications (Table 3). The Cook Islands are currently in the process of tendering ten exploration areas. There are also a few countries which are undergoing the process of developing policies legislation and regulations with the expectation of issuing exploration licences in the future, such as the Federated States of Micronesia, Kiribati, Niue, the Republic of the Marshall Islands, and Tuvalu.

Table 2: Status of ISA contracts for exploration in the Area as of 6 July 2015 (see International Seabed Authority, 2015a)

POLYMETALLIC NODULES					
Contractor	***Date of entry into force***	***Sponsoring State***	***Location of the exploration area***	***Date of expiry***	***Area km^2***
Interoceanmetal Joint Organization	29 March 2001	Bulgaria, Cuba, Czech Republic, Poland, Russian Federation and Slovakia	Clarion-Clipperton Zone	28 March 2016	75,000
Yuzhmorgeologiya	29 March 2001	Russian Federation	Clarion-Clipperton Zone	28 March 2016	75,000
Government of the Republic of Korea	27 April 2001	–	Clarion-Clipperton Zone	26 April 2016	75,000
China Ocean Mineral Resources Research and Development Association	22 May 2001	China	Clarion-Clipperton Zone	21 May 2016	75,000
Deep Ocean Resources Development Co. Ltd.	20 June 2001	Japan	Clarion-Clipperton Zone	19 June 2016	75,000
Institut français de recherche pour l'exploitation de la mer	20 June 2001	France	Clarion-Clipperton Zone	19 June 2016	75,000
Government of India	25 March 2002	–	Central Indian Ocean Basin	24 March 2017	75,000
Federal Institute for Geosciences and Natural Resources of Germany	19 July 2006	Germany	Clarion-Clipperton Zone	18 July 2021	75,000
Nauru Ocean Resources Inc.	22 July 2011	Nauru	Clarion-Clipperton Zone (reserved area)	21 July 2026	75,000
Tonga Offshore Mining Limited	11 January 2012	Tonga	Clarion-Clipperton Zone (reserved area)	10 January 2027	75,000
Global Sea Mineral Resources NV	14 January 2013	Belgium	Clarion-Clipperton Zone	13 January 2028	75,000
UK Seabed Resources Ltd.	8 February 2013	United Kingdom of Great Britain and Northern Ireland	Clarion-Clipperton Zone	7 February 2028	58,600

Marawa Research and Exploration Ltd.	19 January 2015	Kiribati	Clarion-Clipperton Zone (reserved area)	18 January 2030	75,000
Ocean Mineral Singapore Pte Ltd.	Signed in Kingston on 15 January 2015 and in Singapore on 22 January 2015	Singapore	Clarion-Clipperton Zone (reserved area)	21 January 2030	75,000
UK Seabed Resources Ltd.	To be signed	United Kingdom of Great Britain and Northern Ireland	Clarion-Clipperton Zone	–	148,000
Cook Islands Investment Corporation	To be signed	Cook Islands	Clarion-Clipperton Zone (reserved area)	–	75,000
China	To be signed	China	Clarion-Clipperton Zone		
POLYMETALLIC SULPHIDES					
Contractor	***Date of entry into force***	***Sponsoring State***	***Location of the exploration area***	***Date of expiry***	***Area km²***
China Ocean Mineral Resources Research and Development Association	18 November 2011	China	South-west Indian Ridge	17 November 2026	10,000
Government of the Russian Federation	29 October 2012	–	Mid-Atlantic Ridge	28 October 2027	10,000
Government of the Republic of Korea	24 June 2014	–	Central Indian Ocean	23 June 2029	10,000
Institut français de recherche pour l'exploitation de la mer	18 November 2014	France	Mid-Atlantic Ridge	17 November 2029	10,000
Government of India	To be signed	–	Indian Ocean Ridge	–	10,000
Federal Institute for Geosciences and Natural Resources of Germany	6 May 2015	Germany	Central Indian Ridge and South-east Indian Ridge	5 May 2030	10,000
COBALT-RICH CRUSTS					
Contractors	***Date of entry into force***	***Sponsoring State***	***Location of the exploration area***	***Date of expiry***	***Area km²***
Japan Oil, Gas and Metals National Corporation	27 January 2014	Japan	Western Pacific Ocean	26 January 2029	3,000
China Ocean Mineral Resources Research and Development Association	29 April 2014	China	Western Pacific Ocean	28 April 2029	3,000
Ministry of Natural Resources and Environment of the Russian Federation	10 March 2015	–	Magellan Mountains in the Pacific Ocean	9 March 2030	3,000
Companhia de Pesquisa de Recursos Minerais S.A.	To be signed	Brazil	Rio Grande Rise in the South Atlantic Ocean	–	3,000

Table 3: Overview of current deep-sea exploration and mining licenses (including license applications) issued by national governments for polymetallic nodules/SMS, polymetallic sulphides and cobalt- rich crusts. (after ECORYS, 2014).

Contractor	Date of entry into force of contract	Date of expiry of contract	General location of exploration area under contract	Type	License	Depth	Area (km^2)
Diamond Fields International	2010	2040	Deep Sea II project, Red Sea	SMS	Mining	1900 – 2200	62
Pacific Islands							
Nautilus Minerals	2011	2030	Solwara 1 project, Manus Basin, Papua New Guinea	SMS	Mining	1600	59
Nautilus Minerals Inc.	Granted and under application		Papua New Guinea – Woodlark Area	SMS	Exploration		255 (Granted) 3543 (under app)
Nautilus Minerals Inc.	Under application		Papua New Guinea – New Ireland Arc	SMS	Exploration	1500 - 2000	12788
Neptune Minerals	2012	2014	Papua New Guinea	SMS	Exploration		2568
Nautilus Minerals Inc.	19 July 2011	18 July 2014	Solomon Islands	SMS	Exploration		39500
Bluewater Minerals (Nautilus subsidiary)	2007	2014	Solomon Islands	SMS	Exploration		9840
Nautilus Minerals Inc	Granted, year unknown		Kingdom of Tonga	SMS	Exploration	965 – 2360	77563 (granted) 131878 (under app)
Neptune Minerals	2008	2014	Kingdom of Tonga	SMS	Exploration		63949
Korean Institute of Ocean Science and Technology (KIOST)	2008	2014	Kingdom of Tonga	SMS	Exploration		24500
Nautlilus Minerals	2014	2016	Fiji		Exploration		60370
Bluewater Minerals (Nautilus subsidiary)	2012	2014	Fiji	SMS	Exploration		5012
Korean Institute of Ocean Science and Technology (KIOST)	2008	2014	Kingdom of Tonga	SMS	Exploration		24500
Nautilus Minerals	2014	2016	Fiji	SMS	Exploration		
Nautilus Minerals Inc	Granted, year		Vanuatu	SMS	Exploration	1000 - 3000	2768 (granted)

	unknown						1247 (under app)
Bismarck (Neptune subsidiary)	2011 & 2012	2014 & 2015	Vanuatu	SMS	Exploration		10183
Neptune Minerals	Under application		Federated States of Macronesia	SMS	Exploration		
Neptune Minerals	Under application		Palau	SMS	Exploration		
Japan							
Japan Oil, Gas & Metals National Corp (JOGMEC)	2008		Izu & Ogasawara Island Chain & SW Okinawa Islands, Japan	SMS & crusts	Exploration		
Neptune Minerals	Under application		Japan		Exploration		1853
New Zealand							
Nautilus Minerals Inc	Under application		Bay of Plenty, New Zealand (Permit No 39348)	SMS	Exploration		52820
Neptune Resources	Under application		Gisborne, New Zealand (Permit No 53828)	SMS	Exploration	1000 – 1800	3448
Europe							
Nautilus Minerals Inc	Under application		Azores	SMS	Exploration		5904
Nautilus Minerals Inc	Under application		Italy (Tyrrhenian Sea)	SMS	Exploration	500 – 1000	
US / Commonwealth							
Neptune Minerals	Under application		Commonwealth of the Northern Mariana Islands (CNMI), Back-arc basin	SMS	Exploration		147000

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Annex : Case studies

Case Study 1. Solwara 1, Papua New Guinea

Nautilus Minerals plans to begin mining SMS mineral deposits at its Solwara 1 site off shore Papua New Guinea (PNG) in 2018. The site is located in the Bismarck Sea 30 km off the coast of New Ireland Province and at 1600 m water depth. The resource is of high-grade polymetallic sulphide deposits rich in copper and gold with indicated resources of 1,030,000 t of ore containing 7.2% copper and 5.0 g/t gold and inferred resources of 1,540,000 t of ore containing 8.1% copper and 6.4 g/t gold (results based on a copper equivalent cut-off grade of 2.6%) (Lipton, 2012)

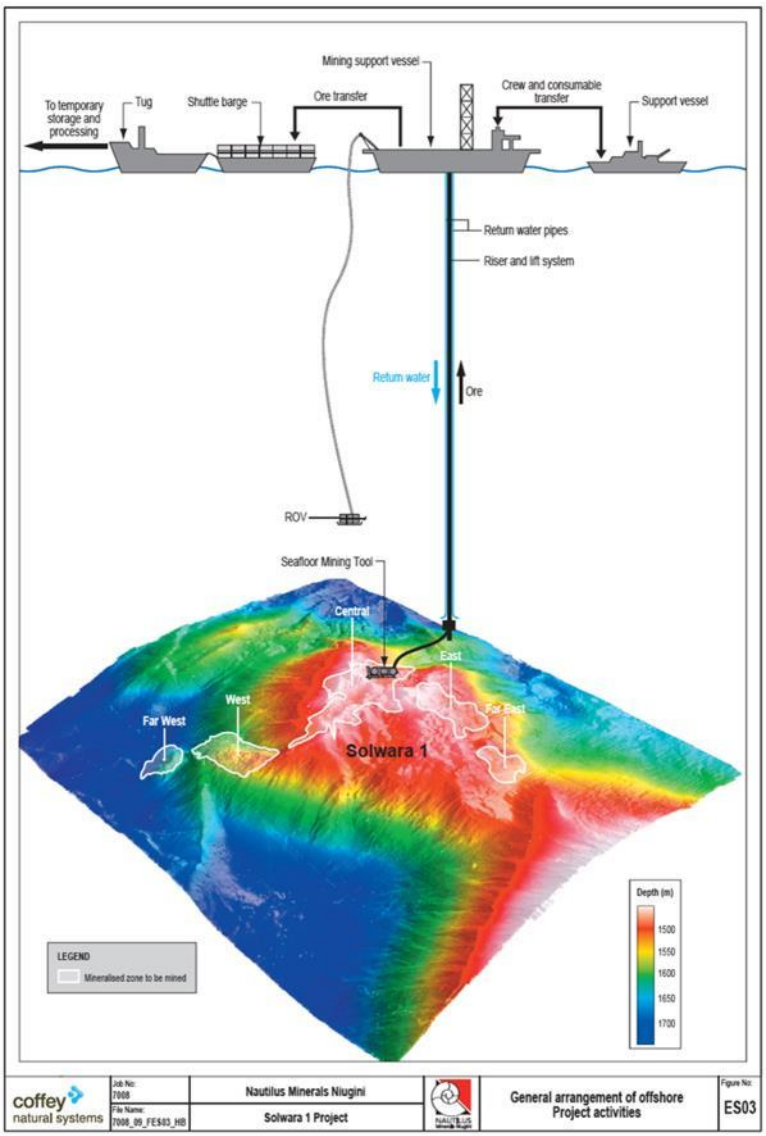

Figure A1: Cartoon showing planned mining activity at Solwara 1. From Coffey Natural Systems, 2008.

The Solwara 1 deposit is one of many sites investigated in the Bismarck Sea and, together with Solwara 12, are the only ones so far so far to have proven commercially viable resources (Hein and Petersen, 2013). The Solwara 1 Field was first identified by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) in 1996. Extensive research campaigns between 1993 and 1997 formed the knowledge base for what would become more intensive commercial development activities. Nautilus Minerals submitted the Solwara 1 Environmental Impact Statement to the PNG

Government in September 2008. The main potential impacts to the environment during the production phase of the Solwara 1 Project were identified as[1]:

1 Material and habitat removal (seafloor);
2 Plume generation / water quality disturbance from cutter head (dead sea);
3 Plume generation / water quality disturbance from return water (seafloor, > 1,300 metres); and
4 Noise / vibrations (on the seafloor and at the surface).

Nautilus was granted its first Mining Lease in January 2011 for Solwara 1, and the Environmental Permit for Solwara 1 was awarded in December 2009[4].

The following is taken from the Nautilus Minerals Environmental impact Statement (Coffey Natural Systems, 2008). The mine area will comprise five disconnected zones that will be mined consecutively (Figure A1). Prior to mining, approximately 130,000 t of unconsolidated sediment will be removed from the five zones and pumped across the seafloor. Additionally, approximately 115,000 t of competent waste material, which is below the mine cut off grade, will be side cast during mining operations. The plume generated by these operations is expected to deposit 0.18 to 500 mm over an area of 2.3 $km^{2.}$

The active venting sites at Solwara 1 and at South Su, are characterised by a number of biomass-dominant species including the gastropods *Alviniconcha* sp. and *Ifremaria nautilei* as well as *Eochionelasmus* sp. (a barnacle) and, at South Su only, the mussel *Bathymodiolus manusensis*. These occur at various densities at different vent sites. These zones of dense animal biomass also provide habitat for many other species, including crabs, squat lobsters, shrimps, limpets and polychaete worms that live in association with the biomass-dominant snails and barnacles.

Away from the active vents there are distinct faunal communities associated with hard surfaces both close to vents with potential for peripheral influence of chemotrophic energy source, and remote from vents. The most conspicuous and characteristic species colonising inactive sites are:

1. Suspension-feeding bamboo corals *Keratoisis* sp.
2. Stalked barnacles Vulcanolepas parensis
3. Hydroids
4. Carnivourous sponges *Abyssocladia* sp.

Unconsolidated sediments are found both associated with diffuse venting and remote from venting areas. Macrofaunal studies in these sediments show that faunal densities in active and inactive sediments are very low - only 220 individuals representing 15 species were observed in 35 cores sampled. The dominant taxa were tanaids (crustaceans) and nuculanoid bivalves at both the Solwara 1 sites and at the South Su inactive site. Meiofauna (53 – 500 µm) are much more abundant especially nematodes and harpacticoid copepods, though even these may be less abundant than elsewhere in the world.

Nautilus Minerals list a number of mitigation strategies in their EIS report including setting aside a reference area to provide a source of recruitment on the South Su volcano which is located 2km up-current from the mine areas; transplanting of some sessile animals to temporary refuges and then returning them when mining has ceased; establishing hard surfaces for settling of bamboo coral larvae; limitation of the plume area – the transfer of the returned water to 25-50 m above the seabed will help in reducing mid water impacts. All of these measures will need to be tested to measure their benefit when mining actually begins. Only then can the full scale of impacts be measured including

[1] *(From http://www.cares.nautilusminerals.com/irm/content/solwara-1-project.aspx?RID=339)*

impacts on vent faunas, non-vent faunas and any problems related to toxicity caused by the release of sulphides due to the mining operation itself.

Van Dover, (2010) makes the following remarks about recovery of faunas at Solwara 1: For Solwara 1 in the Manus Basin, “visual” recovery of vent populations from mining activities is expected to be rapid: within 5 years, differences in biomass and even relative abundance of dominant taxa (snails, barnacles, limpets, shrimp, etc.) seem likely to be difficult to distinguish from pre-mining patterns. Recovery of rare species may require decadal time-scales. Accumulation of other rare species also seems likely, with perhaps no net gain or loss of species diversity within a decade. The risk to genetic diversity will vary by species, depending on the extent to which species’ populations are structured at fine scales (10 km). For inactive sulphide mounds, “visual” recovery may be decadal in scale. Relatively low population densities and slow recruitment and growth rates will likely make it difficult to assess recovery, and apparent or real local loss of species for many years seems probable.

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Case Study 2. Atlantis II Deep, Red Sea

The Atlantis II Deep is the largest metal-rich sea-floor sulphide deposit discovered to date, with an estimated 90 million tons of ore. The site comprises four interlinked sub-basins in 2000 m water located in the Red Sea, approximately 115 km west of Jeddah. The mineralization largely consists of metalliferous muds, instead of massive sulphides, which is a consequence of the high salinity that the hydrothermal fluids acquire by circulation through thick Miocene evaporates at the flanks of the Red Sea rift.

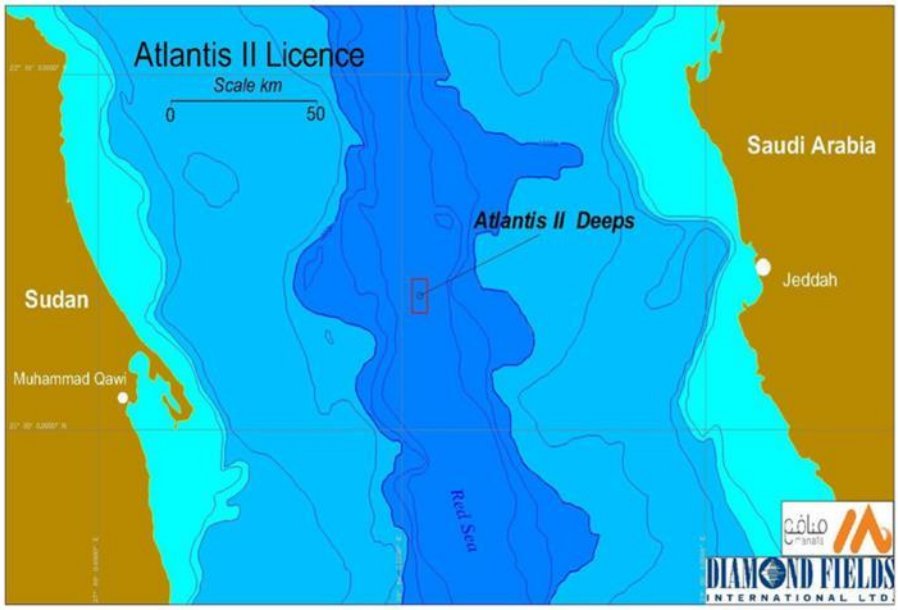

Figure A2: Location of the Atlantis II licence area in the Red Sea. From www.diamondfields.com/s/Image.asp?i=photos/atlantis/Atlantis-Map1.jpg&id=417476

In the 1970s, a pre-pilot test mining study was conducted by a German company (Preussag A. G.). Using what was described as "conventional floatation" means, they recovered 15,000 m^3 of seafloor sediments and brines from four test sites in the Atlantis II basin. They also proceeded to concentrate the recovered material at sea. Environmental and biological assessments were made as part of the MESEDA Programme (see report by Karbe et al., 1981). In 2010 the Red Sea Commission awarded a 30-year licence to develop the Atlantis II deposit to Manafa International Ltd., a Saudi Arabian company based in Jeddah. Diamond Fields has entered in to a joint venture agreement with Manafa to pursue the project. Progress on the project is currently on hold pending a dispute between Manafa and Diamond Fields International.

ECORYS (2014) summarised the findings of the Karbe report as follows:

- Sub-surface, deep-water discharge of tailings: The report stresses the importance of good management and monitoring of tailings discharge in the context of the conservation and protection of marine life in the central Red Sea, adjacent coasts, and adjacent areas that are home to coral reefs.
- The report highlights how planktonic organisms in the vicinity of the possible tailings plumes are the most vulnerable life forms that would be affected by heavy metals and chemical processing agents that could be discharged. In addition, subsequent leaching of any tailings

(release of zinc, copper, cadmium, mercury, and other toxic elements) would produce an important ecological stress.

- The report also describes the high level of uncertainty with respect to the in-situ effects of tailings on oceanic plankton. There are noted concerns as to the fate of plankton that may transport certain levels of toxic elements from the area near the mining activity to other biological communities further afield. It was also noted that the addition of volumes of inorganic material into the “detritus-seston” flow could affect the food supply of deep-water benthic organisms.
- The report notes how plankton recruitment from areas to the South of the mining site would be vital for the recovery of Central Red Sea deep-water ecosystems. A better understanding of population dynamics is therefore needed as so many unknowns persist that limit the ability to properly manage the conditions for recovery.
- The study noted that the impact of tailings discharge on the benthic environment would include both physical and toxicological effects. They calculated a 1,500 km2 area of tailings spread within which areas of intense sedimentation would lead to the creation of an azoic zone. Beyond the area of most intense impact, reduced levels of sedimentation could permit some organisms to survive.
- The study examined the longevity of tailings in the water column and how the residence time might influence the effects of toxicological hazards on benthic organisms. Some leaching trials showed notable removal of heavy metals within a period of two-to-three weeks. Such leaching processes would likely reduce the toxicological risk of tailings that might deposit in the overall impacted area and could thus favour survival of benthic organisms and enable better conditions for post-mining recovery.
- The study warned of possible long-term risks associated with bio-accumulation of toxic heavy metals within the trophic levels of the epipelagic and mesopelagic zones. The more widespread the distribution of tailings materials the higher the risk of unforeseen, long-term environmental issues.
- The report also highlighted how the potential release of natural high salinity brines into the bottom waters of the Red Sea could be enough to cause localised mortality of organisms if not properly mitigated.

Finally, the report outlined a series of key recommendations should mining of the deposit be considered:

1. Pilot mining operations and environmental assessment should take place for at least a 2 year period in order to identify and measure the full-scale of environmental and social impacts of the specific operations.
2. In order to be realistically comparable to actual full-scale mining (with respect to relevant environmental monitoring strategies), pilot mining operations should be conducted in a manner well representative of full-scale mining.
3. For any mining activity, tailings discharge must be restricted to depths greater than 1,100m. It should however be kept in mind that further research may modify this minimum depth level.
4. Monitoring plans must include observations of particulate plume development and sedimentation, observation of ‘liquid’ plume development and its possible extended distribution and observations on potentially toxic substances in relation to ambient concentrations.
5. A solid baseline understanding of the fate of tailings during full scale mining operations needs to be established in advance in order to plan contingencies and set up emergency response plans. Focused research must be directed to address the needs of a proper environmental monitoring programme that would be implemented during mining. This research needs to include:

1.1 An examination of whether plankton replenishment by species from the Gulf of Aden is a viable process to aid in the recovery of habitats destroyed by mining.
1.2 An examination of the nutrient exchange pathways between the Open Ocean and coastal regions.
1.3 Studies to distinguish between impacts caused by the mining activity and similar impacts caused by other land-driven natural and man-made sources.

A large amount of environmental work would therefore be required before mining could take place in the Atlantis II Deep.

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Case Study 3. The SEMPIA workshop

Towards the development of a Strategic Environmental Management Plan for deep seabed mineral exploitation in the Atlantic basin of the Area (SEMPIA)

A scoping workshop to consider issues relevant to an Atlantic SEMP took place in Horta, Azores, Portugal from 1-3 June 2015. At a strategic level, there is a challenge to plan for environmentally sustainable exploitation at the scale of an ocean basin. Such a plan needs to balance the economic benefits of mineral extraction with the value of ecosystem services and the conservation of marine ecosystems, whilst taking appropriate account of other maritime activities. As its geographic scope, the workshop focused on the Area in the North and South Atlantic, in particular the Mid Atlantic Ridge (MAR) and the Rio Grande Rise (RGR) (Figure A3). A Pre-Workshop Data report was compiled to support and inform the workshop. This report collated information from available publications, biogeographic databases, experts, online libraries and habitat suitability models. Data was sourced from major repositories including OBIS, Pangaea, and EMODnet as well as other portals. Data availability was skewed to the northern part of the MAR owing to the paucity of data in the South Atlantic. The workshop agreed that extra effort was needed to obtain existing data. A number of sources were highlighted such as the 37th cruise of the RV Professor Logachev completed in April 2015.

The outcomes from a workshop held in Dinard in 2010 on guidelines for the conservation of vent and seep ecosystems (Van Dover et al., 2011) informed the 2015 SEMPIA Workshop. Design principles for protecting these ecosystems must take account of natural management units based on genetic connectivity as well as conservation planning needs to address the different faunal communities found on active and inactive vents as well as fauna occurring on rocky slopes and in sediments. In particular the description of NW Atlantic EBSA Area No. 7 was taken into account. This EBSA description recognises that not all vents along the MAR have been surveyed, some being inferred based on detection of a chemical signature from the plume in the overlying water column. Such vents are unique habitats dominated by high temperatures and sulphur-rich chemistry supporting a small number of endemic taxa that can occur at high density and biomass, for example dense microbial communities and bresiliid shrimps. Hydrothermal vents form relatively small structures and have communities that are highly localised and are therefore vulnerable to disturbances at local scales including changes to the thermal and chemical properties of the surrounding water column and significant mortality through crushing, loss of available habitat and loss of localised communities (CBD 2014, p.107).

The workshop agreed that further work was needed to produce a detailed scientific case for consideration by the International Seabed Authority (ISA). To that end a roadmap was elaborated, proposing a series of further scientific meetings to establish a robust basis upon which to base an Atlantic SEMP. High-level outcomes from the 2015 SEMPIA workshop were presented to the ISA. The workshop recognised that the ISA has exclusive competence for management of mining-related activities in the Area, and it would be for the ISA to develop, recognise and adopt any SEMP. Thus the roadmap also seeks to interact with future ISA meetings and any SEMP-related initiatives suggested by the ISA Legal and Technical Commission. Workshop participants wished to work with the ISA to achieve an Atlantic SEMP.

In July 2015, at the 21st Session of the International Seabed Authority, the ISA Legal and Technical Commission (hereafter the Commission) "*supported the rationale for an environmental management plan for the Mid-Atlantic Ridge. It noted that a robust scientific case would be developed by the [SEMPIA] workshop participants over the coming years and it was expected that a report would be submitted for consideration and development by the Commission in 2017*". Furthermore, a subsequent Decision by the ISA Council "*Encourages the Commission and the Secretariat to make progress on*

the development of environmental management plans in other international seabed area zones, in particular where there are currently contracts for exploration, in line with the suggestion made by the United Nations General Assembly in paragraph 51 of its Resolution 69/245".

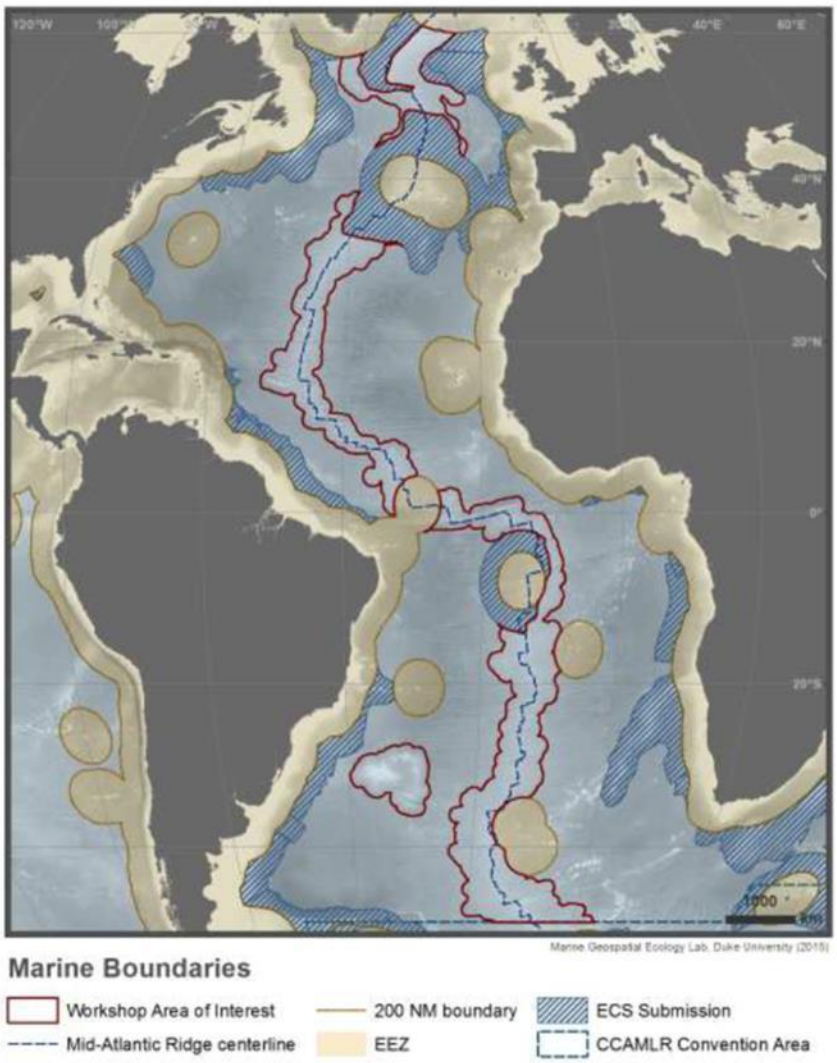

Figure A3: Map of the Mid-Atlantic Ridge, indicating the SEMPIA workshop areas of interest.

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Case Study 4. The Clarion-Clipperton Zone (International Seabed Authority)

Source: text extracted from Johnson and Ferreira, 2015 with updates

The abyssal sediments of the extensive Clarion-Clipperton Zone (CCZ) in the central Pacific represent an established location where a number of State and State Party Contractors to the ISA have been undertaking exploration activities since 2001 and others, including private sector mining corporations, have subsequently been granted exploration licenses (Lodge et al., 2014).

Eventual exploitation in the CCZ will be informed by an Environmental Management Plan (EMP) adopted by the ISA in 2012 (ISBA/18/C/22), to be implemented progressively over an initial three-year period.

The CCZ-EMP sets out a framework of management measures such as Preservation Reference Areas within each Contractor's licence area, as well as a mosaic of nine large Areas of Particular Environmental Interest (APEIs) outside the license areas (see Figure A4). The size and location of the APEIs were proposed at a workshop held in Hawai'i in 2007, where experts recognized the existence of latitudinal and longitudinal productivity gradients in the CCZ, both of which drive changes in the seabed community composition across the region.

Experts recommended "that the zone be divided into three east-west and three north-south strata, with representative preservation reference areas being placed in each of the nine resultant subregions". They further recommended that, in order to "preserve representative and unique habitats, all habitat types for a subregion should be included within a preservation reference area". However, experts acknowledged that whereas "a variety of general habitat types can be recognized" within the CCZ, the biota of seamounts and fracture zones remain "essentially unstudied so the uniqueness of associated biota cannot be assessed". Results from the "Kaplan Project", designed to assess the biodiversity, species ranges, and gene flow in the abyssal Pacific nodule province (CCZ) indicated "high, unanticipated, and still poorly sampled levels of species diversity" of sediment-dwelling faunal components at the sampling locations, and higher habitat heterogeneity than previously assumed. These findings suggest the existence of a characteristic fauna of the abyss, but one which may differ substantially across the CCZ, increasing concerns regarding appropriate representativeness of selected reference protection areas (ISA, 2008)

The original intention was to protect 30–50% of the total CCZ management area, capturing the full range of habitats and communities therein. The size of each protected area should allow for the maintenance of viable population sizes of potentially endemic species (Wedding et al., 2013; Wedding et al., 2015). The final proposal established a mosaic of nine APEIs, one in each biogeographic subregion. Each APEI includes a core area of 200 km Å~ 200 km (40,000km^2), surrounded by a buffer zone 100 km wide (120,000km^2), resulting in a total area per APEI of 400km Å~ 400km (160,000 km2). This proposal placed roughly 1.5 million km^2 of the 4.5 million km^2 CCZ management area under protection – an area larger than that currently licenced for exploration for polymetallic nodules. The proposed terminology of APEIs was selected, provisionally, to avoid confusion with other initiatives to establish marine protected areas (MPAs) in the high seas.

During the summer of 2015 a UK National Oceanography Centre led research cruise studied aspects of the biology and geochemistry of the north-easternmost APEI (APEI-4). An archive of seabed photos, seafloor maps and sediment samples from this cruise will provide a strong baseline dataset for abyssal benthic communities present. The Natural History Museum in London will analyse ca. 600 invertebrate specimens including sponges, crustaceans, molluscs and annelid worms collected during

the cruise. Most are unknown to science. The JPI-Oceans (The Joint Programming Initiative Healthy and Productive Seas and Oceans) research cruise in 2015 made comparable investigations in APEI-3.

The ISA is trying to coordinate data inputs from all contractors to the ISA in order to refine the EMP based on a combined data set from contractors and scientific expeditions. This includes sampling in other APEIs by some contractors and results of taxonomic standardization workshops (see ISA, 2015).

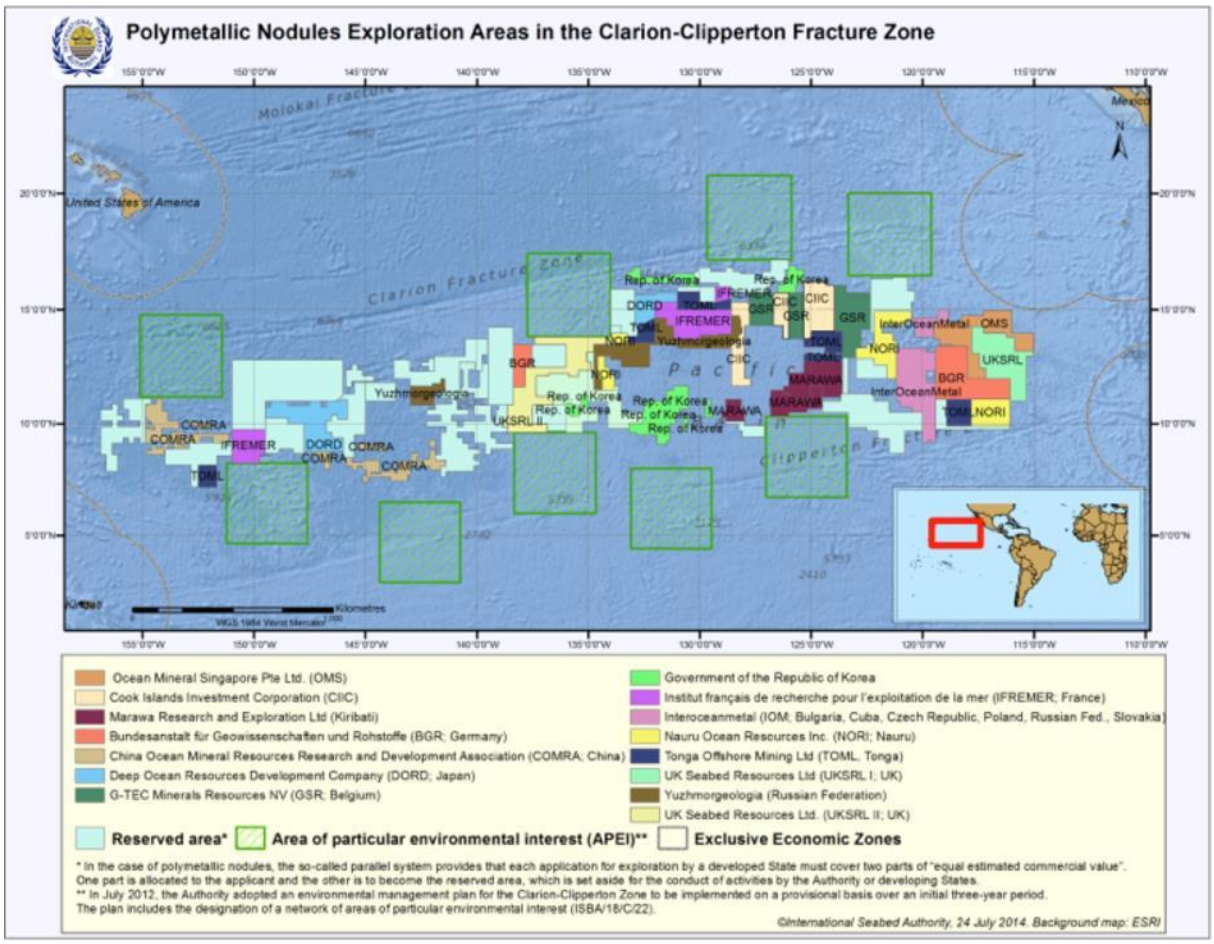

Figure A4: Map of the Clarion-Clipperton Zone showing license areas for polymetallic nodule exploration and the location of APEIs. The figure also shows the areas reserved for ISA. Map used with permission from the ISA.

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Case Study 5. OSPAR Cumulative Effects Assessment

OSPAR, the Regional Seas Convention for Protection of the Environment of the North-East Atlantic, has been considering Cumulative Effects Assessments (CEA) since 2008. At that time national exercises undertaken by the Netherlands EEZ, Norwegian Sea and UK Celtic Sea were evaluated. Main considerations at that stage included calculation schemes, approaches to cumulative, GIS-implementation, and pressures maps.

The QSR 2010 (OSPAR, 2010) reported on a pilot assessment (the 'Utrecht Workshop') that yielded the first indication of cumulative effects, using expert judgement to complement dataset where these were limited. This was considered promising for sessile species but less applicable to mobile species.

Subsequently OSPAR has worked to standardize terminology and identify suitable approaches to CEA including common principles. OSPAR's Environmental Impacts of Human Activities Committee (EIHA) 2015 reviewed a risk-based conceptual model for CEA developed from these common principles. In summary OSPAR (EIHA 15/6/2, Annex 1) noted that:

1. the terms 'cumulative', 'in combination' and 'collective' (Environmental Impacts Assessment Directive, Habitats Directive and Marine Strategy Framework Directive respectively) are in wide use by practitioners engaged in undertaking and evaluating environmental assessments of 'effects', 'impacts' and/or 'pressures' without clarity on how these terms should be defined and applied in environmental management operations;

2. this ambiguity has resulted in some projects working through legislative drivers and others considering the scientific interactions of environmental pressure and how these may combine cumulatively;

3. CEA can be defined as 'a systematic procedure for identifying and evaluating the significance of effects from multiple stressors and/or activities and for providing an estimate on the overall expected impact to inform management measures'. The analysis of the causes (source of stressors), pathways and consequences of these effects on receptors is an essential and integral part of the process;

4. for the assessment of the cumulative effects of multiple stressors it is critical that a complete inventory of the stressors potentially present in a scenario is drawn prior to the assessment; and

5. the interaction used for predicting the joint effects of multiple stressors plays a critical role in the CEA process. The preferred approach may be based on an additive model but one that is open to synergistic or antagonistic interactions. In turn this depends on empirical evidence of stressor interaction.

As part of CEA efforts to implement the MSFD, Vina-Herbon et al. 2015 showcased work on developing and testing an OSPAR Common Indicator[2] termed the 'extent of physical damage to seafloor habitats', that will help evaluate to what extent the integrity of the seafloor and associated ecology is being damaged by anthropogenic activity using a combination of sensitivity assessments and exposure to pressures. The process includes compiling habitat data, assessing habitat resistivity, reviewing the extent and distribution of physical damage (concentrating on surface and sub-surface

[2] *OSPAR 2013 agreed that Common Indicators should be used for assessing the status of and pressures on the marine environment of the OSPAR Maritime Area. HELCOM have a similar initiative under the HELCOM CORESET II Project and the two Regional Conventions are working together where possible.*

abrasion caused by fisheries working with ICES data), determining disturbance categories and finally calculating a Physical Damage Index.

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