



Extended Project
Qualification

Level Three

Deep Sea Mining:

A POTENTIAL SOURCE OF RENEWABLE RESOURCES?

Michael Saunders

“NOT METAPHORICALLY, BUT LITERALLY – THE DEEP SEA IS A GOLD MINE,
AND THAT IS JUST SCRATCHING THE SURFACE.” |

“The known is finite, the unknown infinite; intellectually we stand on an islet in the midst of an illimitable ocean of inexplicability. Our business in every generation is to reclaim a little more land, to add something to the extent and the solidity of our possessions.”

Thomas Huxley
1825 – 1895



Abstract

I ask the question, “Can Deep Sea Mining (DSM) be regulated viably to promote a ‘renewable resource’ status, endorse international law and manage related controversy?” The evidence available, at this time, suggests that a “system of ‘apathetic’ (*i.e.* not dynamic) equilibrium - where the rate of deposit formation and rate of exploitation are equal” is possible.

Deep Sea Mining is a controversial, yet quite essential, new frontier of the mineral exploration and exploitation industry. In this short dissertation I explain the importance of excavating these previously unobtainable and valuable resources. I discuss the viable possibilities of how sustainable the extraction and exploitation, of these resources, can be. I detail some simple regulations, which could be put in place, to ensure this sustainability. In closing, I explain how these simple regulations can minimize the effect on submarine ecosystems, thus minimizing the controversies related to a potential foundation of tomorrows’ society.

Contents and Content Key

At the top left corner of each page of this document there are six coloured triangles, each associated with a section of the dissertation. When a triangle has solid edges, the section associated with the colour is on the page. For example, the red triangle with solid edges on the previous page indicates the “Abstract” page. The full ‘content key’ is displayed below:

▼	Abstract/Project Outline (Page 3)	▼
▼	Introduction (Page 4)	▼
▼	Research Review (Page 6)	▼
▼	Discussion/Development/Analysis (Page 10)	▼
▼	Evaluation/Conclusion (Page 14)	▼
▼	References (Page 15)	▼



The human population of our planet is increasing. China, already the world's most populated country, have begun to relax their 'one child policy' (BBC News, 2013). There are also over one hundred and fifty more developing countries internationally (World Trade Organisation, n.d.), meaning over the next generations the human populous will grow dramatically. An ever growing demand then, for an ever depleting supply of natural resources, is getting – and will continue to get – harder to satisfy.

The society that both you and I live in is dependent on minerals: this has been apparent since the Iron Age, where haematite and goethite (primary iron ores) were collected and crudely reduced. In the Bronze Age; malachite, azurite and chalcopyrite were exploited for copper, as well as cassiterite for tin. In that age, minerals were highly abundant, easily obtainable and thus revolutionary.

Today however, increased technological and civil demands are putting much more strain on supplies of minerals and metals. The human population has recently exceeded seven billion (BBC News, 2011), and not everybody now has a home. When figures increase further, along with many metals, steel will be required to reinforce more buildings (illustrated by Figure 1). For larger structures, the use of structural reinforcement is nigh on imperative. Steel, an alloy, is based on iron: which has long been mined commercially in Australia (Rio Tinto, n.d.). This as it offers quick shipping for China, where cheap manufacturing is plentiful, the alloy is the distributed internationally on an industrial scale.



Figure 1: Steel infrastructure being constructed at Bridgwater College, Somerset.

Additionally, we live in an era dubbed the 'silicon age': At the researching stage, in the college library, I counted the applications of metal I could see: there were at least twenty plug sockets, two laptops, three people on smart phones, five tower PCs and monitors, a Wi-Fi router above me and all of the linking cables. Everything here has copper, as well as in wires within the device, either to supply power to, or to charge the device. This conveniently introduces rechargeable batteries. My laptop for instance boasts a "3-cell Li-ion battery". Lithium, an alkaline earth metal, is extracted from seams of lepidolite pegmatite which containing spodumene (lithium ore). Many of which exist in in South America and Australia. Building upon the idea of energy supply, Hydrogen Fuel Cells (HFCs): which are assumed to be the future of energy, and the successor of hydrocarbon fuels, require over 10 kilograms of lanthanum (Goodbody, 2014). Lanthanum is a 'Rare Earth Element' (REE), which could help HFCs yield amazing potential.

Contradicting the existing and potential strain it creates, new technology obviously has its benefits, and not only in making everyday life easier: the same technologies, the fresh innovations and the emerging ingenuity open the doors to new frontiers in the mining industry. It is after more than fifty years of research, hypothetical planning and legislation that Deep Sea Mining is becoming a possibility. It is a pioneering prospect which is likely to become the forefront of the mining industry. This leads me into my first simple question: *What is 'Deep Sea Mining'?*

In a sentence it is the discipline in exploring, excavating, extracting and processing mineral from the ocean floor. Contrary to common belief, it is not a new idea. Submarine excavations are already underway, but only to a depth of around 150 metres. Diamonds, for use in both jewellery and industry, are found quite commonly off of the southwest coast of the African land mass. Tin, in many forms, including cassiterite, is extracted from rocks found below the shorelines of the Indonesian archipelago (Albrecht, 2013) (Rutherford, 2013).



Years of research, by governments and companies, have found that other areas of the ocean are rich in commercially and industrially valuable resources. These include metal ores and rare earth elements. These exist in many different forms and are found at varying depths, so they have to be excavated differently (Goodbody, 2014).

On Saturday 10th May 2014, an American Remotely Operated Vehicle (ROV), manufactured by the Woods Hole Oceanographic Institute (WHOI), imploded on a deep sea expedition. The unit, ‘Nereus’, had cost eight-million US Dollars (Orechio-Egresitz, 2014), and was described by the BBC as “one of the world’s most capable deep sea research subs” (Amos, 2014). Its final dive was a part of a “high risk, high reward” 40-day expedition. On day thirty: operating at depths near 10, 000 metres, the vehicle failed under pressures of approximately 16,000 PSI (~110x Standard Air Pressure). Until new, more resistant technology is engineered, there are only a few known major exploitable formations:

Polymetallic Sulphides

Copper, zinc and lead are commonly found as azurite, sphalerite and galena in polymetallic sulphides; in addition to these, *gold, silver and cobalt* have been recorded.

Pictured to the right is a black smoker. They are created when sulphide solutions escape from faults or stresses in the ocean floor and create stalagmitic chimney formations. These are made of extremely fine, mineral rich, crystalline rock. As they are most commonly found at depths between 1.4 and 3.7 kilometres below sea level, the only way to access them is by using an ROV. They form very quickly, making them ideal for the extraction of “renewable resources”, generally speaking, extrusive crystals form over a period of weeks or months in air (Armstrong, et al., 2008).

One of the fundamental ‘points of dispute’ with the mining of polymetallic sulphide chimneys is the presence of extremophiles (The Living Planet, 1984), organisms depending on the forming structures to live. Due to their rarity, environmental dependence and simply our curiosity, the species are heavily protected by various conservation laws. (Goodbody, 2014)

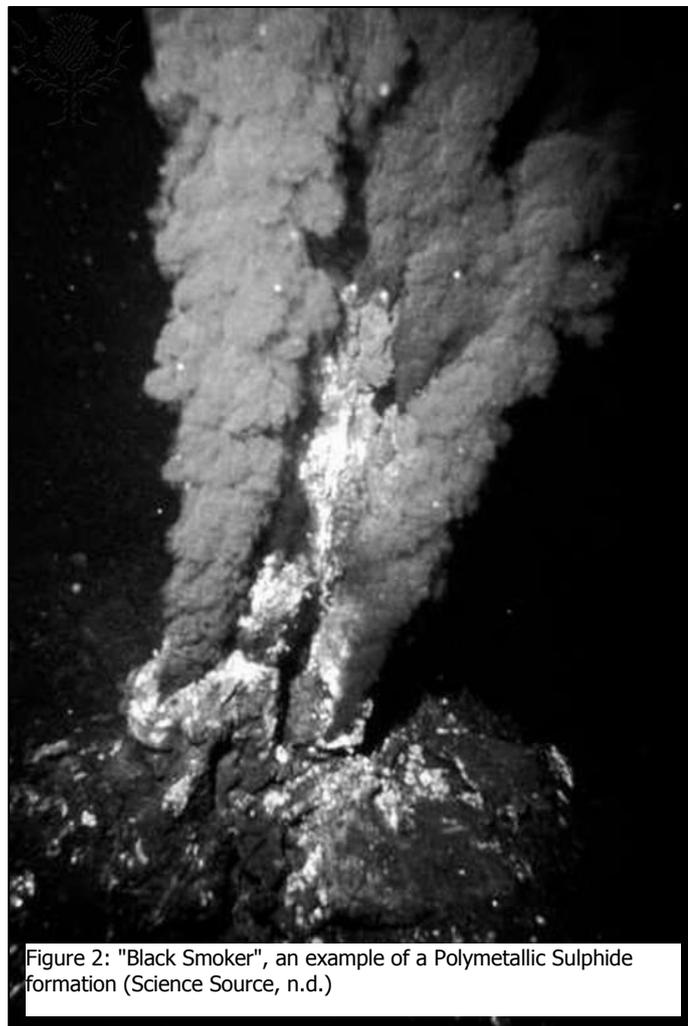


Figure 2: "Black Smoker", an example of a Polymetallic Sulphide formation (Science Source, n.d.)

Polymetallic Nodules

Found as globular metallic xenoliths (foreign geological bodies) in the silts, sands and muds of the ocean bed, polymetallic nodules are one of the more abundant seabed resources. Varying greatly in size, the nodules tend to form botryoidally up to sizes of 30 cm. These often contain *manganese, copper, cobalt and nickel*, so are of considerable interest to industry.



The proposed way of extracting the nodules is to use ROVs, operating in the area of 3.0 to 6.0 km below sea level (the abyssal plane, which is a region applying to 50% of the oceans). ROVs will be employed to disturb the ocean floor and sieve out the nodules. An obvious ‘point of dispute’ here is the disturbance to the seabed, lowering water quality and having the potential to kill sea life, damaging delicate ecosystems.
(Goodbody, 2014)

Ferromanganese Crusts

Formed by precipitation, over tens of millions of years, minerals containing *lead, bismuth, tellurium and platinum* are formed on existing geological structures. They are of massive interest to industry due to the metals’ rarity. Platinum, particularly, is useful as catalysts in many chemical industry processes and in catalytic converters of modern vehicles.
(Goodbody, 2014)

It is estimated that in a major zone of the Pacific Ocean - the Clarion-Clipperton Zone (CCZ) - accounting for 5.0 Mm² of stressed and fractured seabed that: there are two billion tonnes of polymetallic nodules, seven billion tonnes of manganese, 340 million tonnes of nickel, 290 million tonnes of Copper and 78 million tonnes of cobalt (Goodbody, 2014). To put these into perspective a logarithmic chart has been constructed, Figure 3, which compares these masses to the mass of concrete used in the Three Gorges Dam, Yangtze River, China: six million tonnes (Wikipedia, 2014).

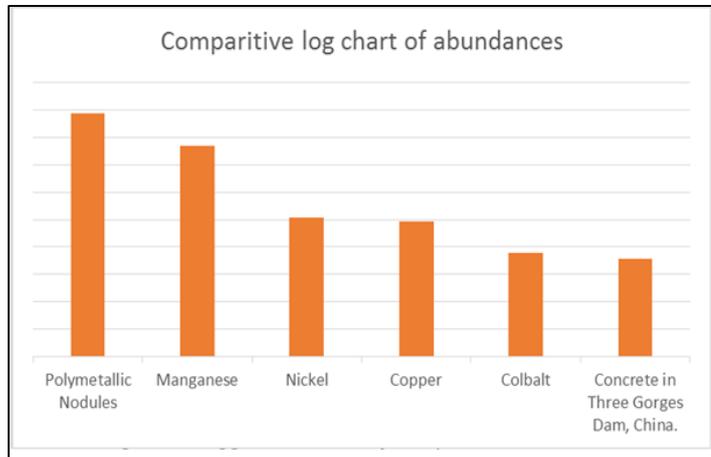


Figure 4: Logged Bar Chart of comparative abundances

Research Review – Legislation

In this section I shall discuss the legislation that is intended to regulate DSM, in attempts to make it less controversial and internationally favourable. I intend to refer back to these in my discussion.
The idea of excavating the ocean floor has been in planning for over half a century. Conferences have been held and legislation passed in regards to the idea, but with great difficulty. In 1952 the first ‘United Nations Convention on the Law Of the Sea’ (UNCLOS) was held, in international negotiations regarding the control of international waters. Later, in 1982, the UNCLOS was introduced as international law: which came into effect on 16th November 1994. The United Nations now consists of 193 member states obligated to recognise UN law, including the Convention (worldometers, 2015). In regards to Deep Sea Mining, the most recent implementation of Part XI entered into force as of the 28th July 1996, after amendments. I have iterated some of the more interesting points, however I would like to stress, being written law, they are quoted directly and articles I may have missed are without doubt equal in importance. NB: “The seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction (>200 nautical miles from land) constitute the “Area”. (United Nations, 2012)



Part XI, Section 1, Article 133, Paragraph 1a

“Resources” means all solid, liquid or gaseous mineral resources *in situ* in the Area at or beneath the seabed, including polymetallic nodules.’

Part XI, Section 1, Article 133, Paragraph 1b

“Resources”, when recovered from the Area are referred to as “minerals.”

Part XI, Section 2, Article 136, Paragraph 1a

‘The Area and its resources are the common heritage of mankind.’

Part XI, Section 2, Article 137, Paragraph 2.

‘All rights in the resources of the Area are vested in mankind as a whole, on whose behalf the Authority shall act. These resources are not subject to alienation. The minerals recovered from the Area, however, may only be alienated in accordance with this Part and the rules, regulations and procedures of the Authority.’

Part XI, Section 2, Article 140, Paragraph 1.

‘Activities in the Area shall, as specifically provided for in this Part, be carried out for the benefit of mankind as a whole, irrespective of the geographical location of States, whether coastal or land-locked, and taking into particular consideration the interests and needs of developing States and of peoples who have not attained full independence or other self-governing status recognized by the United Nations in accordance with General Assembly resolution 1514 (XV) and other relevant General Assembly resolutions.’

Part XI, Section 2, Article 143, Paragraph 2.

‘The Authority may carry out marine scientific research concerning the Area and its resources, and may enter into contracts for that purpose. The Authority shall promote and encourage the conduct of marine scientific research in the Area, and shall coordinate and disseminate the results of such research and analysis when available.’

Part XI, Section 2, Article 145, Paragraph 1 and 1a.

‘Necessary measures shall be taken in accordance with this Convention with respect to activities in the Area to ensure effective protection for the marine environment from harmful effects which may arise from such activities. To this end the Authority shall adopt appropriate rules, regulations and procedures for inter alia: the prevention, reduction and control of pollution and other hazards to the marine environment, including the coastline, and of interference with the ecological balance of the marine environment, particular attention being paid to the need for protection from harmful effects of such activities as drilling, dredging, excavation, disposal of waste, construction and operation or maintenance of installations, pipelines and other devices related to such activities;’

Part XI, Section 3, Article 150, Segment from Paragraph 1

‘Activities in the Area shall, as specifically provided for in this Part, be carried out in such a manner as to foster healthy development of the world economy and balanced growth of international trade...’

(United Nations, 1982)

Among the 1994 amended Part XI the following was not mentioned: although the general pamphlet, marking 30 years of UNCLOS covers further, broader, aspects of the Convention and states that; “The Convention requires all states to protect and preserve the marine environment, including rare or fragile ecosystems and the habitat of endangered species. “

(United Nations, 2012)

A Bill (Parliament, 2014), amending the UK’s Deep Sea Mining (Temporary Provisions) Act of 1981 has recently been put before the House of Commons and was granted Royal Assent on May 14th 2014, it is yet to be introduced as law. As a part of the deep sea exploration race, the UK want to be able to issue ‘exploration’ and ‘exploitation’ permits to companies. In Canada, Nautilus Minerals Incorporated was issued the first permit to explore areas of the Pacific Ocean, but only recently have



the British government awarded UK Seabed Resources Ltd, a wholly owned subsidiary of Lockheed Martin UK, sponsorship to explore a 58000km² area of the Pacific (BBC News, 2014). (Coles, et al., 2014)

Interestingly, as it was prior to UNCLOS; the Deep Sea Mining (Temporary Provisions) Act of 1981, which I shall refer to as the 'Act', stated in Section One – Prohibition of Unlicensed Deep Sea Mining - "... a person to whom this section applies shall not explore for **the hard mineral resources** of any part of the deep sea bed...".

In The Deep Sea Mining Bill of 2014, which I shall refer to as 'The Bill', has amended this with respect to Article 133 of UNCLOS, specifying "A person to whom this section applies ("P") may not explore **mineral resources of any description**..." This goes on to discuss the nature of permits to be issuable by the state. The Act even specifies further its decommissioned definition of "hard mineral resources", describing them as "deposits of nodules containing (in quantities greater than trace) at least one of the following elements, that is to say, manganese, nickel, cobalt, copper, phosphorus and molybdenum." This then discriminates polymetallic sulphides and ferromanganese crusts. This is possible due to the controversies against "destructive practices" and their effects on "rare or fragile ecosystems" (UNCLOS).

In Section Two of the Bill, 'Exploration and Exploitation Licenses', the Seabed Authority is introduced; based in Jamaica, The Seabed Authority was created by the United Nations to enforce the Law of the Sea (UNCLOS) in the 1980s. (United Nations, 1982)

The section also discusses the terms of which an exploration and/or exploitation license can be awarded. Among the expected articles such as not issuing two permits for one area, strict conditions are set: Common to all mining activities, terrestrial or offshore, spoil/waste disposal is regulated, in this case the licensee must dispose of waste according to UNCLOS. The issuer also reserves the right of "requiring samples of the licensed discovered in or extracted from the licensed area." as well as plans, returns, accounts and other records relevant to said area.

Throughout the listed amendments in the Bill, two awarding bodies are listed to grant permits for deep sea mining in the UK, to quote an amendment to Section Two: "An exploration or exploitation license – (a) may be granted for such period as the **Secretary of State** thinks fit or, as the case may be, the **Scottish Ministers** think fit..." This is due to another political situation in Great Britain, Scottish Independence. In the case that the referendum due September 2014 indicated that Scotland wishes to separate for the UK, the Bill would still apply to both states individually, and would still stand if Scotland did not become independent (Parliament, 2014). Since the Bill was passed, a majority vote of "No" ruled out Scottish Independence, however the right of the Scottish Ministers to grant permits stands.



Research Review – Efforts towards and evidence of the need for, sustainability

Below there are four graphs (Figure 4) representing the metals of abundance in subsea formations, courtesy of London Metal Exchange. Cobalt, dating back four years. Copper, Nickel and Zinc, all dating back five years.

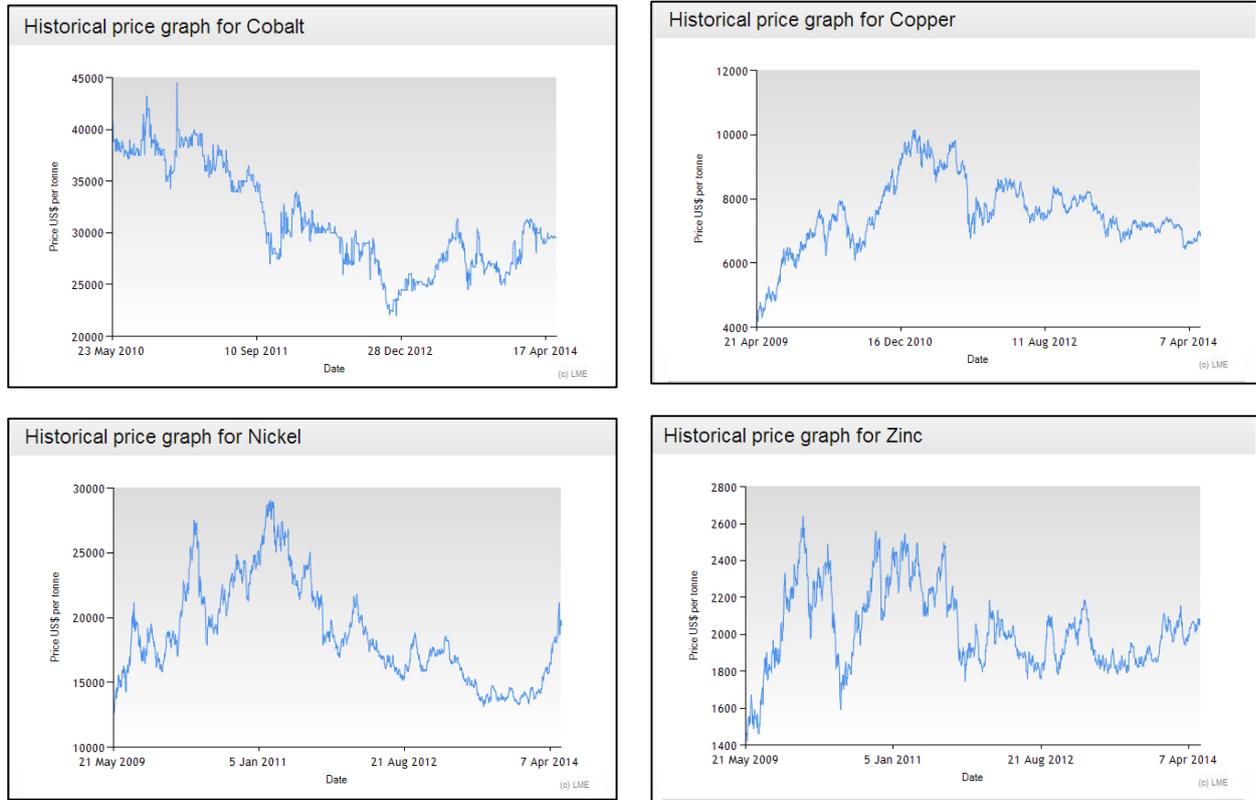


Figure 4: Graphs of historical metal prices; Courtesy of LME.
(LME, 2014)

Values of metals are prone to oscillation over time, as demonstrated in the graphs above: these prices are determined by the market. When supply exceeds demand, the value drops and when demand exceeds supply, the value rises. As ores are exploited, there is less ore in the ground and supply decreases; of course this means that the general trend of metal value goes up – even if demand is constant. This assumes the resource is not replaced.

A case in the UK was the dilemma regarding old copper coinage: In 1971 the GB money system decimalised. This saw the introduction of the ‘New Penny’ (£0.01) and the ‘Two New Pence’ (£0.02) coins, all of which manufactured out of Bronze, an alloy of 97% Copper. In 1981, a decade after the release, the coins changed to “One Penny” and “Two Pence” (Cuhaj, 2009). After a further eleven years, in the late 1980s, the value of copper in the bronze coin exceeded the face value of the coin itself, as ‘New Pence’ were quickly identified they were known to illegally melted down, despite being legal tender. In 2006, the scrap value of a New Pence coin was the equivalent of £0.04 (White, 2015). This demonstrates, even in less than a dozen years, metal value can multiply. In the light of this, the Royal Mint replaced the material of these coins into copper plated steel.

Examples of replacements due to the increasing cost are ever more common. Materials science, the field responsible, has long been a formidable industry, which seeks sustainability, renewability and versatility.



As stated in the introduction “We live in an era dubbed the ‘silicon age’”; however it is likely the silicon age is to end in the not-too-distant future. This does not mean that electronic computer chips will no longer be manufactured. Silicon however, may not be what they are manufactured from. Graphene, which is a synthetic allotrope of Carbon, is said to be the successor of Silicon (Hudson, 2011). This is due to Graphene’s comparatively ease of manufacture, astonishing conductivity and versatility, for example Graphene has even been considered to replace latex in medical gloves and contraception. (Lorimer & MacDonald, 2014)

Referring to metalliferous ores and their sources, in unfortunate cases the supply of metals can be disrupted quite considerable due to politics, a case of this being Platinum. The major deposits of this rare metal are exploited in South Africa, although the country is noticeably more stable in recent decades, there had been strikes for several months at platinum mines in the country. This has sparked fear in the metal industry. Overcoming this however, materials science: at the Massachusetts Institute of Technology, has been working to replace ‘platinum-group metals (PGMs)’. A possible material being Tungsten Carbide. (Jamasmie, 2014)

An effort towards the sustainability of metals is ‘Waste Electrical and Electrical Equipment’ (WEEE) regulations; all electrical goods manufactured after Saturday 13th August 2005 (Health and Safety Executive, n.d.) are required to display the symbol in Figure 5 on the unit – this prevents electronic goods being disposed, so the metals used in appliances can be reused.

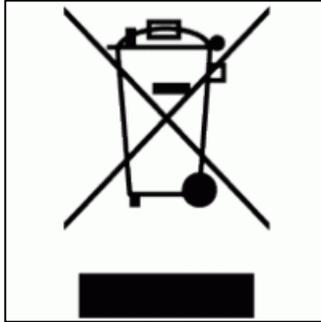


Figure 5: WEEE symbol

Discussion;

“Sustainability: an ability of capacity of something to be maintained or sustain itself... If an activity is said to be ‘sustainable’, it should be able to continue for ever.”

(Land Learn, n.d.)

Sustainability is not only in the interests of financial profiteers from deep sea mining, as it will be inevitable that the human race as a whole would, and has, profited from the continuous application of minerals. It is, without doubt, in the interest of mankind and making reference to Article 136, Paragraph 1a of the UNCLOS; “The Area and its resources are the common heritage of mankind.” (United Nations, 1982) That does not discount mankind of tomorrow; the children of your generation, the children of my generation, of theirs and so forth.

The title of this dissertation is “Deep Sea Mining – a potential source of “Renewable Resources”?” To disambiguate the term, “Renewable resource” is used to describe a resource which can form, or be replaced, as quickly as it is exploited. Thence it can be said, to be a ‘renewable resource’, there needs to be a system of ‘apathetic’ (*i.e.* not dynamic) equilibrium – where the rate of deposit formation and rate of exploitation are equal.

For a system of equilibrium - for the moment, regardless of viability – the rate of exploitation would have to be restricted, and measures taken to increase the rate of formation/deposition.

Rate of Exploitation

“Nobody wants to (be) the first ones out, but everybody wants to be first out in second place. I think it’s important to start in the shallows and work deeper as the technology develops. Not the other way around.”

~ Thomas Sunde, President of Poseidon Offshore Mining, Norway.



Although exploration licences have been granted, so far exploitation of subsea minerals has only occurred in Exclusive Financial Zones (EFZs) of the sea: defined by the UNCLOS as areas less than 24 nautical miles from a country's coast, 'the shallows'. Mr Sunde has tells us of the costs in subsea mining, he makes reference to 'De Beers LTD', a Namibian Diamond mining company exploiting the Namibian EFZ; *“De Beers have an operating cost of 300,000USD a day for one of their ships - A ship built for deep sea mining (of) nodules or crust(s) would need to be much bigger and complex, and would also be much more expensive to operate, I would conservatively estimate 4- 5 times more.”* (Sunde, 2014)

This is a massive cost; however, as De Beers are mining no less than diamonds, it is deemed acceptable. In the case of metal ores, their value is steadily increasing, and with considerable funding going to Research and Development, the operating costs are bound to fall almost exponentially. When the time comes, so that we are not hindered by lack of technology or unjustifiable expenses, the net rate of exploitation would need to be reduced. *How can this be done?*

The analogy “how do you eat an elephant?” is commonly heard as a student: the answer being “in tiny pieces.” This logic can be applied to Deep Sea Mining. The task of mining the entirety of an ocean bed in an area such as the 5,000,000 km² Clarion-Clipperton zone (Goodbody, 2014), would be one of eating an elephant *per se*. A way of decreasing the net rate of exploitation would be to divide up the area, and exploit the sections rotationally. Using the 'Clarion Clipperton Zone' - which is licensed for exploration to Nautilus Minerals Incorporated - as a theoretical example: the space could be sectioned. In concordance with the UNCLOS (Article 136 on Page 5), it could be divided into areas exploitable by different countries, of which there are 196 (although there are many discrepancies on this) (Wikipedia, 2014). In a communistic ideology, where areas under national jurisdiction will be equal in size, each area would span 25,510.2 km² ±5 m². If each country were to set a fifty year rotation, mining one area of ~42.5 km² per month, each area would hold a considerable yield in 50 years' time.

The deposits on the ocean floor are not uniform: one country's area may be rich in Copper while another is rich in Cobalt, which would enable another admirable aspect of this idea: it would allow trading. This concurs with the segment of paragraph 1 of Article 150 of the UNCLOS; “balanced growth of international trade” (United Nations, 1982).

It may be the case that for some months of the year operations are halted; to quote Mr Sunde again, *“we don't know that much about what is down there”* (Sunde, 2014). This could easily apply to ocean conditions or submarine migrations. This may mean that vessels have to halt excavations or abandon them to protect safety of those working and the integrity of the equipment: in the case of Nereus, as an example at \$8 Million, this would be understandable. Perhaps then, a less viable – but quite essential - method would be “seasonal exploitation”.

We could mine in an open, 'safe' season and withdraw from the area when conditions are not suitable. However, this could lead to very likely problem, due to an inconsistent supply of resources. The result of this is lower productivity in months of dwindling supply and a market 'boom' when this is replenished. This damages viability, investment and customer reliability: but is in some industries is entirely necessary.

To deal with this, resources need to be 'over-exploited' and reserved, some resource goes straight to the market and some held back, this stabilises market fluctuation and allows for a steadier value increase.

The diamond industry, up until the turn of the century, was an ideal example of resource management. The Kimberley “Big Hole” Mine, situated in Central South Africa is possibly the World's most famous mine, among the many Kimberley Diamond Pipes. De Beers operated the “Big Hole” Mine between 1871 and 1914 (43 years), and retrieved an unfathomable number of diamonds.

The point of this is, a large number of Diamonds, of varying carat and quality were extracted, the reason the value (which as iterated, is based on supply and demand) of diamond does not fluctuate like that of metals is that these diamonds are held, and had been gradually fed to the market (Ziminisky, 2013). There is no market 'boom', just a steady increase in value.



In reality, assuming the scenario that for some months the resources are not exploitable, both ideas could be enforced, or rather “recommended”. As a going concern, let’s say that it is too dangerous for the workers or the environment to mine for, four months of the year. The eight months of exploitation could supply resources for immediate consumption and reserve some for the four months absence. This would not be a foolish idea, the area I proposed to exploit, of ~42.5km², is a similar size to the Garzweiler Lignite (Surface) Mine II (48km²) (RWE, 2014). Exploited by RWE, and employing multiple Bucket Wheel Excavators – including the largest vehicle ever manufactured, the Krupp-Rheinbraun Bagger 288 BWE (Wikipedia, 2014) – it is said that, when the mine opened in 2006, it would take up to 2045 to fully exploit (39 years) (LME AG, n.d.).

In the month given, the aim is not to fully exploit, it would be to exploit the major deposits in that area. In a working month at Garzweiler, 2.9 – 3.3 Million Tonnes of material is extracted, NB: Lignite is considerably less dense than metal ore.

A major ‘pro’ of this idea is to concentrate exploitation on a ‘small’ area, leaving areas close for sea life to move, or be ushered to when the area is being exploited. To a degree, this would conserve the organisms living on the sea bed and conserve ⁵⁹⁹/₆₀₀ of the sea floor environment in the first month of this example (in CCZ), without modelling it is impossible to foretell the exact rate of replenishment. In terms of extremophiles -

removing the ‘dead’ formations, would allow more to form, providing more environment for the organisms to thrive, as they need the heat exerted by *forming* sulphides.



Figure 6; Bagger 288 (Wikipedia, n.d.)

Rate of Formation

When addressing the formation of mineral deposits, the principle of uniformitarianism is important. It allows the assumption that minerals will form, and will continue to form, just as they have in the past. Equally, a consideration would be ‘what deposit is forming’: for a viable equilibrium, the highest rate of formation is required.

Polymetallic nodules have eluded many geologists in their formation; their first recorded discovery was by HMS Challenger, in 1873. It has been concluded that they form concentrically by oxidation, it is estimated that each one millimetre “layer” takes 1,000,000 years to form (National Institute of Oceanography, n.d.). This is a slow rate of formation which is unlikely to be increased.

Polymetallic sulphides are formed by extrusive crystallisation, a quick process – in air it occurs in weeks or perhaps months – the 600 month rotation then should allow the formation to replenish and become inactive before it is exploited again.

Ferromanganese crusts form as a precipitate on rocks in deep, pressurised water. It is a slow, precipitation reaction: taking tens of millions of years to form – however, the rate of precipitation is something that can be modified.

It is due to this that polymetallic nodules will now be discounted from the discussion, leaving the question: *How could the rates of formation be increased?*

In 1985, the Gaia Hypothesis was made public, it was the theory that described the earth as a living organism (Ravilious, 2008); which brings me to an analogy for polymetallic sulphides. We have all had a graze or a scab which we have managed to uncover, a scab forms again and the wound slowly heals: visually, the quickest process is the scabbing over. Effectively then, the more times the sulphide is removed, the more it will reform. With a bigger fault, more “scabby” sulphides form. A way to increase yield further is to increase the surface area deposits can grow on, from experience,



putting a plaster on an open graze is not comfortable for this reason, this can equally be applied to mineral deposits.

My idea is to place gabions (crates of broken rock) into intensely fractured areas of sea bed: minerals will form around the rocks in a matrix affinity, as observed in any porphyritic (igneous) or porphyroblastic (metamorphic) texture. This not only increases the rate of formation in Sulphides and Crusts, but tackles a problem outlined by Thomas Sunde; how to “get the resource(s) on-board” (Sunde, 2014) – ROVs could be used to break the gabion away, and a hoist on the crate, along with counterbalance, can get the minerals to the vessel at less expense and possibly quicker.

In future study, which is intended, pursuing this idea could involve the shape of the rocks in the gabions: perhaps to have the largest blocks closest to the source for highest permeability and let the size grade down, decreasing vacant space per volume, as to terminate and limit the size of the deposit.

The material the gabion contains may also be a factor, initially an igneous rock may be functional: which could be gangue material from terrestrial or offshore exploitation, another “green” aspect. The material must be somewhat inert under the conditions posed by forming deposits, and shouldn’t deform physically. It could be proposed that mafic rocks are used, due to a higher melting point, however substitutes could be plastics, even recycled waste materials from human society.

Alike the analogy, the ‘scab’ or structure first has to be uncovered, Nautilus Minerals Incorporated has developed designs for Deep Sea Mining vehicles: many of which have been manufactured and would have been used in the exploitation of the Solwara project off of the Papa New Guinea (PNG) Coastline, which was postponed after disputes with the government of PNG. Since then, negotiations between the state and Nautilus have been successful (Nautilus Minerals Inc., n.d.); it is likely the Canadian company will be the “first ones out.”

The ‘pro’s and ‘con’s

The “recommendations” which I would propose to impose are bound to have positive and negative effects;

*The values of metals will at first drop, this is expected when any major source of resource is made available – particularly due to Deep Sea Mining’s publicity. To give an example; Rio Tinto’s major Copper mine in Mongolia had this affect when the following was released; “On 9 July 2013(**), Oyu Tolgoi reached a major milestone when shipping commenced with trucks carrying copper concentrate leaving the mine gates bound for customers in China. The 100,000 tonne-per-day concentrator began processing ore at the beginning of 2013(*), from Oyu Tolgoi’s open pit.”*

– See Figure 6.
(Rio Tinto, 2013)

If “recommendations” are put into place this drop in value may not be as large, which is subject to perception of whether this is a pro or con. To the average consumer, it may not be noticed, to the sharper consumers – perhaps a con and either way, to the companies – a pro.

The *Job market* will inevitably grow when companies begin their explorations. Deep Sea Mining is bound to open “opportunities for forward-looking people” (Drielsma, 2014) – Johannes Drielsma, European Association of Mining Industries. The ideas I have proposed may negatively affect this, although personnel would be in a more concentrated area, it would be likely to decrease the total

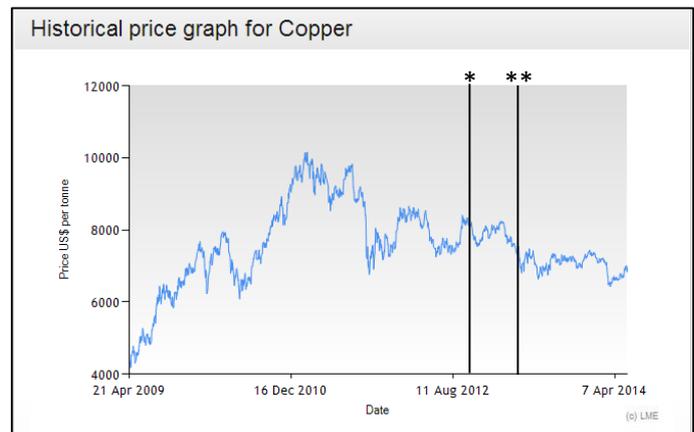


Figure 7; Annotated copper value fluctuations. (LME, 2014)



number of personnel across the entire ocean. However, splitting zones into areas of jurisdiction would increase the job market internationally. Overall this is a con, but a necessary compromise if the ideas are followed.

The industries surrounding *materials research* and recycling may suffer at the hands of deep sea mining, but this is entirely attributed to the attitude of society. We are unlikely to make changes if we do not need to; if sustainable sources of metals are found, replacement will not be “needed”. A functional society resists change. As an example, residential recycling: several years ago councils changed the bin system over, making it easier for us to recycle in England. I admit: I did not recycle general home waste before this. However, materials research could allow the industry to work more efficiently, and it has already, Silicon Carbide drill tips are commonly used in oil and mining. In this case, Deep sea mining can be a market, a pro, for materials research – or it can damage, be a con, to it.

Conclusions

To the question, ‘Deep Sea Mining – A potential source of “renewable resources”?’ One might assume the answer is “Yes.” You, after reading just a few thousand words, might agree. Of course, there is a ‘but’, the Abstract of this dissertation contains one term, and it is that one term which defines the entire project: without it, I would be able to answer my question indefinitely: but the term in question is “viable”.

‘Can Deep Sea Mining (DSM) be regulated viably to; promote a “renewable resource” status, comply with international law and manage controversy?’ – The question I asked on the project proposal.

‘This dissertation aims to... discuss the viable possibilities of how sustainable the extraction, of these resources, can be.’ – An extract from the Abstract.

Before concluding then, it is worth explaining viability as a whole for Deep Sea Mining. The ocean covers around 70% of the Earth’s surface, and the Clarion-Clipperton Zone: of which I had used as an example throughout, only covers 13.9% of that 70%. The UNCLOS at 30 pamphlet stated the abyssal plane, of which all is reachable now, covers 50% of the ocean floor (United Nations, 2012). Not metaphorically, but literally – The deep sea is a gold mine, that is only scratching the surface. Some companies are looking to conduct pit mining and exploit the ocean floor further. To ask, is Deep Sea Mining viable, or is Deep Sea Mining feasible, you would be laughed out of anywhere.

Luis Haro Socota (Socota, 2014), a mining professional, says; *“you are taking a “green” approach of the scenario”*. This is likely to be the view of many professionals who wish to profit without constraint to Deep Sea Mining.

Rossen Halatchev (Halatchev, 2014), a Principal Mining Consultant, says; *“ocean occupies 2/3 of the Earth’s area, and this is the area the future mining has to focus on.”*

The opposing argument to abiding recommendations is the inherent contradiction to industrial capitalism: however this has already been hindered, Article 137, of Section 2 in Part XI of the UNCLOS states “These resources are not subject to alienation.” Limiting the opportunity of independent financial benefaction.

I would not respect any conclusion that I could draw from my dissertation today, as it would be based on theoretical evidence, not practical evidence: so, although I am confident in my opinion, that deep sea mining could source “renewable resources” at a reasonable rate, I am choosing not to end the endeavours here; this dissertation, I hope then, will serve as an invitation. I would encourage companies, organisations and the individuals to experiment with the principle ideas I have outlined, of course my examples are entirely fictitious, but they offer an accurate situation.

The ideas, such as use of gabions, rotational exploitation and seasonal exploitation, have to be trialed in a real world situation. It could be argued that the environment of formation could be recreated for testing, however an artificial setup would be highly simplified and can too easily be manipulated. I welcome my ideas to be worked upon, I would be more than happy to participate in any forwarding of the idea – but to definitively find a viable “region” which equilibrium could satisfy, the wisdom of a professional is needed. In this, I very much agree with little known quote,



“Knowledge comes from learning. Wisdom comes from experience.” As nobody has exploited the deep seas, I believe these principles need to be used full scale to indefinitely answer my question. This, unfortunately, is obviously out of my means.

References

- Albrecht, M.**, 2013. Sea bed mining [Interview] (5 August 2013).
- Amos, J.**, 2014. BBC News: Nereus deep sea sub 'implodes' 10km-down. [Online]
Available at: <http://www.bbc.co.uk/news/science-environment-27374326>
[Accessed 21 May 2014].
- Armstrong, D. et al.**, 2008. OCR Geology. 1st ed. Essex: Heinemann.
- BBC News**, 2014. UK Seabed Resources joins deep-ocean mineral-mining rush. [Online]
Available at: <http://www.bbc.co.uk/news/science-environment-21774447>
[Accessed 14 May 2014].
- Coles, I., Pearce, L. & Young Park, B.**, 2014. The law of the sea. Mining Magazine, April 2014(April 2014), pp. 101-102.
- Cuhaj, G. S.** (., 2009. 2010 Standard Catalog: Modern Coins 1901-2000. Ioia: Krause Publications.
- De Beers**, n.d. Kimberley. [Online]
Available at: <http://www.debeersgroup.com/operations/mining/mining-operations/de-beers-consolidated-mines/kimberley/>
[Accessed 16 June 2014].
- Drielsma, J.**, 2014. [Interview] (9 May 2014).
- Goodbody, A.**, 2014. Delving the depths. Mining Magazine, April 2014(April 2014), p. 97.
- Halatchev, R.**, 2014. Deep Sea Mining [Interview] (18 April 2014).
- Hudson, A.**, 2011. Is Graphene a miracle material. [Online]
Available at: http://news.bbc.co.uk/1/hi/programmes/click_online/9491789.stm
[Accessed 6 June 2014].
- Jamasmie, C.**, 2014. MIT developing platinum replacement. [Online]
Available at: <http://www.mining.com/mit-developing-platinum-replacement-38176/>
[Accessed 6 June 2014].
- LME AG**, n.d. Garzweiler opencast mine. [Online]
Available at: <https://www.rwe.com/web/cms/en/59998/rwe-power-ag/locations/lignite/garzweiler/>
[Accessed 17 June 2014].



LME, 2014. London Metal Exchange. [Online]

Available at: <http://www.lme.com/metals/>

[Accessed 23 May 2014].

Lorimer, K. & MacDonald, J., 2014. Graphene Condoms: Super Thin and Tough, But Is That Enough to Make People Have Safer Sex?. [Online]

Available at: <http://www.livescience.com/42889-graphene-condoms-super-thin-and-tough-but-is-that-enough-to-make-people-have-safer-sex.html>

[Accessed 6 June 2014].

National Institute of Oceanography, n.d. Genesis and occurrence of deep sea mineral deposits. [Online]

Available at: http://www.nio.org/?option=com_projectdisplay&task=view&tid=2&sid=15&pid=15

[Accessed 16 June 2014].

Nautilus Minerals Inc., n.d. Solwara 1. [Online]

Available at: <http://www.nautilusminerals.com/s/Projects-Solwara.asp>

[Accessed 18 June 2014].

Orecchio-Egresitz, H., 2014. \$8M WHOI research sub goes missing in New Zealand. [Online]

Available at:

<http://www.capecodonline.com/apps/pbcs.dll/article?AID=/20140510/NEWS11/140519977>

[Accessed 21 May 2014].

Parliament, 2014. Deep Sea Mining Bill 2014. London: Unpublished.

Ravilious, K., 2008. Perfect Harmony. [Online]

Available at: <http://www.theguardian.com/science/2008/apr/28/scienceofclimatechange.biodiversity>

[Accessed 16 June 2014].

Rio Tinto, 2013. Oya Tolgoi. [Online]

Available at: <http://www.riotinto.com/copper/oyu-tolgoi-4025.aspx>

[Accessed 17 June 2014].

Rutherford, M., 2013. Re: . [Interview] (8 October 2013).

Science Source, n.d. Britannica Image Quest. [Online]

Available at:

http://quest.eb.com/images/139_1972763?subjectId=0&collectionId=0&keyword=Black+Smoker&localizeMetaData=false

[Accessed 07 05 2014].



Socota, L. H., 2014. Deep Sea Mining [Interview] (17 April 2014).

Sunde, T., 2014. Poseidon Offshore Mining [Interview] (7 June 2014).

The Living Planet. 1984. [Film] Directed by Richard Brock. United Kingdom: BBC.

United Nations, 1982. AGREEMENT RELATING TO THE IMPLEMENTATION OF PART XI OF THE CONVENTION (full texts). [Online]

Available at: http://www.un.org/Depts/los/convention_agreements/texts/unclos/closindx.htm

[Accessed 10 5 2014].

United Nations, 2012. UNCLOS at 30, New York: United Nations.

Wikipedia, 2014. Bagger 288. [Online]

Available at: http://en.wikipedia.org/wiki/Bagger_288

[Accessed 16 June 2014].

Wikipedia, 2014. Garzweiler surface mine. [Online]

Available at: http://en.wikipedia.org/wiki/Tagebau_Garzweiler

[Accessed 16 June 2014].

Wikipedia, 2014. Order of Magnitude - Area. [Online]

Available at: [http://en.wikipedia.org/wiki/Orders_of_magnitude_\(area\)](http://en.wikipedia.org/wiki/Orders_of_magnitude_(area))

[Accessed 9 May 2014].

Wikipedia, n.d. WEEE Directive. [Online]

Available at:

http://en.wikipedia.org/wiki/Waste_Electrical_and_Electronic_Equipment_Directive#UK_implementation

[Accessed 6 June 2014].

Wikipedia, n.d. Wikipedia. [Online]

Available at: ru.wikipedia.org

[Accessed 16 June 2014].