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POSTNOTE

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Deep-Sea Mining

In March 2013, the Prime Minister said that deep-sea mining could be worth £40bn to the UK over the next 30 years.[1] This briefing summarises the framework governing activity in international waters. It also describes the mineral deposit types being considered and the proposed extraction methods, potential environmental effects and mitigation options.

Overview

- The first deep-sea mining in national waters, off the coast of Papua New Guinea, may begin in 2018. For the UK, current deep-sea mining focus is on international waters, regulations for which are under development.
- Three different types of deposit are being considered, each associated with a distinct geology and ecosystem. However, the extreme environment of the deep sea poses new engineering challenges.
- Some deposits are found in areas that are known to have high ecological value.
- The environmental impacts of deep-sea mining are uncertain because little is known about deep-sea organisms, their distribution or their sensitivity to disturbance.

Background

Where oceans are more than 500 m deep they are referred to as the 'deep sea'.[2] Valuable minerals are known to be deposited at or near the surface of the deep seabed. Such deposits were first considered for extraction in the 1960s,[3] but at that time it was technologically and financially unfeasible.[4] There has been renewed interest in the last decade because of the growing demand for metals, the increasingly inaccessible and degraded land-based deposits and advances in marine submersible and mining technology.

Exploration for three main types of mineral deposit in international waters is regulated by the International Seabed Authority (ISA), a body established under the 1982 UN Convention on the Law of the Sea (UNCLOS).[5-7] In 2014, The Deep Sea Mining Act was updated to bring UK law in line with UNCLOS.[8] However, international regulations for commercial recovery (mining) are still being developed by ISA.[9] The UK has world-leading marine engineering, marine science and marine consultancy industries. It has been estimated that deep-sea mining activity in international waters could involve a supply chain of up to 100 British companies and create thousands of jobs.[1]

No deep-sea mining in international waters has yet taken place, but UK Seabed Resources is exploring a specific geographic area of the Pacific Ocean. Deep-sea exploration is being undertaken in national waters, subject to the regulations of those nations. On the basis of exploration, Nautilus Minerals has stated that it plans to begin mining in Papua New Guinea national waters in 2018.[10]

There are concerns about the potential environmental impacts of mining, and bodies such as the Deep Sea Conservation Coalition, have called for a moratorium on deep-sea mining activities pending public debate and regulatory development.[11-14] It was only discovered in the 1960s that the diversity of life in the deep sea could be as high or higher than in shallow water,[15] and the deep sea remains largely unexplored.[16] This POSTnote sets out:

- the resource security challenges driving deep-sea mining and the current and future regulatory framework
- the three deep-sea deposit types being considered and the mining technologies that are being developed
- current knowledge about deep-sea ecosystems and the potential impacts from mining activities.

Resource Security and Legislation

Global metal prices have been declining since 2011 and are expected to continue to do so in the short term because of new production capacity and lower demand.[17] In the medium to long term, a growing global population, the emerging economies and a larger low carbon sector are expected to increase demand and prices for metals.[18,19] There are also concerns about security of supply, particularly for rare earth elements (REEs), which are used in many high-tech goods, such as mobile phones, as well as low-carbon technologies, such as solar panels (POSTnote 368). China produces 91% of the world's REEs[20] and is the source of 41% of REE imports into the EU.[21] It imposed strict quotas to limit exports until this year, when they were lifted following a Word Trade Organisation ruling.[22]

In 2011, the House of Commons Science and Technology Committee published a report expressing concerns about supplies of critical metals for the UK. It observed that there may be a need to exploit lower grade minerals to meet growing demand.[23] In response, the Government released the 2012 Resource Security Action Plan, which also discussed the necessity of further primary extraction.[24] Investing in deep-sea mining is just one way to meet future demand.[25,26] Other options include:

- designing products to make the recycling of REEs economically desirable[27]
- substituting current technologies with ones that do not need REEs[24]
- investing in alternative land-based mining resources, such as abandoned mines.[28] Although declared land-based resources are being depleted, innovations in exploration, extraction and processing allow the exploitation of previously inaccessible resources.[25]

Mining in National Waters
UNCLOS defines waters within 200 nautical miles as the exclusive economic zone (EEZ), where signatory states have sovereign rights over resources of the sea. It also recognises that some states are entitled to a continental shelf beyond this 200 nautical mile limit. To claim this, they must submit information on their outer limits to the Commission on the Limits of the Continental Shelf.[29] The expectation is that UK offshore waters will contain deposits of interest,[30] but these have not yet been officially identified. Although all three mineral deposit types (see below) have been identified within UK Overseas Territories waters, their commercial potential is unknown.[31] There are concerns about the capacity of governments of small developing states, particularly Pacific Island states, to manage deep-sea mining in their national waters.[12]

Mining in International Waters
Beyond the EEZ or extended continental shelf (in legislation, known as the 'Area') mineral resources are regulated by ISA (Box 1),[29] which has established a Mining Code that includes prospecting and exploration regulations.[5-7]

Deep-Sea Mineral Deposits
The deep sea contains a range of different minerals which naturally occur in three main types of deposit:

- seafloor massive sulphides (SMS)
- polymetallic nodules
- cobalt-rich crusts.

Other deposits found in the deep sea that are being considered for extraction include phosphate deposits (POSTnote 477)[34,35] and REE-rich muds,[36] but these are not yet covered by international regulation.

Box 1. Regulation of Deep-Sea Mining

The International Seabed Authority (ISA)

To enter into a contract with ISA, contractors must be sponsored by a state government, pay an application fee of $500,000 and submit work plans, which are reviewed by the Legal and Technical Commission (LTC) of ISA. A 15-year exclusive exploration contract is issued for a specific area, the size of which depends on the type of deposit.[5-7] To date, the Council of ISA has approved 26 exploration contracts.[32] The first contracts awarded expire in 2016,[32] but contractors may apply for an extension of five years or submit a plan of work for exploitation.[29] Work has begun by ISA on the development of a regulatory framework for the exploitation of minerals in international waters, with an initial focus on polymetallic nodules.[9]

The Deep Sea Mining Act 2014

To mine in international waters, UK contractors must apply for a domestic licence, which includes both financial and environmental conditions, from the UK Government (Department for Business, Innovation and Skills) before making a sponsored application to ISA.[33] The Deep Sea Mining Act,[8] a Private Members' Bill, received royal assent in May 2014 and amended the Deep Sea Mining (Temporary Provisions) Act 1981 which was passed prior to UNCLOS:

- requiring that contractors obtain a contract from, are regulated by, and comply with ISA (although they must also report back to the UK Government)
- enforcing decisions of the Seabed Disputes Chamber of the International Tribunal for the Law of the Sea, which has exclusive jurisdiction over mining disputes under UNCLOS.

Seafloor Massive Sulphides (SMS)
SMS are associated with hydrothermal vents (Box 2). They contain many metals including copper, zinc, lead, gold, silver and small quantities of other metals.[37] Areas of particular commercial interest include the Mid-Atlantic Ridge, the Indian Ocean ridges and the South West Pacific in both national and international waters.[38] Estimates suggest that there is around 30 million tonnes of metal in SMS associated with active vents; equivalent to about 10% of total discovered metal in land-based deposits.[39] There is also evidence that there may be significant quantities of SMS at inactive vent sites.[40] These are harder to find but easier to mine; exploration tools are being developed.[39]

Polymetallic Nodules
Polymetallic nodules are formed where minerals are deposited on rocks and build up over time; they are scattered across the soft sediment surface of the abyssal plains (Box 2). They generally range from 1-12 cm in length and form over millions of years.[41] The major components of polymetallic nodules are manganese, nickel and copper, but they also contain cobalt, small quantities of other metals and REEs.[41] Nodules were the focus of exploration in the 1960s and 1970s.[3] Areas containing nodules include the Clarion-Clipperton Zone (CCZ, Box 3), the Peru Basin, the Penrhyn Basin and the Central Indian Ocean.[41] Estimates suggest that the amount of manganese found in nodules in the CCZ is more than that found in the total land reserve base.[41,43]

Cobalt-rich Crusts
Cobalt-rich crusts are found on seamounts (Box 2) and other rock surfaces. They are formed by minerals in seawater deposited onto these surfaces.[41] Crusts can be up to 26 cm thick[41] and are mostly composed of iron and manganese, but can also include cobalt, nickel, titanium, copper, tellurium and REEs.[43-45] Areas containing cobalt-

Box 2. Deep-Sea Geological Features

- **Hydrothermal Vents**, commonly known as 'black (or white) smokers', are cracks in the sea floor where sea water seeps down and becomes superheated (up to 400°C) and enriched with minerals in the earth's crust. It rises up as smoke-like clouds of mineral-rich particles, some of which are deposited as chimneys on the sea floor. They are found along ocean ridges in areas of deep-sea volcanic activity (between 2,000 and 5,000 m[57]) and at shallower water depths.[38]
- **Abyssal Plains** are large, continuous areas of the seabed, at depths of 4,000 to 6,500 m.[41] They account for more than 90% of the deep-sea floor.[16]
- **Seamounts** are underwater mountains, generally extinct volcanoes, with summit depths of between 100-4,000 m.[58]

rich crusts include the Pacific Prime Crust Zone (PPCZ) and the North East Atlantic.[41] Estimates suggest that the amount of tellurium (used in alloys, solar cells and electronics) found in crusts in the PPCZ is nine times greater than that found in the total land reserve base.[41,43]

Proposed Mining Methods

There are a number of ongoing, and mostly exploration, projects.[46] Technologies for deep-sea mining vary by mineral deposit type and are under development. They are more developed for SMS and polymetallic nodules (Boxes 3 and 4) than cobalt-rich crusts. A typical operation[47,48] will consist of:

- sea floor production tools which cut (crusts and sulphides) or collect (nodules) and transport the ore to a riser and lifting system
- a riser and lifting system through which ore is pumped to a surface support vessel
- a surface support vessel which removes water from the ore for transportation to a processing facility on land. The waste water is pumped back down to the site of ore collection, the water column or surface waters.

Some advanced technologies developed for the offshore oil and gas, dredging and trenching industries can be adapted for the extraction of deep-sea minerals.[49,50] For example, autonomous underwater vehicles (AUVs) are used to survey the seabed prior to extraction[51] and remotely operated vehicles (ROVs) play a role in the sampling of deposits, the mining itself and monitoring of the mining process.[50]

Environmental Effects

The deep sea accounts for about 60% of the Earth's surface,[16] but only about 5% has been explored.[52] As well as being a repository of biological diversity,[53] it provides a number of environmental benefits supporting human wellbeing (ecosystem services, POSTnote 378)[54-56] including:

- the provision of products used by humans such as fish, which as well as being used for food, also provide genes and proteins for industrial and pharmaceutical uses
- the support and regulation of processes such as water circulation, CO_2 exchange, waste absorption and detoxification and nutrient cycling (see below).

Given how much is unexplored, there are few estimates of the deep sea's total value, both in biological and monetary terms (POSTnote 288). A study estimated that deep-sea fish from UK-Irish offshore waters sequester one million tonnes of CO_2 per year from the surface to the deep-sea floor, worth €8-14 million under the EU Emissions Trading Scheme.[65] Some evidence suggests a positive correlation between deep-sea biodiversity and the production of benefits, but the strength of this relationship varies between ecosystems.[66]

Vulnerabilities of Deep-Sea Biodiversity

The total species richness of the deep sea has been estimated to be between 500,000 and 10 million species,[67] but only about 25,000 have been described.[2] This lack of knowledge about deep-sea biodiversity[68] limits the ability to predict impacts.[16,69] However, it is known that impacts will vary according to habitat type and typically include:

- physical destruction of the habitats and organisms directly in the path of mining machines,[70] potentially leading to changes in the composition (Box 5) and functioning of ecosystems, as well as species extinction[16] changes in light and noise levels, which may interfere with organisms' ability to communicate[71,72]
- the formation of sediment plumes (either from direct contact of mining machines with the seabed or from the return of mining waste to the water). This could affect the concentration and character of suspended sediment in the water above the seabed and the organisms living on and above the seabed, including the upper water column (within 100 m of the surface).

The physical behaviour of plumes can be modelled using techniques developed for the dredging industry.[73] However, most deep-sea regions lack ground-truth data for important variables such as the speed of currents on the sea floor.[74] The sensitivity and recoverability of organisms to sediment

Box 3. Mining in the Clarion-Clipperton Zone (CCZ)

To enter into a contract with ISA for exploration for nodules, a contractor must divide its proposed claim site into two sites of equal commercial value. One of which is allocated to the contractor, the other is reserved for a developing state or the commercial arm of ISA (the Enterprise, which has yet to be created).[59] The greatest abundance of nodules is found in the Clarion-Clipperton Zone (CCZ), an area of 4.5 million km^2 in the North Pacific Ocean.[60] 16 of the 26 exploration contracts approved to date by the Council of ISA are for this area, and involve states including Germany, France, China, Russia and the UK.[32] Because of the high level of commercial interest in this area, ISA has provisionally adopted an Environmental Management Plan for CCZ. This includes a network of nine Areas of Particular Environmental Interest where mining is prohibited, covering around one-sixth of CCZ.[61]

The UK-sponsored contractor, UK Seabed Resources (UKSR), a subsidiary of Lockheed Martin UK, holds a contract to explore an area of the CCZ and has been approved for another. Together, these two contracts cover an area of more than 130,000 km^2, neighboured by the Singapore claim area, in which UKSR also has a minority stake.[48] The majority of nodules have been found at depths of 4,000 to 5,000 m and are 5 cm or less below the surface of the seabed; UKSR envisages multiple nodule collecting machines scooping up theses nodules from the seabed.[48] The company has invested £12 million into its exploration programme, working with an international consortium of research institutions including Senkenburg (Germany), IRIS (Norway), University of Hawaii, Scripps Institution of Oceanography (US), Natural History Museum and National Oceanography Centre (UK).[48]

Box 4. Mining in the Solwara 1 Area of the Bismarck Sea

A Canadian-registered company, Nautilus Minerals, plans to begin mining SMS in the Bismarck Sea, Papua New Guinea (PNG) in 2018.[10] The area to be mined, Solwara 1, is 0.112 km^2, at a depth of 1600 m below sea level and is associated with mostly inactive hydrothermal vents.[62] Nautilus Minerals received its Environmental Permit in 2009 and a Mining Lease in 2011 from the PNG government, but has been delayed by disagreements over the financial terms.[63] NGOs and civil society groups are concerned about the environmental, social and economic impacts, particularly on nearby fisheries.[12,64] The operation is expected to last 2.5 years,[62] and the technologies required are being developed by a range of contractors including General Marine Contractors, a US company, and Soil Machine Dynamics (SMD), a Chinese-owned company based in Newcastle upon Tyne.[10] SMD is developing sea floor production tools including:

- an Auxiliary Cutter which will level the seabed and allow access for the other tools
- a Bulk Cutter which is the primary production tool for cutting material on the seabed and pumping it to a stockpile
- a Collecting Machine which will collect the stockpile and transfer it via a pump through a riser and up to a support vessel (front picture).[10,47]

plumes is also unknown; plumes may physically bury organisms, interfere with organisms' filter-feeding activities or expose organisms to toxic chemicals leaching out of the sediment.[70,75] They may also interfere with ecological linkages between ecosystems, both along the seabed and through the water column.[76]

Hydrothermal Vents

Hydrothermal ecosystems are unique. They rely on bacteria to extract energy from dissolved minerals and are characterised by a large amount of life.[77] The most well studied communities are on fast spreading ridges, which experience frequent disturbance (e.g. volcanic activity).[39] Organisms appear to be adapted to disperse between, and rapidly populate, vents in order to survive. However, dispersal distances have only been tested in a few species out of about 400 currently-described vent species.[74] For example, giant tube worms have a larval stage that lasts on average 38 days during which they can cover a distance of 100 km.[78] Such characteristics may allow recovery after mining activity.[79] The dispersal ability and vulnerability of organisms found at slow-spreading ridges is even less well understood,[80,81] but these sites are associated with SMS deposits which are larger.[39] Most plans for mining have focussed on inactive vents with less extreme environments (Box 4), but their ecology is poorly understood. These ecosystems may be less-productive[77] but also less dynamic and hence more vulnerable to disturbance.[76]

Abyssal Plains

Abyssal plain sites are typically high in biodiversity[82] but at low densities,[83] with organisms living on both the nodules themselves and in the seabed sediment.[84,85] Biodiversity estimates come from a few studies at individual sites that have recorded many new species but without full description.[86] Species descriptions are needed to estimate the regional diversity and distribution of species in areas such as the CCZ.[74] Studies suggest that some species exist in genetically distinct populations in different areas.[87,88] These could be at greater risk of extinction as they may be adapted to specific habitats or have low dispersal abilities.[74]

Seamounts

Seamounts are high in biodiversity[54] and are important sites for fish spawning and feeding.[89] Fishing in these areas has led to rapid and long-lasting damage. For instance, in New Zealand and Australian waters, fishing has led to declining stocks of orange roughy,[91] a deep sea fish species that has low resilience to disturbance because it only reaches reproductive maturity at about 20 years.[90] Mining of crusts on seamounts, may pose a high extinction risk for the species that inhabit them.[92,93]

Researching Environmental Effects

An agreement was reached by the UN to begin negotiating a new biodiversity conservation agreement for the high seas under UNCLOS in January 2015. A Preparatory Committee will begin drafting this agreement in 2016.[94] There are a range of methods that might mitigate the impacts of deep-sea mining (Box 5). International research programmes, such as the ongoing EU-funded and UK-led MIDAS project, can also further our understanding of the environmental impacts of deep-sea mining, including the potential effects of sediment plumes in the water column.[95-97] Surveys by governments and ISA authorised contractors are being undertaken,[48] but deep sea habitats are difficult and expensive to sample and survey, requiring ROVs and AUVs.

Box 5. Predicting and Minimising Effects of Deep-Sea Mining

Several small-scale impact experiments have been conducted to investigate the recovery time and sensitivity of the seabed community on the abyssal plains to nodule mining.[98-100] In one study, direct disturbance of an area of 11 km^2 led to the abundance and diversity of large animals remaining below pre-disturbance levels for seven years after disturbance.[101] However, such studies can only give an indication of the potential impacts of commercial-scale mining.[16] Some theoretical methods to mitigate the potential impacts include:

- applying the precautionary principle – in the absence of scientific consensus that an action is not harmful, the burden of proof that it is not harmful should fall on those proposing the action
- designating protected areas where mining activity is prohibited,[61] requiring data to identify suitable areas[102,101] and to coordinate mining with other activities[102,104,105]
- real-time monitoring of operations, using existing[106,107] and emerging technologies,[50] to ensure that mining impacts do not exceed expectations[76]
- designing mining machines to minimise environmental effects, including shrouds to reduce sediment plume generation.[50]

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