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MASTER OF SCIENCE IN PETROLEUM AND MINING ENGINEERING

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THE ENVIRONMENTAL IMPACTS OF THE WORLD ENERGY TRANSITION: THE ROLE OF RAW MATERIALS MINING

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Abstract

Seafloor minerals, many of which can be found in the deep ocean areas of the international waters, have attracted increasing attention over the last years due to the discovery of large volumes of deposits with high metal grades and to the growth in global demand for strategic minerals such as copper, nickel, cobalt, and rare earth. At the same time, the growing diffusion of electric vehicle batteries has had an impact on the demand for both land and deep-sea metal ores.

This thesis provides a comprehensive analysis about the environmental, social and economic impacts associated with land and deep-sea mining operations of metallic minerals such as cobalt and manganese used for the production of EV batteries. In detail, the environmental impacts of both land mining and deep-sea mining have been assessed and compared based on research conducted by a number of countries and organizations all over the world.
Additionally, land and deep-sea ores mineralogy, global distribution and technologies used in exploration, extraction, transportation and processing were explored.

The regulations and legal status of mining activities in the oceans and deep seas are directly related to the regions in which these activities will be carried out. Conversely, in cases where sea floor mining activities are realized in international waters, the International Seabed Authority (ISA), which was established on the basis of the United Nations Convention on the Law of the Sea adopted in 1982, is authorized to carry out control and management activities.
Taking this into account, the legal aspects of the extraction of these metals were also outlined in this thesis.

The comparative study of mining technologies and strategies for the analysed minerals will play an increasingly important role in the future definition of the benefits of a more ethical, environmental and economic transition to green energy.

Keywords: Energy transition, Batteries, Deep-Sea mining, Environmental issues, Sustainable development

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CHAPTER 1

INTRODUCTION

Every year, about a hundred billion resources are extracted from the planet to meet our needs (Oberle et al, 2019). Our relentless resource extraction is disrupting the world's natural order, making our land, oceans, and atmosphere uninhabitable for the people of the planet.

One of the main factors affecting the global environment is the use of fossil fuels, which account for 16% of the world's annual resource use. The use of fossil fuels marked the beginning of the industrial age and the formation of greenhouse gases, which led to unprecedented changes in the global climate. As a result, our planet has warmed more than 1° C since pre-industrial levels, global sea levels have risen by 25 centimeters, leading to an increase in extreme weather events (more extreme flooding, coral bleaching and die-offs, and collapsing fish populations.) and the death of every 7 million people from air pollution (İPCC, 2018; Who, 2019).

As a global society, the main goal is to limit global warming to 1.5° C (UN, 2015) and reduce the amount of carbon dioxide emitted into the atmosphere by 45% below 2010 levels and reaching zero by 2050. This plan can be implemented based on the age-old energy transition using green technologies. The scale of green transition is monumental, the timeline daunting (İPCC, 2018).

The rapid development of green technologies will require a massive new demand of metals. Nowadays, metals are extracted and processed from ore bodies. This type of mining creates negative externalities on a global scale. For example, while the use of fossil fuels emits 37 billion tons of waste into the atmosphere, this figure means 350 billion tons of waste for metal production (Blight, 2011). These wastes are partially toxic, and it ends up in our soil, our rivers, our air, our ocean, and our bodies. In particular, metal production accounts for 11% of global energy consumption (İPCC, 2014). Each year, tens of thousands of square kilometers of forest are cleared every year to reach metal ore bodies, leading to habitat loss and biodiversity loss (Stewart, 2019).

The mining industry is considered one of the most dangerous professions in the world and kills hundreds of miners. That is, the production of metals required for the green transition may increase the above-mentioned problems, and the green transition itself will not solve environmental problems but it will just shift the environmental and social burden from fossil fuels to metals.

How can we solve these problems? First of all, we need to replace internal combustion engines, which generate 15% of global emissions each year with EVs (İPCC, 2014). Compared to conventional cars, EVs will require more copper for electrical connectors and nickel, manganese, and cobalt for battery cathodes. This means that the production of raw metals, which are the main component of EV batteries, from ore bodies emits more CO_2 into the environment (about three times more than a conventional car), thereby negating the gains from reducing tailpipe emissions (Hausfather, 2019).

All metals in EV batteries are currently produced from land-based ores. There are two alternatives to that source to produce the world's greenest, most ethical EVs andreduce the damage caused by the green transition itself. These include secondary metals (i.e., recycled metals), and ocean minerals (e.g., polymetallic seafloor nodules).

The first option is the recycling of existing metal stocks, which is effective in solving the problems posed by mining resources. However, it will take us decades to build up the primary stock of metals to enable mass-scale EV metal recycling possible. Therefore, other primary sources of metals on land and in the ocean are needed to reduce environmental impacts during this period.

Land mining could be more sustainable by strengthening the electrification of equipment and transport, use of renewable energy sources, reduction of miners' deaths by mechanization and automation, and reduction of toxic spills. However, structural problems such as declining metal grades in ores, declining resources, and reduced accessibility due tothe deeper location of ore bodies remain.

Ocean minerals come in several forms: seafloor massive sulfides (SMSs—similar to land sulfides), cobalt crusts, and polymetallic nodules. These minerals are rich in base metals of EV batteries and have never been mined on a commercial scale to date. In addition, the impact of deep-sea minerals has fewer environmental impacts on the environment.

This thesis will provide a comparative economic, social and environmental analysis of these two sources — soil ores and deep-sea minerals — to supply the transition requirements for metals used in the manufacture of EV battery cathodes and wires. In particular, the two main metals, cobalt and manganese and their compounds will be the main subject of the proposed research.
Information, analysis approaches and results for land ores are also obtained from existing literatureand documented models.

CHAPTER 2

RAW MATERIALS

2.1 Cobalt

Cobalt, the 27th element of the periodic table, is a lustrous, grayish-silver and brittle element. Cobalt can maintain its strength at very high temperatures and has a fairly low thermal and electrical conductivity. In addition, cobalt is a ferromagnetic metal with a specific gravity of 8.9 and therefore can be magnetized. One of the most important properties of cobalt on an industrial scale is its ability to form alloys with other metals, maintaining its magnetic properties at high temperatures, up to about 1121°C. This property is higher than other metals. Refers to all other physical properties, electrical conductivity 1.7 x107 S / m, density 8.90 g / cm3, melting point 1495° C, boiling point 2927° C, crystal structure hexagonal close-packed, hardness 5.0 on the Mohr scale.

Cobalt is not found in pure form in nature, it is distributed in nature mainly in the form of compounds. Almost all dry deposits of cobalt are found in the combination with nickel and copper. Cobalt is therefore a by-product of the nickel and copper mining industry. Several methods have been developed to separate cobalt from copper and nickel. For example, flotation can be used to enrich cobalt ores. More information will be provided in the following sections.

Cobalt is considered a transition group metal and has only one naturally occurring isotope (Co^{59}). In addition, there are 22 radioisotopes of cobalt, of which only Co^{60},which has a half-life of 5.27 years and emits strong gamma rays, is one of the mostwidely used.

2.2 Manganese

Manganese, the 25th element of the periodic table, is a silver-gray metal and looks like iron. Manganese is very hard, brittle, difficult to fuse and easily oxidized. Manganese metal and its common ions have paramagnetic properties and can be easily oxidized in air. Manganese is the 12th most abundant element found in the world's upper crust, which makes up 1000ppm (0.1%) of the Earth's crust. (Rudnick et al, 2003). Refers to all other physical properties, electrical conductivity 60 x104 S / m, density 7.47 g / cm3, melting point 1246° C, boiling point 2061° C, crystal structure body-centered cubic, hardness 6.0 on the Mohr scale.
Manganese is the fourth most consumed metal in the world after iron, copper and aluminum, and is mainly produced from oxides and carbonates. However, it is very common in some silicate ores mixed with oxide. Manganese is found mostly in the form of pyrolysite (MnO2) in the Earth's crust, in the southern hemisphere (Elvers et al , 1990).
87% of manganese is used as a raw material in steel production (1 ton of steel consists of 8 kg manganese). The role of manganese in the production of iron and steel is very important,

especially two important properties. One of them is the presence of manganese as a strong desulphurising agent and its effective reductant. The second important feature is to improve the quality of steel.
Manganese is also widely used in the manufacture of aluminum containers and food containers to increase the corrosion resistance of containers. Thus, the addition of 1.5% manganese to such alloys dramatically increases their corrosion resistance.

2.3 Batteries

Cobalt is a very important element for low-carbon economy: increasing demand for electric vehicles and lithium-ion batteries, which play an important role in energy storage, in turn increases the need for Cobalt. However, one of the biggest obstacles to the development of such batteries is the Cobalt availability. The reason is the presence of cobalt reserves in risky areas and other factors which will be listed later.
Cobalt metal, oxide and hydroxide are used in the manufacture of cathodes in rechargeable batteries. Nodaway most of the electric vehicle batteries use nickel-manganese-cobalt cathodes, with are composed by 60% nickel and 20% each of cobalt and manganese.

The second most common application area of the mined manganese (after metal alloys) is its use as a depolarizer in the production of dry-cell batteries. This is 5% of total manganese consumption. The use of manganese in batteries (MnO_2, pyrolysite, earlyknown as magnesia negra) is based on its good redox ability, which prevents the evolution of hydrogen gas during battery charging. Manganese can be used in a variety of batteries, ranging from NiCd batteries to Li-ion technology. Compared to other types of batteries, lithium-manganese batteries have high cycle life, high energy density, rapid power discharge. Due to the capacity of electric storage batteries in the future, manganese belongs to the group of metals planned for contributing in low-carbon technologies; as a consequence, the demand for manganese has begun to increase (Fenget et al, 1999).

The World Bank showed in its report "The Growing Role of Mineralsand Metals for a Low Carbon Future" that the demand of manganese in these technologies can multiply".

As said above, lithium-ion batteries are one of the most important applications of cobalt and manganese as raw materials. For our analysis, we will focus on 4 main types of batteries that are widely used in EV, Battery electric vehicles (BEVs), Plug-in hybrid electric vehicles (PHEVs), cameras, phones, tablets (Battery University, 2021). These batteries include Lithium Cobalt Oxide - LCO, Lithium Manganese Oxide - LMO, Lithium Nickel Manganese Cobalt Oxide - NMC,Lithium Nickel Manganese Oxide – LNMO.

- Lithium Cobalt Oxide, $LiCoO_2$ – LCO

High-specific power makes Li-cobalt batteries a popular choice for mobile phones,laptops, and digital cameras. These batteries contain 60% cobalt and the specific capacity of the battery is 150-200 Wh / kg. LCO batteries consist of a cobalt oxide cathode and a graphite carbon anode. These batteries have some disadvantages compared to others, including relatively short life and limited specific power. In addition, the battery is not as safe as other types, according to the Battery University.

- Lithium Manganese Oxide, $LiMn_2O_4$- LMO

Unlike other lithium batteries, Li-manganese batteries are safer and more resistant to high temperatures and the specific capacity of the battery is 100-150Wh/kg. Due to this feature, these batteries can often be used in medical equipment anddevices, as well as power tools, electric bicycles. Sometimes these batteries can be used to power laptops and electric powertrain cars.

- Lithium Nickel Manganese Cobalt Oxide, $LiNiMnCoO_2$ – NMC

Like other lithium-ion batteries, NMC batteries can either have a high specific energy density or a high specific power. There are three main types of this battery, NMC-111 (30% Co, 28% Mn), NMC-622 (18% Co, 17% Mn), and NMC-811 (9% Co, 8% Mn). This type of battery is most common in power tools and power units for vehicles. Because the amount of cobalt is relatively low compared to other batteries, this lowers the cost and makes these batteries cheaper. The cost of these batteries is expected to fall further in the future, as some battery manufacturers intend to use less cobalt. This battery type is commonly preferred for electric vehicles due to its very low self-heating rate.

- Lithium Nickel Manganese Oxide, $LiNi_{0.5}Mn_{1.5}O_4$-LNMO

LNMO cathode material is a cobalt-free high-voltage (5V) spinel for use in next-generation lithium-ion rechargeable batteries. These batteries have many advantages, including high working potential and high energy density, leading to a longer operating range or a smaller battery package whilst the three-dimensional spinel structure allows for high discharge rates and fast battery charging. The lack of cobalt and low nickel content is a viable alternative to today's major lithium-ion battery chemistries.

CHAPTER 3

Exploration of Cobalt and Manganese in the Earth crust

3.1 Exploration of Cobalt

Mineralogy

There are about 70 minerals of Cobalt in nature. Cobalt is mainly present incombination with the Nickel, Iron and Manganese minerals. It is estimated that the concentration of Cobalt in the Earth's crust is between 15-30 ppm. (Yaylalı et al, 2020). Cobalt concentrations in ultramafic igneous rocks such as Dunite and Serpentinite range from 109 to 115 ppm, while in mafic igneous rocks such as basalt,this figure varies from 47ppm (Petavratzi et al, 2016).

The most common cobalt minerals in nature are shown in **Table 1**. Cobalt does not exist in pure form in nature and is distributed in the form of mineral groups.The most common mineral groups of cobalt are sulfides, sulfate salts, arsenides and oxides. The main source of cobalt is arsenic sulfur (the main mineral is cobaltite, (Co, Fe) AsS) ores. In addition, lateritic nickel, nickel sulfur, copper-cobalt sulfur, and oxidized copper-cobalt ores may also contain significant amounts of cobalt (Yaylalı et al, 2020).

Name	Group	Formula	Cobalt content (weight %)	Example deposits
Erythrite	Arsenate	$Co_3(AsO_4)_2 \cdot 8H_2O$	29.53	Daniel Mine, Germany; Bou Azzer, Morroco.
Skutterudite	Arsenide	$(Co,Ni)As_3$	10.9-20.9	Skutterud Mines, Norway; Bou Azzer, Morroco.
Cobaltite	Sulphosalt	CoAsS	35.52	Sudbury, Canada; Broken Hill, New South Wales, Australia.
Carrollite	Sulphide	$Cu(Co,Ni)_2S_4$	28.56	Chambishi, Copperbelt, Zambia; Carroll County, Maryland, USA.
Linnaeite	Sulphide	$Co^{2+}Co_2^{3+}S_4$	58.0 (theoretical)	Bou Azzer, Morroco; Nor'ilsk, Russia, Bastnäs mines, Riddarhyttan, Västmanland, Sweden
Asbolite (Asbolane)	Oxide	$(Ni,Co)_{2-x}Mn^{4+}(O,OH)_4 \cdot nH_2O$	0.5-5.0	Koniambo Massif, New Caledonia.
Safflorite	Arsenide	$CoAs_2$	21.25	Neuglück Mine, Germany; Daniel Mine, Germany, Oumlil Mine, Morocco

Table 1: Common cobalt-bearing minerals (Petavratzi, 2016, Yaylalı, 2020).

In general, the amount of cobalt in rock-forming minerals is not enough to meet economic indicators. However, cobalt, which has a high economic-concentration, can be found in the olivine minerals, spinel and chlorite in lateritic (lateritic) and hydrothermal deposits.

World Resources

The total Cobalt reserves in the world are approximately 7 million tons, excluding the cobalt contained in deep-sea nodules and crusts on the sea floor (**Table 2**). Approximately 51% of this is located in Africa, 12% in America, 21% in Australia and 5% in Asia (USGS, 2017).
Copper-cobalt deposits, where cobalt is obtained as a by-product of copper production, are predominantly located in Congo and Zambia(Yaylalı et al, 2020). When analyzed in terms of production amount, Congo takes the first place and Russia is the second-largest producer (USGS, 2019).
Despite the economic stagnation in mining in the last decade, cobalt production has increased from 57,500 tons/year in 2006 to 140,000 tons/year in 2018 (USGS, 2007 and 2019).

Country	Reserve (tonnes)	2019 production (tonnes)	2020 production (tonnes)	İncrease in production rate per year, %
Congo	3,600,000	100,000	95,000	8.3
Australia	1,400,000	5,740	5,700	
Cuba	500.000	3,800	3,600	
Philippines	260,000	5,100	4,700	
Canada	220,000	3,340	3,200	
Russia	250,000	6,300	6,300	
Madagascar	100,000	3,400	700	
China	80,000	2,500	2,300	
Papua New Guinea	51,000	2,910	2,800	
USA	53,000	500	600	
South America	40,000	2,100	1,800	
Morocco	14,000	2,300	1,900	
Other Countries	560,000	6,320	6,400	
Total	7,100.000	144,000	140,000	

Table 2: Cobalt reserves and production in the world (modified from USGS, 2019 and 2020).

Deposits

Cobalt is generally obtained as a by-product from copper and nickel (lateritic and sulphide) ores (Yaylalı et al, 2020). As seen in Table 3, 54% of cobalt production is carried out from facilities that produce copper as the main product. The share of cobalt plants in the production is 12%, while the share of facilities with nickel as themain product is 34%. However, with the newly established nickel plants, it is observed that the share of the plants whose main product is nickel in cobaltproduction is increasing significantly **(Table 3**) (Yaylalı et al, 2020).

	Copper (%)	Cobalt (%)	Nickel (%)
Production facility	54	12	34
In pre-production or commissioning phase	47	17	36
In the last stage *	20	12	68

Table 3: the share of plants with primary products CU, CO or NI in cobalt production (%).

* The reserve has been determined and designed, but mines where production decision has not been made yet.

Concentrations of cobalt, which are considered economically viable, are mainly found in four geological formations (Roskill Information Services, 2014, Cobalt Institute, 2018).

➢ Sediment hosted

These deposits are mainly used in the production of copper as a raw material, and cobalt is obtained as a by-product as a result of the process. More than 50% of the world's cobalt production is obtained from the development of such deposits. The main deposits are ore minerals organically rich in pyrite shales and sandstones, which are formed in the coastal or lagoon environment as a result of theconversion of seawater sulfates to sulfides in a diagenetic process. This process leads to an increase in the concentration of metals that are considered important for industry, especially copper and cobalt.

The economic value of cobalt in such deposits varies from 0.1 to 0.4. It should be noted that the largest deposits were found between the Upper Proterozoic (approximately 1500 to 600 Ma[6]) and Permian and Triassic periods (300 to 200 Ma).One of the main reasons for this was the widespread spread of arid and semi-arid environments on the Earth's surface at that time (Petavratzi et al, 2019)

The largest and most popular of these deposits are the European Kupferschiefer and the Central African Copperbelt. The Central African Copperbelt is considered one of the most important cobalt deposits in the world. It stretches for more than 500 kilometers across northwestern Zambia and the Republic of the Congo and has reserves of about 6 million tons of cobalt, which is estimated to vary between 0.17 0.25 in the economic grade of cobalt in this mineral. One of the other major sources of cobalt is also considered The European Kupferschiefer, which is considered the main source for many metals. Such minerals are mainly rich in copper, silver and cobalt as a by-product. The content of cobalt inthese minerals varies between 20-30 ppm and 100-300ppm in areas rich in cobalt. The European Kupferschiefer stretches from the northeast of England along the North Sea to Poland. Most of the fields are located in central Germany and Lower Silesia, Poland.

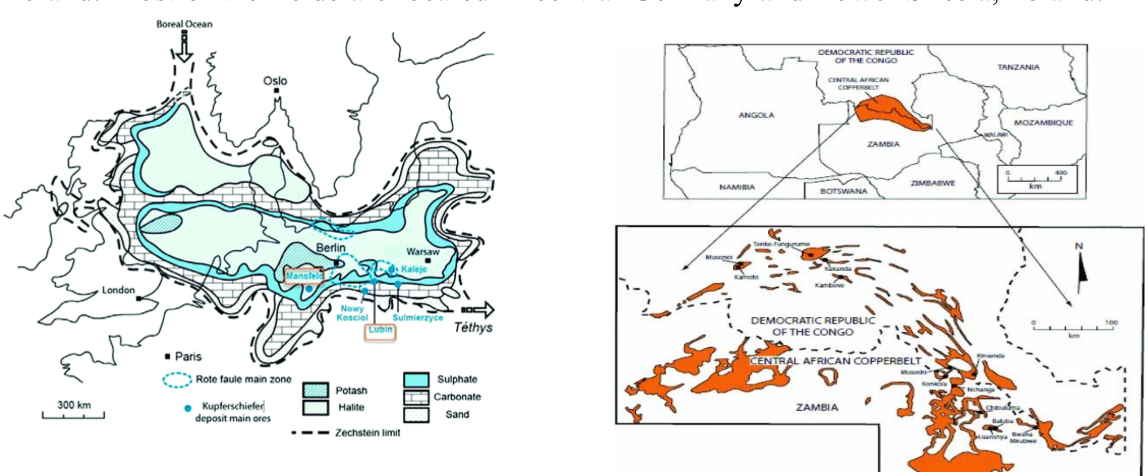


FIGURE 1: European kupferschiefer and the central african copperbelt (Mejia, 2015 and Dacil, 2016)

Other important cobalt deposits include Mount İsa, Australia and Kilembe, Uganda. In such deposits, cobalt is mainly obtained from gold deposits as a by-product.

➢ Hydrothermal/ volcanogenic

Hydrothermal mineral deposits are formed from hot water circulating in cracks in the earth's crust due to the volcanic activity. As a result of this process, rich-metallic fluids begin to accumulate in a certain volume of rock, which becomes supersaturated, resulting in the precipitate of the ore minerals.

In all these examples, cobalt mining is obtained as a by-product of other ores. The only mine where cobalt is obtained as a primary raw material is the Bou Azzer field in Morocco. Here, cobalt arsenides were formed by the serpentinization of cobalt- rich peridotites in the ophiolite complex formed as a result of the Pan-African deformation (about 685 million years ago). It was then further enriched as a result of the weathering process, and economic concentrations occurred during the Hercynian Orogeny period. As a result, metals began to crystallize again, accumulating in faults and fractures (Cobalt İnstitute, 2016).

- Magmatic sulphide deposits

Magmatic sulfide deposits are formed when mafic* and ultramafic magmas begin to saturate in sulfur and an immiscible liquid sulfide phase is formed. This occurs during contact with crustal rock. The resulting deposit is rich in elements of the Nickel, Cobalt and Platinum group with different concentrations. Thus, these elements are separated from the residual magma and stored in sulphide-rich layers (BGS, 2009).

Mafic*: dark colored rocks containing iron and magnesium-bearing minerals e.g. olivine.
Magmatic sulfide deposits are divided into different categories according to their morphological features, age and type of mineralization. The most common types are:

- **basal deposits**, sulfur saturation of mafic magma cause an increase in the density of cobalt and nickel in the basal sections of the magma chamber. Thus, as magma with a high metal content moves between cracks in the earth's crust, it comes into contact with sulfur-containing rocks, such as evaporites. The passage of fresh magma through the same cracks feeds the volcanic pile. This repetitive process increases the concentration of Ni, Cu, Co and PGE metals. The most famous of these deposits is Norilsk, Russia.
- **stratabound deposits**, are deposits formed during the precipitation and segregation of minerals from magma because of very slow cooling in a major magma chamber in a large gabbroic magma chamber (this process is also called fractional crystallization) causes the deposition of sulfite layers containing cobalt, nickel, copper and platinum group minerals. After precipitation and segregation, the residual magma and minerals gradually crystallize and change their chemical composition. We can point to such mineral deposits as MerenskyReef, South Africa.
- **deposits in extrusive ultramafic rocks.** Komatiite, an ultramafic, magnesium-rich, high-temperature volcanic rock derived from the hot mantle, is formed as a result of the crystallization of lava and flows become sulphur saturated by differentiation and host rock assimilation. Such minerals are rich in cobalt, nickel and platinum group minerals. It is a very rare mineral and is found mainly in Archaean rocks, with few Proterozoic or Phanerozoic rocks. In Kambal, Western Australia is one of the most widespread sources of such minerals.

- Laterite deposits

Lateritic deposits are formed as a result of the degradation of olivine-containing ultramafic rocks such as dunite, peridotite and serpentinite due to heavy rainfall in tropical and subtropical climates. In this process, silicon, manganese, and nickel dissolve selectively and accumulate at lower levels. Lateritic deposits contain significant amounts of cobalt (Bamber and Barnes, 2019). As a result of weathering, cobalt becomes remobilized and deposited in the weathered layer as hydroxides,

oxides. But in the deeper layers, it exists in the form of sulfides, these deposits are generally about 20 metres thick. The average cobalt grade in these deposits is 0.025-0.1%. The most typical examples are found in Australia, Cuba, New Caledonia, Indonesia, the Philippines and Brazil, New Caledonia and Cuba due to large areas of serpentinised peridotites and ideal weathering conditions (Cobalt İnstitute, 2016).

3.2 Exploration of Manganese

Mineralogy

Manganese is found as a trace element in many minerals. Manganese ores are distributed in the form of oxides, hydroxides, carbonates and silicates; they are rich in various types of manganese minerals, mainly in fine-grained or microscopic form. It is very difficult to visually identify different types of such minerals in the same ore. It is possible to obtain information about the mineral structure and composition of manganese minerals using modern analytical methods.

Although manganese minerals exist in very different forms in the same ore, some minor generalizations allow us to identify many aspects of ore mineralogy. The most commonly found manganese mineral is manganese oxides, followed by manganese carbonates. Among all other types of manganese minerals, manganese carbonates differ in the high content of manganese. Among the oxides, pyrolusite (MnO_2) and cryptomelane ($K(Mn4+, Mn2+)_8 O_{16})$) is the most widely exploited and studied mineral, although it is not significantly rich in manganese.

The most well-known carbonate minerals are rhodochrosite ($MnCO_3$) and kutnahorite ($CaMn_2+(CO_3)_2$). Although rhodochrosite is by far the most well-known of the manganese carbonates, kutnahorite is more prevalent in the Kalahari manganese ores of South Africa. Braunite, the hydroxide form of manganese and the silicate form, is also very common. The characteristics of manganese minerals, which are widespread in nature and of industrial importance, are shown in Table-4.

Name	Group	Formula	Manganese content (weight %)	Example Deposits
Rhodochrosite	Carbonate	$MnCO3$	47.79	Galerie Elisabeth, Cavnic, Maramures, Romaina, Sweet Home mine, Alma, USA
Braunite	Silicate	$Mn^{2+}Mn^{3+}_6 [O_8 \vert SiO_4]$	63.60	Black Rock Mine, Kalahari Manganese Field, South Africa.
Cryptomelane	Oxide	$K (Mn^{4+}, Mn^{2+})8\ O16$	59.83	Brazil, Gabon, South Africa, Ojuela mine, Mapimi, Druango, Mexico
Manganite	Hydroxide	MnO (OH)	62.47	Gabon, Ghana, Kalahari Manganese Field, South Africa
Pyrolusite	Oxide	$MnO2$	63.19	Brazil, Gabon, Ghana, Georgia, South Africa, Hori Blatna, Czech Republic

Table 4: Common manganese-bearing minerals (from: http://webmineral.com/)

❖ Rhodochrosite

Rhodochrosite carbonate mineral is considered to be the most common manganese mineral known, including subeconomic deposits. The main deposits for these ores are a number of deposits in Molango, Mexico and China. Obtaining economically viable manganese from the rhodochrosite mineral requires processing to convert manganese carbonates to manganese oxides. As a result, the concentration of manganese increases.

❖ Braunite

Braunite is classified as a silicate mineral even though it contains less than 10% silicon dioxide or silica. Although the Braunite mineral contains less than 10% silicon dioxide or silica, it is classified as a silicate mineral and is found in the Kalahari manganese district in South Africa.

- Cryptomelane

Potassium-rich mineral is found as a highly oxidized mineral in many manganese- producing countries, especially Brazil, Gabon and South Africa.

- Manganite

Manganite or manganese hydroxide is formed by the oxidation of ore on the surface or near the top layer of the earth as a result of interaction with groundwater. Such deposits are found in Gabon, Ghana, as well as in Kalahara.

- Pyrolusite

Due to its composition, it is a simple MnO_2 and is formed in a highly acidic (lower pH) and oxidizing environment. Pyrolusite ores are found in Brazil, Gabon, Georgia, Ghana and South Africa.

World Resources

According to the USGS report (2019), the vast majority of manganese reserves are located in South Africa, Ukraine and Brazil, which together account for 65% of total world reserves. The Kalahari district in South Africa accounts for 25% of the world's reserves. According to the USGS, manganese reserves in the world are estimated at 810,000 tons.

Manganese resources are divided into two categories, such as cobalt deposits: 1. land-based deposits and 2. seabed deposits.

In the deep seas, although it is still technologically and economically more difficult, manganese reserves are many times greater than land-base deposits such as cobalt reserves. More information will be provided in the following sections.

Total manganese reserves are estimated at 17,273,000 tonnes, including both identified land-based resources and future manganese-enriched ore reserves (Cannon et al, 2017).

	Reserve (tonnes)	2019 production (tonnes)	2020 production (tonnes)	İncrease in production rate per year,
United States	-	-	-	4.3%
Australia	230,000	3,180	3,300	
Brazil	270,000	1,740	1,200	
Burma	NA	430	400	
China	54,000	1,330	1,300	
Cote d'Ivoire	NA	482	460	
Gabon	61,000	2,510	2,800	
Georgia	NA	116	150	
Ghana	13,000	1,550	1,400	
India	34,000	801	640	
Kazakhstan, concentrate	5,000	140	130	
Malaysia	NA	390	350	
Mexico	5,000	202	190	

South Africa	**520,000**	5,800	5,200
Ukraine, concentrate	**140,000**	500	550
Other countries	Small	270	270
World total (rounded)	1,300,000	19,600	18,50 0

Table 5: Manganese reserves and production in the world (modified from USGS 2019 and 2020).

Deposits

Manganese deposits are mainly divided into 4 main groups:

- Magmatic manganese deposits

Magmatic manganese deposits are formed by the release of manganese ore-bearing hydrothermal fluids into the ocean reservoir due to submarine volcanism, resulting in the formation of stratiform ore. These kind of ore deposits are called sedimentary exhalative deposits (SedEx) (Colin-Garcia, 2016). These deposits are characterized by a very complex mineralogy. In general, manganese oxides (hausmannite), silicates (braunite) and carbonates (rhodochrosite) are found in these deposits. The most important deposits of SedEx manganese ores are found in Mexico, India, Europe, Spain, Slovakia, Cyprus and Portugal (Dill, 2010; Pohl, 2011).

- Sedimentary manganese deposits

Sedimentary manganese deposits differ from others by a very wide range. These include: 1. Strata-bound manganese deposits (i.e. sandstones, siltstones). These deposits are more widespread in Ukraine (Nikopol), Georgia (Chiatura) and northernAustralia (Groote Eylandt). 2. Organic rich manganese deposits (black shales). 3. Ferromanganese crusts and nodules, which are found on the seabed. 4. Lateritic orebodies, which are formed as a result of weathering and are rich in 30% manganese.The deposits, known as supergene or lateritic, are mostly exploited in South Africa, Brazil (Minas Gerais), India (Orissa), Gabon (Moanda) and China (Pohl, 2011).

- Structure-related manganese deposits

Structure-related deposits are the growth of crystals on the walls of planar fractures in different types of rocks (e.g. limestones, granites and gneisses) after the circulation of hydraulic flow. As a result, hydraulic veins are formed, which are very rich in mineralogy. Pyrolusite, psilomelane, manganite, hausmannite and braunite are found in these veins. Although these deposits are rich in metals other than manganese, they are not currently of economic interest. Structure-related deposits are mainly found in France and Germany (Dill, 2010).

- Metamorphic manganese deposits

Metamorphic manganese deposits or manganiferous banded iron formations are considered to be economically significant deposits because they are composed of very complex metamorphosed sediments and volcanic rocks rich in manganese oxides, silicates and carbonates. In particular, these deposits are characterized by high grade manganese (up to 50% manganese). Examples are found in Kalahari Field in South Africa, India and Brazil (Dill, 2010; Pohl, 2011).

CHAPTER 4

METAL PRODUCTION PROCESSES

Mining is developing over time and the demand for old mines is declining. Especially in our modern world, mines have moved to more remote locations. As a result, public awareness of the mining procedure is limited. Extraction of metals from seabed surface is a very innovative and unexplored procedure and an alternative to land base deposits. A comparison of land ores and deep-sea nodules can be clarified by determining the differences between their production processes.

Below we will provide an overview of the nature of each of these sources, ore extraction and processing procedures, and the impact of each stage.

- Generalized Process

The production of any type of metal consists of complex chemical reactions, chemicals, energy-intensive processes and interactions between the stages during theproduction process. We begin with a very simple procedure, consider the productionthat is common to both land base ores and seafloor nodules.

Metal production is built in three main stages **(Figure 2)**:

1. **Mining**: At this stage, mineral ores are extracted from either land-ore bodies or deep-sea nodules. The "benefit" or "comminution" method can be used to increase the grade of ore if needed. This stage is considered a very complex life cycle and significantly distinguishes between land-based ores and nodules. Because in deep sea mining, especially during the extraction of polymetallic nodules, there is no needfor drilling. Because these nodules are semi-suppressed and scattered on the surface of the seafloor, it is necessary to collect them with the help of special vehicles. However, when extracting land base ores, we must take into account ore-body grade,geology and location of the mine.

2. **Processing:** Water, heat and chemical compounds are used at this stage to separate metals from ore. The processing stage is the stage carried out in metallurgical plants. Ores are subjected to different processing to separate metals from ores, and this process can be different depending on the type of ore. Two of these processes are considered to be more common approaches (or flowsheets), which include pyrometallurgical (heat intensive) and hydrometallurgical (water intensive).

- Pyrometallurgical process

In order to separate metals in the pyrometallurgical process, the ores introduced as input are heated to a high temperature in the presence of reducing agents and then smelted. As a result, the phases obtained in the molten state form layers such as oil and water, which makes it easier to separate the metals. Because such processes take place at high temperatures, pyrometallurgy is considered heat intensive and requires large amounts of coal, natural gas, electricity and other energy sources. In this method, sulfides and carbonates are first converted into oxides. To purify the compounds, pyrometallurgy must extract oxygen from metal oxides. Given that coalis used in the process, the released oxygen interacts with the coal and results in the release of CO_2. In sulfide ores, SO_2 release is observed. Slag generated as a result ofthe process can sometimes be considered significant for other processes such as byproducts.

- Hydrometallurgical process

İn the Hydrometallurgy method, the ores from the mining are converted into the solution phase, and this solution subject to a reduction process by using more active metals than the metal itself or using an electrical current. The separation of metals from oresis based on their leaching with aqueous solutions. These include washing with acids,bases, oxidizing or reducing agents. There are different methods for the leaching ofthe metal extraction in the mine site including pressure leaching, dump leaching, heap leaching, or in situ leaching. Each method characterized by its own energy and material requirements. The hydrometallurgy process demands a large amount of water, energy and produces waste residues and effluents.

Refining: The main purpose is to refine the metal and convert it from intermediate forms to final desired pure metal or alloys. Refining methods include electrowinning, electrorefining, solvent extraction, and stepwise crystallization. The electrolytic process used on an industrial scale is called electrowinning. The main purpose of this process is to separate the metal from the ore using metal electric current in metal-rich solutions and collect it on the cathode. Electrorefining is based on the same process and is used to separate impurities from metal and deposit the metal over the cathode. The crystallization process is mainly based on the reaction of metal oxides with sulfuric acid. For example, the reaction of cobalt oxide with sulfuric acid produces the salt cobalt sulfate.

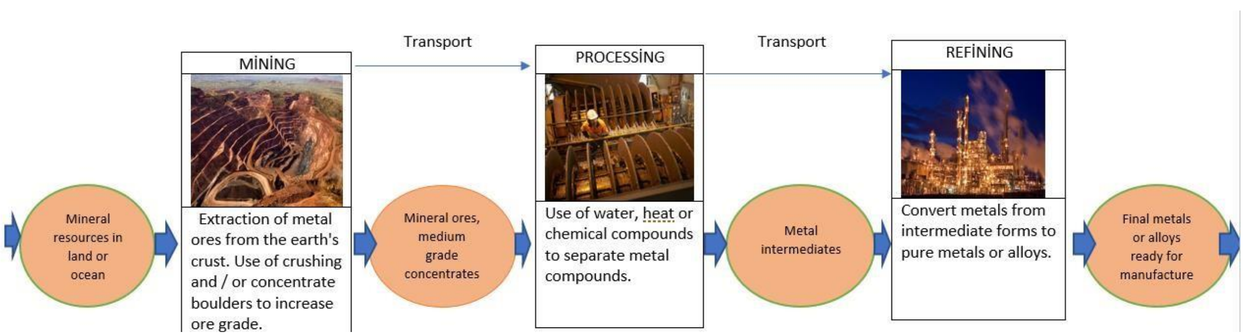


Figure 2: Generalized production of metals, cradle-to-gate (Nuss and Eckelman, 2014)

All of the above processes describe metal production, regardless of the source of theore. However, during the production of cobalt and manganese based on land resources and nodules used in electric vehicles (EV), batteries and other fields, there are significant differences, both in terms of environment and economics. Differences are beginning to emerge, especially in the Mining, Processing and Refining phases.We will describe these differences in detail.

- Production from land ores

The production of metals in land base mines is very complex, time-consuming, economically and environmentally expensive **(Figure 2)**.

The initial stage of the mining procedure is the prospecting and exploring of the size, quality and economic performance of the ore deposits. This process costs millions of dollars and is a very risky process that takes 8-10 years to complete.

Depending on the location of the discovered ore deposit, the development of a new mine is a very long-term, expensive and wide-ranging process. If the ore deposits are located in the populated area, the local community should be relocated to safer areas. If the ore deposits are located in remote areas, the first step is to build the infrastructure, which is a very expensive and time-consuming process. Such infrastructure includes the construction of roads, railways, power supply, housing for miners and other facilities.

Figure 3: Metal production from land ores: mining life cycle. superfund research program (University of Arizona, 2019).

Several methods are used to extract ores from land base mines. These include open-pit mining, underground mining or a combination of open-pit mining and underground. All these methods depend on the size, class, type of deposit and surface type of ore in the deposits (Chmielewski et al2016). Cobalt and manganese ores are extracted in land base mines mainly by open-pit mining and underground mining methods.

- **Open pit mining:**

where ore deposits are located close to the surface (approximately 100 meters belowthe surface), the open pit mining method is more economically viable than the underground method. In this case, various types of trucks or other conveying vehicles are used to remove overburdens. (Zhao et al 2013). It should be noted that open-pit mining leads to the destruction of forests and vegetation in large areas, the removal of the topsoil covering the ore deposits and their disposal in nearby areas. In order to connect high-tonnage trucks and mining equipment to the ore deposits, spiral roads are being built around the field, which covers a very large area. 2-10 tons of country rock is extracted for each ton of ore.

- **The underground mining**

The method is used when ore deposits are located deeper than 100 meters from the surface. Different types of standard mining methods can be used in underground mining, depending on the type and nature of the deposits. These include block caving(for large, uniform deposits), room and pillars (mainly used for flat and shallow deposits), and various other methods for narrow and steeply dipping ore deposits.

Underground mining takes years to establish a connection between the shafts. In addition, the development of tunnels, the construction of underground infrastructure,the provision of energy and ventilation systems are very important and expensive procedures. Billions of dollars are spent before a single ton of ore is extracted. Thistype of mining is considered very risky.

Sometimes both open-pit mining and underground mining methods can be used simultaneously. It depends on the type of ore deposits in the mine. In the same mine, ore deposits can be found both near the surface and in deeper layers, in this case both methods need to be used simultaneously.

The bulk of the original tonnage obtained as a result of such a mining process turnsinto "tailings". Tailings are mainly composed of toxic chemicals and are dangerous to the environment. Such tailings are stored outside the mine area, in specially built dams. Dams are considered one of the biggest problems of land base mining and hada long-term impact. Accidents can lead to ecosystem damage, deaths and other problems.

Mine closure and reclamation procedures are an incredibly difficult, time-consuming and expensive processes. In this process, it is very important to cover the surface of the sulfur rocks, otherwise it will mix with rainwater and form sulfuric acid, which is harmful to the environment, conditions are created for evaporation of tailing pods,then the surfaces are covered to protect them from dust, topsoil is applied to re- vegetate the areas, open pits are fenced, and shafts are closed. Without such reclamation and closer procedures, open pits can cause toxic metal-contaminated water to mix with the stream, contaminate soil and groundwater with toxic substances, spread toxic dust, and cause injuries.

It should be noted that rehabilitation is often underestimated and is not of interest to many operators. Because the cost of rehabilitation can even lead to the bankruptcy of the company. That is why these cases are often transferred to the state. Depending on the size, the cost of rehabilitating a single mine can be as high as $ 100 million (McCarthaigh, 2019). For example, for the production of metals and minerals in northern Canada, the value of the mine, which has been exploited since 1977, is estimated at $ 18 billion, while the estimated cost of closing the mine is more than $1 billion (Caldwell, 2013)

Some mines are temporarily closed for use in the future when technology improves.This is because the grade of ore in these mines is either too low or the cost of extracting the ore has started to increase so much that it is not considered economically viable. There are more than 500,000 abandoned mines in the United States alone, which contain 50 billion tons of untreated and unreclaimed waste (IIED, 2002).

According to the Center for Western Priorities in 2015, more than $ 21 billion will be needed to reactivate more than 100,000 mines in the western United States (Weiss, 2015).

In the following sections, the production of cobalt, manganese and deep-sea minerals, which are considered raw materials for the production of batteries, will be studied in detail.

4.1 Cobalt Production

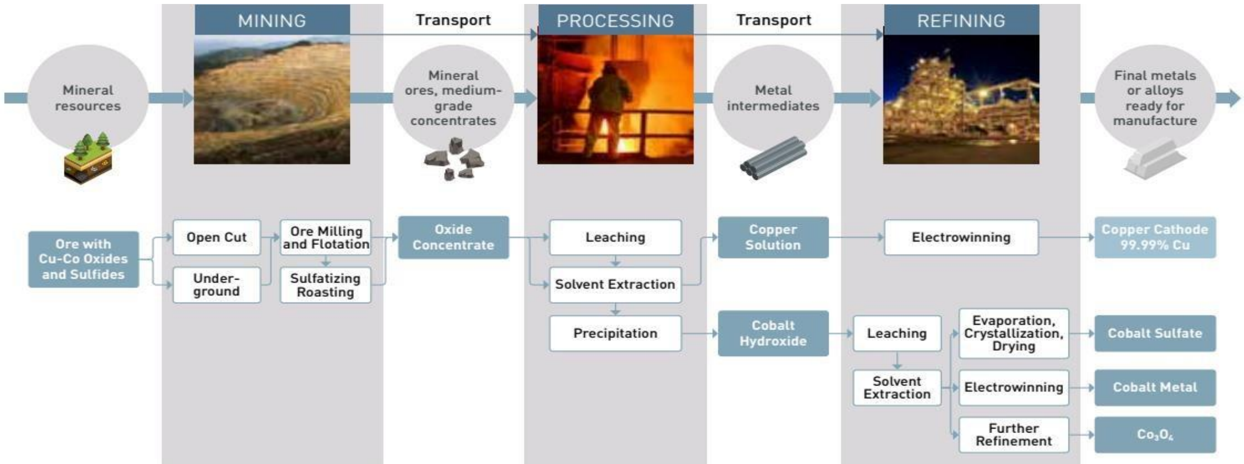


Figure 4: Cobalt production as byproduct of copper oxides (hydro) (Dai et al., 2018).

Cobalt is usually extracted from ores by the application of pyrometallurgical, hydrometallurgical and electro-metallurgical methods (Yaylalı et al, 2020). The appropriate production method is determined according to the mineralogical structure and cobalt content of the ore. The classification of ores containing cobalt and the proposed production methods according to the ore type are presented in **Table 6**. Cobalt is produced from arsenic sulphide ores as the main product. As a by-product, it is obtained from lateritic nickel, sulphurous-nickel, sulphide copper- cobalt and oxidized copper-cobalt ores (Yaylalı et al, 2020).

It should be noted that two-thirds of cobalt production is obtained from stratiform sedimentary deposits, and 27% is obtained by leaching from nickel-cobalt laterites or by smelting nickel-sulfides from magmatic sulfide deposits. In addition, the demand for cobalt is derived from ores from VMS deposits.

According to the requirements, cobalt can be produced and traded in various forms.These include cobalt concentrates, salts, intermediates, and a highly pure metallic form.

	Ore Type	Metal Grade	Cobalt Source / Mineral	Production methods
	Arsenic Sulfur (main product cobalt)	-	Cobaltite - (Co,Fe)AsS	Roasting + Pressure leaching
Cobalt as a by-product	Nickel-Cobalt laterite ore	0.1% Co 1.26% Ni 46.5% Fe 0.1% Mg 1.9 % SiO_2	Limonite- (Fe,Ni,Co)OOH	1.High pressure sulfuric acid leaching 2.Reductive roasting + Ammonia leaching (Caron process)
	Nickel-Cobalt sulfide ore	1.1% ±0.3 Co 36 % Ni	Pentlandite - $(Ni,Fe,Co)_9 S_8$	1.Flotation + Flash smelting 2.Flotation + High pressure ammonia leaching (Sherritt-Gordon process)
	Copper-Cobalt Sulfide ore	0.4% Co 4-6% Cu	Carrolite – $Cu (Co,Ni)_2S_4$	Roasting + Sulfuric acid leaching in atmospheric conditions
	Copper-Cobalt Oxidized Ores	0.3 % Co 3 % Cu	Heterogenite- CoO(OH) Spherocobaltite - CoCO3	Reductive sulfuric acid leaching using SO_2 in atmospheric conditions

Table 6: Classification and production methods of cobalt ores (Yaylalı, 2020).

As we can see from cobalt mineralogy, cobalt is mainly formed in nickel and copperores. That is why nickel and copper are used as by-products in production.

Coproduction with nickel- More than half of cobalt production is obtained with nickel as a by-product during production. The production of cobalt as a by-product of nickel is based on two main processes, pyrometallurgical extraction from sulfides and hydrometallurgical extraction from laterites.

Cobalt as a copper byproduct - The typical conceptual production scheme for copper-cobalt ores obtained during mining at the DRC and produced at various plants in China is given in **Figure 4.** Sulfide and oxide compounds of cobalt are mainly found together in minerals. After the oxide and sulfide ores are extracted, milling and floating are done to increase their concentration. In the initial stage, the sulfur compounds are pre-treated by roasting or pressure-oxidation, and at this stage,the release of SO_2 gas is observed. To reduce the impact on the environment, the SO_2 gas obtained at this stage is recycled in order to be used for other processes (e.g.H_2SO_4 production) instead of being released into the air.

After this pretreatment process, cobalt sulfide and oxide compounds can be subjected to a hydrometallurgical process together. The resulting concentrates are leached with acid to obtain a copper-cobalt solution. Two types of solution are obtained as a result of the solvent extraction process. These include cobalt-rich solution and copper-rich solution. Copper is electrowinned to obtain a copper cathode. Cobalt is precipitated and separated from impurities and can undergo various processes depending on the final product. For example, cobalt sulfates can be obtained, which play an important role in the production of batteries or can be produced in the form of oxides or pure metal.

China obtains cobalt in the form of cobalt sulfate for the production of batteries, which have a special role in electric motors, ie it does not carry out the procedure tothe pure cobalt stage, and China is a world leader in this field. This is why an additional crystallization process is added to produce battery-grade cobalt sulphate from pure cobalt. Globally, cobalt is processed in the form of pure metal for use in catalysts, pigments, superalloys, hard materials and other fields (Umicore, 2013).

Cobalt production leads to an increase in the impact on the environment during that production. Particles released during cobalt production cause various problems for human health. Such problems include vision problems, vomiting, nausea, cancer, and thyroid damage. Cobalt is an important gamma-ray source which is used as a radio therapeutic agent for cancer treatment (Baskar et al, 2012). Highconcentrations of cobalt can cause diseases such as asthma and pneumonia. (Ruokonen et al). Studies have shown that cobalt particles are found in plants and fruits growing in contaminated soils. Such particles are found in soil, rocks, water and plants, where they are released from the air in the form of dust, in the form of surface water and radioactive particles from mining areas (Fordyce, 2013).

4.2 Manganese Production

Unlike cobalt, manganese is mainly produced as a primary product. For manganese production, mining methods vary greatly depending on the type of ore and the width of the deposit. For example, metals close to the surface are extracted by the open-pit method, and deeper ones are extracted by the underground method. Manganese ores can be used in a variety of products, including pure manganese, alloys (ferromanganese, silicomanganese, high-carbon alloys), oxides, concentrates, slagsand sulfates.

It should be noted that manganese is of great importance in steel production, so 80%of manganese production is used in steel production such as Ferromanganese and silicomanganese. Out of the two, silicon manganese accounts for 70% of total production. Both products are produced by pyrometallurgical method, first the ores are melted in blast furnace or electric-arc furnace and the amount of manganese oxides is reduced. The general process is shown in **Figure 5**.

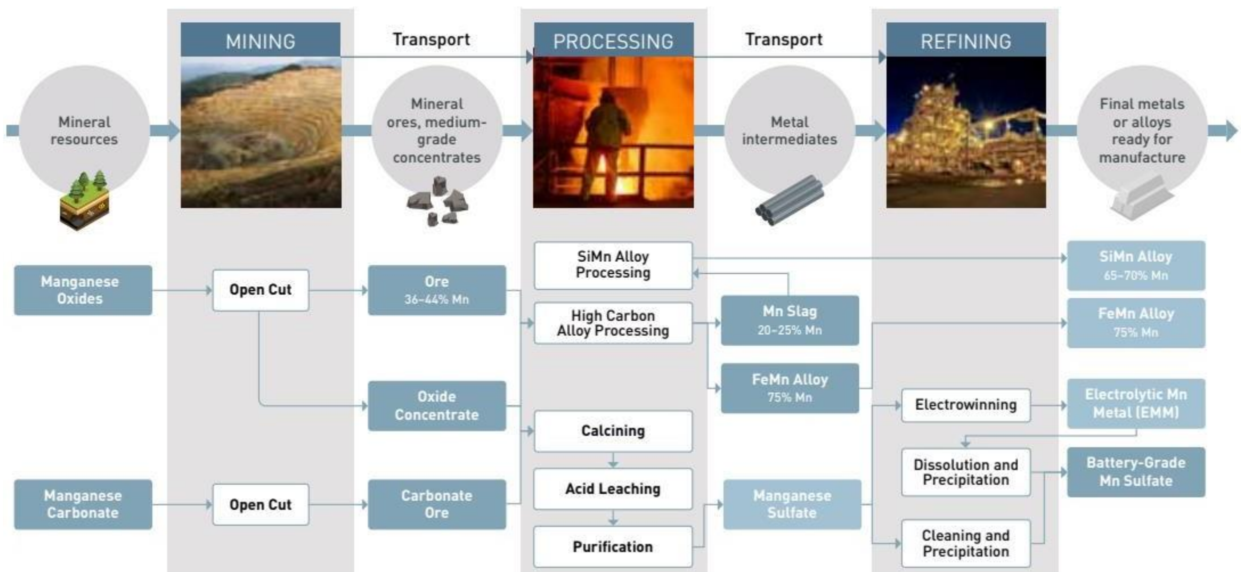


Figure 5: Manganese sulfate and alloy production (Dai et al.,, 2018)

Pure manganese can also be obtained from hydrometallurgy and electrolytic processes using carbonate ores or slags as raw materials.

Regardless of the mining method, manganese ores are first crushed and milled. After this process, various physical (e.g. gravity) or chemical (e.g. floatation) separation methods are used to separate the ores from their non-ore minerals (gangue). These individual processes can be different depending on the composition of the mined ore.

Pyrometallurgy is used to further increase the manganese concentration. As a result,the concentrate is converted to ferromanganese alloys, which contain 76% manganese. This conversion is carried out at high temperatures (ca. 1200 °C), using carbon oxide as a reductant and calcium oxide as a flux. It should be noted that the composition of ferromanganese can be changed by adding carbon, iron and silicon (Zhanget al, 2007).

Depending on the amount of carbon in ferromanganese, it is divided into 3 main groups and each product is used for different purposes, including high carbon or standard ferro-manganese (HC FeMn), Medium-carbon ferromanganese (MC FeMn), Low-carbon ferromanganese (LC FeMn). High-carbon ferro-manganese alloys are obtained from the direct melting of manganese ores in a three-phase submerged electric arc furnace and have a manganese content of 74 to 82% and a carbon content of 7 to 7.5%. varies. Low carbon ferromanganese (LC FeMn) is obtained by silicothermic process and manganese content ranges from 80 to 90%, and carbon is 0.75%. Finally, using an Oxygen-blown converter, we can obtain medium-carbon ferromanganese by reducing the amount of carbon in the Ferromanganese by the decarburization process. Another important manganese product is Ferrosilicomanganese which is obtained by smelting in submerged electric arc furnaces and contains 63–66% Mn, 28–32% Si, and less than0.08% C (Lee, 2001)

Battery-grade manganese sulfate is obtained by two main processes. The first is based on the refining and return of electrolytic manganese metal (EMM) to the process. This method is very easy but very expensive. Another method is the chemical refinement of ore, which is considered technically very difficult. Both methods are shown in **Figure 5**. Battery-grade manganese sulfate production is againled by China, as is cobalt sulfate production.

CHAPTER 5

DEEP SEA MINING

Seabed minerals, which are mainly distributed in international waters, have recently become of great interest. One of the main reasons for this is that these minerals are rich in elements of strategic importance for industry. These elements include Copper, Nickel, Cobalt, Manganese and Rare earth elements. In addition, the deposits of such minerals on the seabed are very large. This means that there are enough new and undiscovered fields to meet the world's growing demand every year.

In addition, all countries around the world are currently implementing various projects for the transition to clean energy. The main goal is to meet energy needs, find alternatives to fossil energy, reduce environmental damage, low carbon energy, green infrastructure and is to develop green technologies. The main elements for the implementation of these processes are Manganese, Nickel, Copper and Cobalt (World Bank, 2017), which are experiencing a number of political, technological problems in the extraction of terrestrial mining. These elements can be found in mineral and polymetallic nodules from seabed mining and are richer.

It should be noted that the seabed is rich in such minerals, and their research is carried out in accordance with the international regulations and developing technologies. At the same time, deep-sea mining is new to science, and its impact on the seabed and marine ecosystem has not been fully explored. In this section, we will discuss the discovery of new deposits for deep-sea mining, their mining, transportation, and the environmental issues and concerns that arise as a result of all these processes. All this will play a great role in the future prospects of deep-sea mining, their application, and as a result, deep-sea mining will become a reality and sustainable development will be ensured.

5.1 History

Deep-sea manganese nodules and cobalt crusts were first discovered in 1873-1876 by the HMS Challenger expedition in the Atlantic, Pacific, Southern Indian oceans,and the China Sea. The importance of these minerals for industry and their mining was decided in the 1960s and attracted the interest of the USA, West Germany, Japan, Canada and other industrialized countries (Mero, 1965). The location of thesedeep-sea ores in extremely difficult environments, high pressure, technological problems to explore the seabed and the lack of information about it have led to technical and environmental challenges. In the 1970s, the availability of land base minerals, their ease of extraction and theirlow cost created another obstacle for deep-sea mining. Afterwards, the collapse of metal prices in the world market further reduced the interest in seabed mining. However, in recent decades, political problems in land-based mining countries (e.g., the DRC), rapid depletion of deposits, and increased environmental damage have renewed interest in this field, and deep-sea mining based on new methods has been introduced by many countries and private companies (SPC 2013a, b, c, d; Ecorys, 2014; Langee, 2014; Arezki , 2015; Rogers, 2015; Worldbank, 2016). The set of rules relating to seabed exploration is controlled by the International Seabed Authority (ISA), established in 1994 under the United Nations Convention on the Law of the Sea (UNCLOS). ISA signed 6 contracts in 2001 and 15 contracts in 2002for the exploration of polymetallic nodules, cobalt crusts and seafloor massive sulphides (SMS), which are rich with industrially important metals.

5.2 Types of Mineral Deposits

Deep-sea mining is divided into **three main commercial sources**:

1. Manganese nodules, also known as polymetallic nodules, spread over the abyssal plain in the Pacific Ocean;

2. Cobalt crusts, also known as Ferromanganese crusts at seamounts in PacificOcean;

3. Seafloor massive sulfides (SMS) at hydrothermal vents in the coast of Papua NewGuinea.

The most interesting of these seabed minerals are polymetallic nodules. Because such nodules are spread on the soft surface of the ocean and unattached to the oceanfloor. Due to this feature, nodules can be collected from the ocean surface floor without destructive rock cutting, unlike land mining (Secretariat of the Pacific Community,2013). In addition, a single ore of polymetallic nodules contains a very high-to medium grade of metals, and also these nodules do not have a level of toxicity because they do not contain toxic levels of heavy elements (Haynes, 1985). The composition of such nodules coincides with the metals Nickel, Cobalt, Manganese and Copper, which are used in the manufacture of batteries for electric vehicles (EV) (AMY, 2018). Another advantage of the nodules obtained in the Clarion-Clipperton Zone is that the metals they contain may become the main deposit for batteries in the coming decades.

- **Polymetallic or manganese nodules**

Polymetallic nodules (PM) were first discovered in the Kara Sea of Siberia, and laterits presence in all the world's oceans was determined by the HMS challenger expedition from 1872 to 1876 (Bender et al., 1966). These nodules are called manganese or ferro-manganese nodules because they contain significantly higher amounts of manganese (28%) and iron oxides (6%) as well as copper (1.1%), nickel(1.3%) and cobalt (0.2%). found around crystallized manganese core (Scott, 2011).In addition to the above elements, such nodules are also rich in other economically important elements, especially lanthanides, which are considered rare earth elements (REE), are of high economic interest and are widely used in new technologies. Based on publications of the International Seabed Authority, chemical composition of the nodules is shown in **Table 7.**

	Type	Volume	Metals and their mean concentration	Principal Deposits
	Polymetallic nodules	Nodules: average 5-10 cm; deposits: up to thousands of km^2	**Mn (28,4%),** Ni (13 ppm), Cu (10,7 ppm), **Co (2098 ppm),** Mo (590 ppm), Zn (1366 ppm), Zr (307 ppm), Li (131 ppm), Pt (128 ppm), Ti (199 ppm), Y (96 ppm), REEs (813 ppm) (CCZ)	Clarion Clipperton Zone (CCZ), Peru Basin, Central Indian Ocean and Penrhyn Basin

Table 7: General characteristics and chemical composition of polymetallic nodules (Hein et al., 2013).

Depending on the location of the nodules, their size can vary from a few microscopic particles to pallets larger than 20 cm. The average diameter of the nodules varies from 5cm to 10cm, and they are potato-like in shape. It should be noted that the formation of nodules of these sizes takes millions of years- rates that can be as low as 1 mm per thousand years and their origin, growth and formation is a geologically controversial phenomenon, and several theories have been put forward in this regard (ISA, 2012) Today, it is believed that the growth and occurrence of the nodules are to be related to hydrogenous, hydrothermal, diagenetic, halmyrolitic and biogenic processes:

- As a result of slow accumulation of authigenic manganese. Authigenic manganese minerals form during sedimentation by precipitation or recrystallization in deep-sea.
- Rapid accumulation of manganese from submarine volcanic exhalates
- Constant accumulation of manganese within deep-sea sediments.
- Decomposition of basaltic debris in the seawater
- Catalysing activity of microorganisms

- **Ferromanganese crusts**

Cobalt-rich crusts, also known as ferromanganese crusts, form over millions of years at the seafloor on the flanks, slopes and summits of the seamounts, ridges, plateus and abyssal hills. These crusts are very rich in manganese, iron, cobalt, copper, nickel and platinum metals, **Table 8** (Hein et al, 2013). The richness of crusts in such metals could make them the main source of raw materials for electric motors and batteries in the future and meet the demand for raw materials.

	Type	Volume	Metals and their mean concentration	Principal Deposits
	Ferromanganese crusts	Up to several km2; <3 m thick	**Mn (21%),** **Co (6647 ppm),** Ni (4326 ppm), Cu (573 ppm), Te (34 ppm), Mo (431 ppm), Zr (423 ppm), Ti (TiO_2–1.4%), Pt (0.273 ppm), W (68 ppm), REEs (1628 ppm)	Equatorial Pacific Ocean and Central Atlantic Ocean

Table 8: General characteristics and chemical composition of ferromanganese crusts (Petavratzi et al, 2016).

The precipitation of minerals can be possible with two different processes. One of them is the hydrogenetic process which is based on the precipitation of minerals from the cold ambient bottom waters to form crusts. The second precipitation related to the combination of hydrogenetic and hydrothermal processes where the process realizes in the region of hydrothermal vents near volcanic arcs and hotspot volcanoes. Crusts are firmly attached to the seabed and that's why, comparing to polymetallic nodules, it is tough to collect the crusts from the seabed.

- **Seafloor massive sulfides**

Seafloor massive sulfides at tectonic plate boundaries along volcanically active ocean ridges (mid-ocean ridges, volcanic arcs and backarc basins) are formed by hydrothermal processes at a depth of about 2,000 meters and were first discovered.

in 1977 at the Galapagos Rift in the Pacific. Hydrothermal vents are very rich in minerals, especially sulfide compounds, copper, gold, zinc, barium, silver, etc. (Heinet al., 2013). It is shown in detail in **Table 9**. Such hydrothermal vents can be both active and inactive. These vents discharge warm seawater from hot volcanic rocks, at temperatures up to 400° C, into the ocean, resulting in the mineral-rich three-dimensional ore bodies (SMS) that can be meters to tens of meters thick. They are called 'black smokers' because they produce black plumes from hydrothermal vents.

	Type	Volume	Metals and their mean concentration	Principal Deposits
	Seafloor massive sulfides	Up to several km2; up to tens of meters thick	Cu (0.8–17.9%), Au (0.4–13.2 ppm), Ag (64–1260 ppm), Zn (2.7–17.5%), Pb (0.02–9.7%), Co, As, Al, Si, REEs	Red Sea, back-arc basins, mid-oceanic ridges, and other plate boundaries, oceanic hotspots (intraplate volcanoes)

Table 9: General Characteristics And Chemical Composition Of Seafloor Massive Sulfides (Cherkashov et al, 2017).

Schematically, the processes in hydrothermal vents are shown in detail in **Figure 6.**
As a result of such processes, the deposition and precipitation of plumes, which are rich in metals, lead to the formation of other ores (e.g. crusts, nodules) on the ocean surface.

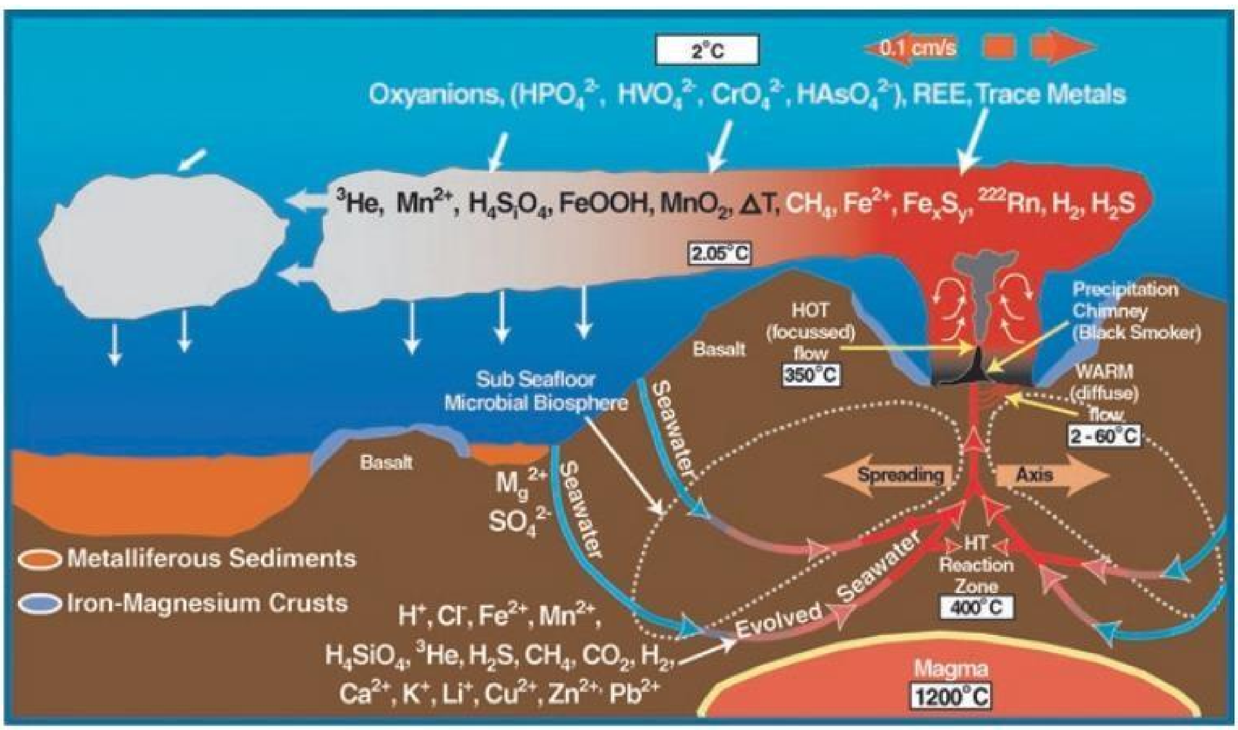


Figure 6: Schematic diagram of hydrothermal vent system (Sharma, 2019)

5.3 Distribution of Seafloor Mineral Deposits

Areas deeper than 200 meters of seawater are called deep seas and cover 360 million km^2 of the Earth (~50%), which provides 95% of the global biospheric habitat (Thistle, 2003; Smith, 2009; Danovaro, 2014). Topographically, most of the seabed is an abyssal plain, located at a depth of more than 3,000 meters and characterized by submarine canyons, oceanic trenches, ridges, hydrothermal vents, and seamounts. It should be noted that most of the deep-sea environment and its biodiversity have not yet been studied and very little information is available. **Table10** provides an overview of deposits and reserves of metals that are important for future industries, particularly cobalt and manganese, both onshore and in the deep sea.

Location Elements	Global Reserves on Land (Economically Minable Deposits Today)	Global Reserves and Resources on Land (Economically Minable as Well as Sub Economic Deposits)	Cobalt Crusts in the Prime Crust Zone (PCZ)	Manganese Nodules in the Clarion Clipperton Zone (CCZ)	Estimated Amount of SMS Deposits without Atlantis II
Manganese (Mn)	630	5200	1714	5992	-
Cobalt (Co)	7	13	50	44	-
Copper (Cu)	690	1000+	7.4	226	10
Titanium (Ti)	414	899	88	67	-
Rare earth oxides	110	150	16	15	-
Nickel (Ni)	78	130	32	274	-
Vanadium (V)	19	38	4.8	9.4	-
Molybdenum (Mo)	10	19	3.5	12	-
Lithium (Li)	13	14	0.02	2.8	-
Tungsten (W)	3.1	6.3	0.67	1.3	-
Niobium (Nb)	4.3	4.3	0.67	1.3	-
Arsenic (As)	1	1.6	2.9	1.4	-
Thorium (Th)	1.2	1.2	0.09	0.32	-
Bismuth (Bi)	0.3	0.7	0.32	0.18	-
Yttrium (Y)	0.5	0.5	1.7	2	-
Platinum group	0.07	0.08	0.004	0.003	-
Tellurium (Te)	0.025	0.05	0.45	0.08	-
Thallium (Tl)	0.0004	0.0007	1.2	4.2	-
Gold (Au)	0.05-0.057	0.1157	-	0.000095	0.00102
Silver (Ag)	0.57	-	-	0.0036	0.069
Zinc (Zn)	220-230	1900	-	13	20

Table 10: Metal resources and reserves on land and seabed for crusts and nodules (millions of tonnes) and an example of sulphide type (Hein, 2013; Lange, 2014, USGS, 2017).

Deep marine mining sources are found almost all over the world, both in national waters and in international waters. Economically important sources for exploration are not found in European waters, but rather in international waters. The world wide distribution of each deep-sea mining mineral is shown below.

- Distribution of Polymetallic Nodules

The nodules are distributed in the vast sediment-covered abyssal plain of the ocean,at a depth of 4000-6500 meters (Hein et al, 2013; SPC 2013b). The highest concentration of metal-rich nodules of economic interest is found in the Clarion- Clipperton Zone (CCZ), which covers areas from the west coast of Mexico to Hawaii **(Figure 7, blue).** Such nodule concentrations are also found in the Peruvian Basin, near the Cook Islands, in the abyssal depths of India, and in the Atlantic Ocean (Hein, 2013 and 2015). Manganese nodules in the CCZ abyssal sediment cover an area of at least 9 million square kilometers. Billions of potato-sized nodules are spread over the muddy bottom of the CCZ or in a half-embedded form. Their removal mainly requires scraping this mud layer to a depth of 5-10 centimeters.

These nodules must then be separated from the mud, pumped to the surface vessel through giant pipes, and the seawater and fine particles must be returned through another pipe after the seawater separation process has been carried out on that vessel.

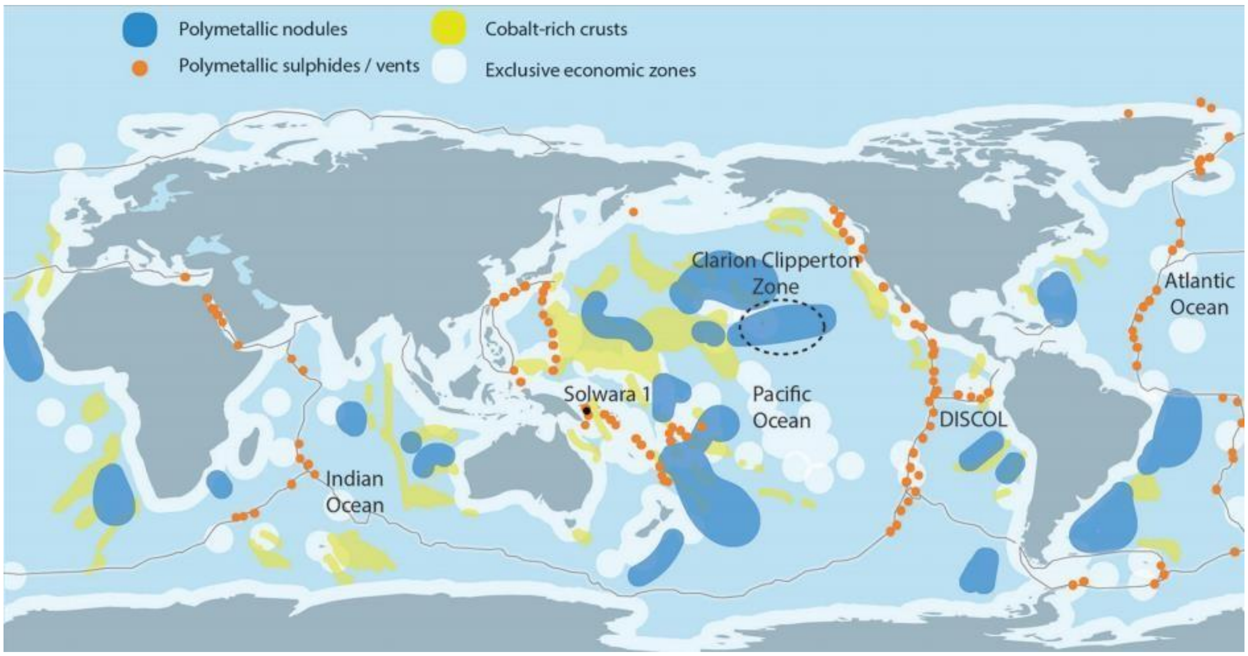


Figure 7: A world map showing the location of the three main mineral deposits: polymetallicnodules (blue); polymetallic or seaflorr massive sulfides (orange); and cobalt-rich ferromanganese crusts (yellow) (Miller, 2018)

As a result of research conducted within the MARIBE (Marine İnvestment for the Blue Economy) project, it was found that appropriate concentrations of polymetallic nodules were not found in the Atlantic, Baltic / North Sea and Mediterranean basins.A new study in 2015 identified some spots in the tropical Atlantic (north of French Guyana and west of Africa) with significant nodules. However, there are no publications or reports on the prospects of this discovery. In addition, in the Galicia Bank region (northwest Iberian margin, NE Atlantic), phosphorite slabs, nodules, ferromanganese crusts and cobalt-rich manganese nodule deposits have been discovered, but their quantities required for commercial exploitation have not yet been estimated (Gonzalez et al, 2016).

CCZ covers 1.5% of the world's abyssal plains. There are 34 billion wet metric tons of nodules on the surface of these plains, which contain 6 billion tons of manganese, 270 million tons of nickel, 234 million tons of copper and 46 million tons of cobalt(Morgan, 2000). These figures are very large compared to the same type of metal deposits found on land. If we could collect half of these metals, the total commercial value of the metals they contain would be more than $ 5 trillion (AMC Consultants,2019).

➢ Distribution of Cobalt crusts

Cobalt crusts accumulate by precipitating minerals from seawater over flanks and seamounts at depths of 400-7000 meters, but it is commonly found between 1000- 3000 meters. The most important sources of Fe-Mn crusts found in the world are Aleutian Trench in the Pacific and Iceland in the Atlantic and as far south as the Circum-Antarctic Ridge in the Pacific, Atlantic, and Indian Ocean seamounts. The most extensive and detailed studies of Fe-Mn crusts are Pacific, especially from theEEZ of island nations including the Federated States of Micronesia, Marshall Islands, Kiribati, as well as in the EEZ of Hawaii, Johnston Island, international waters in the Mid-Pacific Found in the mountains.

Cobalt-rich crusts are more common at depths of 800-2200 meters, known as the oxygen minimum zone (OMZ, **Figure 8)**. As the water depth increases, the crust thickness decreases because of mass movements and reworking of the deposits on the seamount flanks. Thick crusts are very rarely found in the Atlantic and Indian Oceans, so the maximum thickness of crust extracted from the New England seamount chain (NW Atlantic) is up to 125 mm, and the maximum thickness of crust extracted from the Central Indian Basin is up to 72 mm. It should be noted that where Fe-Mn crusts are abundant and very thick, this means that seamount biological communities in the area are characterized by low density and low diversity. The main reason for this is the low amount of oxygen in the region, known as OMZ. Populations above and below the OMZ can be larger and more varied.

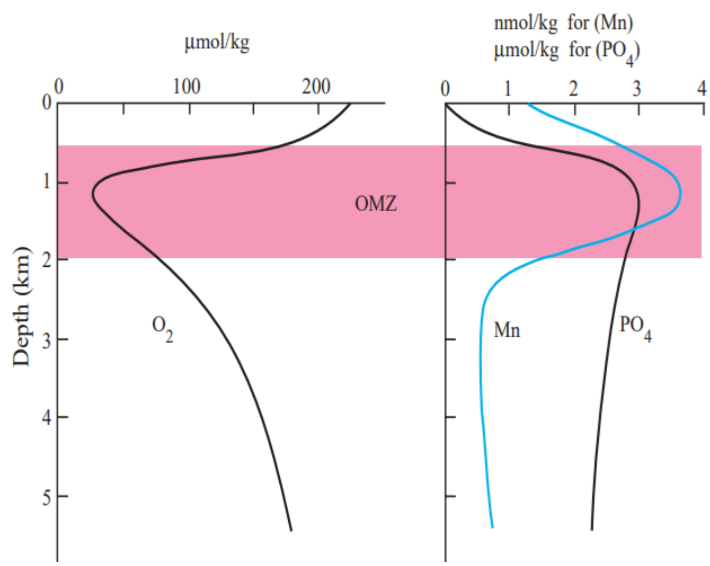


Figure 8: Profiles of dissolved manganese and phosphate compared tooxygen content of seawater over a seamount; low-oxygen seawater (the oxygen minimum zone, omz) is a reservoir for high manganese contents.

Globally, it is estimated that there are more than 100,000 seamounts higher than 1,000 meters, but few of them are considered suitable for cobalt crust extraction.

The oldest seamounts in the world are found in western Pacific. That is why crusts found in these areas are thicker than others and are very rich in minerals due to long-term precipitation. This area is located about 3,000 kilometers southwest of Japan and is known as the Prime Crust Zone (PCZ, **Figure 7, orange)** (Hein, 2013; SPC, 2013b; Petersen, 2016).

Commercially exploitable seamounts for Europe have been found at depths of 750 meters to 4600 meters in the Madeira, the Canary, the Azores islands, the Galicia Bank, the Iberian margin and the western Mediterranean Sea. Ferromanganese crust sources within and adjacent to the Portuguese EEZ areas have the potential to be comparable to the central Pacific in the future.

The commercial perspectives of the Galicia Bank and Iberian margin reserves need to be determined. It should be noted that crust deposits in the Galicia bank are not asrich as nodules (Gonzalez et al, 2016; Hein et al, 2013).

- Distribution of Seafloor massive sulphides

SMS deposits are potentially widespread in the Mediterranean, Azores and Norwegian waters at the Mid Atlantic Ridge (Marques and Scott 2011; Ortega, 2014).There is a need for further research to determine the commercial performance of SMS deposits. It is estimated that there are about 600 million tons of sulphide compounds (Hannington, 2010 and 2011, **Figure 7, red**).

5.4 Exploration and Exploitation

Deep-sea minerals exploration and exploitation are provided by using some relevant technologies like an Echo sounder, remotely operating vehicles (ROV), and autonomous underwater vehicles (AUV).

- 4.4.1 Seabed Exploration and Mapping

There is a need to study the geographical and geological conditions of the seabed in order to obtain commercial information and comprehensive information of the minerals on the seabed. These processes are carried out using various types of equipment and techniques.

- Echo Sounding Exploration Technologies

To determine the depth of the water, the echo sounder sends sound pulses to the water, and records the time interval between the time when the wave begins to propagate and its echo return. Knowing that the speed of sound propagation in water,it is easy to calculate the depth of water. Two main types of echo sounders are used for these purposes: Single-Beam Echo Sounder (SBES) and Multi-Beam Echo Sounder (MBES). We can see an illustration of this process in **Figure 9**. SBES is commonly used to determine the depth of water using the transceiver that emits and detects echo time series at normal incidences. However, unlike SBES, MBES consists of multiple transceivers that send sound waves at different angles, which helps to provide more information about the seabed.

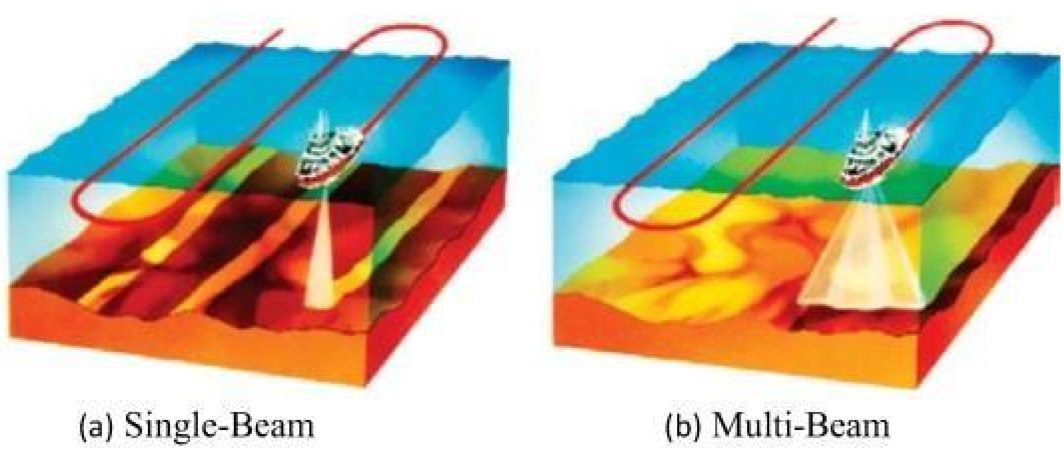


Figure 9:COVERAGE OF SINGLE-BEAM AND MULTI-BEAM ECHO SOUNDERS (KEARNS AND BREMAN, 2010).

- Electromagnetic Exploration Technologies

Another offshore technology used to obtain seabed information is electromagnetic exploration technology. These technologies include controlled-source electromagnetic (CSEM) surveying and magnetotelluric (MT) surveying. Electromagnetic exploration methods are carried out either by using the magnetic casing of the ground or by applying an electromagnetic field into the ground througha dipole. In the CSEM surveying, a powerful horizontal electric dipole is towed 30 meters above the seabed, and the dipole sources are very carefully designed and send low-frequency electromagnetic waves to the marine subsurface. The energy waves propagating on the seabed surface are determined by the seabed receivers of the grids. The resulting data is then processed, post-modeled and inversed, and a 3D volume of the seabed is produced. The information obtained helps to make the mining process more secure when combined with other available subsurface information.

Magnetotelluric (MT) is a naturally sourced method that exploits the changes in themagnetic field of the earth. Magnetotelluric (MT) method is a geophysical method used to determine the electrical conductivity of underground structures in various geological environments and surveys map subsurface resistivity variations. The source of the MT field is found in the atmosphere, ionosphere or magnetosphere depending on various events. These currents are formed by the effect of the electromagnetic field created as a result of the explosions in the sun. The resistivityof the rocks is determined by measuring the electrical and magnetic voltages causedby these currents in the rocks. MT surveying technology is more perfect at mapping and interpreting seabed geology with a lower frequency, deep sensing nature.

- Remotely Operated Vehicles

Unmanned underwater vehicles basically consist of two main groups, Cable Controlled and Wireless-Autonomous. Cable-controlled ones are called "ROV (Remote Operating Vehicle)", while wireless autonomous ones are called "AUV (Autonomous Underwater Vehicle)". ROVs are the maneuverable and remotely operated underwater vehicle that consists of the cables which are for carrying electricpower to an underwater vehicle, getting information from a photo and video cameras, and providing signals between operator on vessel and vehicle for managing. ROVs at least equipped with video cameras and lights, also possible to add some devices on purpose to provide additional information. These include cutting arms, grabbing arms, water samplers or devices to identify water clarity, lightpenetration, and temperature.

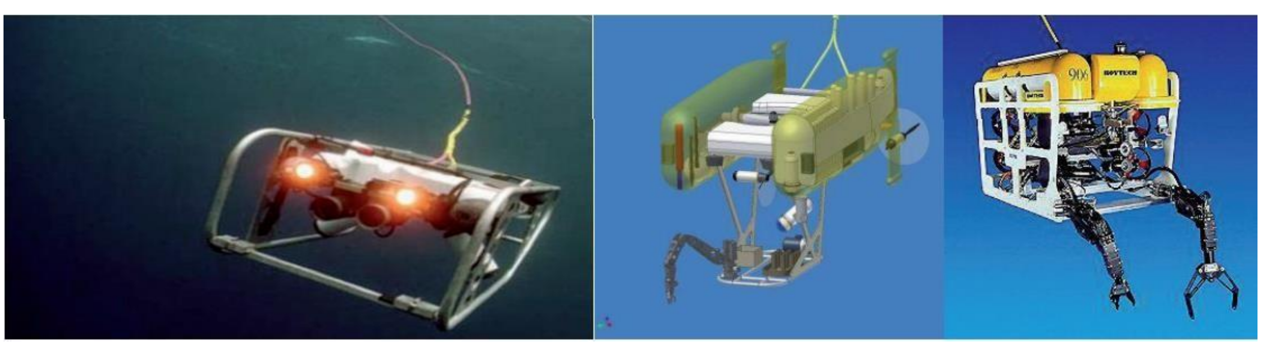


Figure 10: Types of remotely operated cehicles (Egorov, 2014)

- Autonomous Underwater Vehicles

The main difference of AUVs from ROVs; It can be summarized as AUVs being autonomous/semi-autonomous and having their own power sources. Thanks to their power source, they can move independently.

AUV is a robot used to travel underwater without the need for input commands from the operator to obtain information about the concentration of various elements or compounds, light reflection and absorption, underwater organisms, and the environment. Such devices are equipped with various types of sensors, echo sounders. These devices can also be used to carry sensors to different areas for underwater research and then return tothe ship (Sharma, 2019).
Edokko-1 is a small, unmanned diver developed in Japan in 2013 by the JAMSTEC project to study the seabed environment and wildlife. For the first time, the device took pictures of the seabed in Japan Trench using a 3D fullhi-vision video camera at a depth of 7800 meters. Mainly developed for environmental research in cobalt-rich ferromanganese crust and seafloor massive sulfide areas. It is slowly immersed in the seabed, and the deviceis battery-powered, durable, and are designed for repeated use. Edokko-1 takes pictures at regular intervals to study the daily, monthly, and seasonal cycles ofthe seabed (see Figure 11; Sharma, 2019).

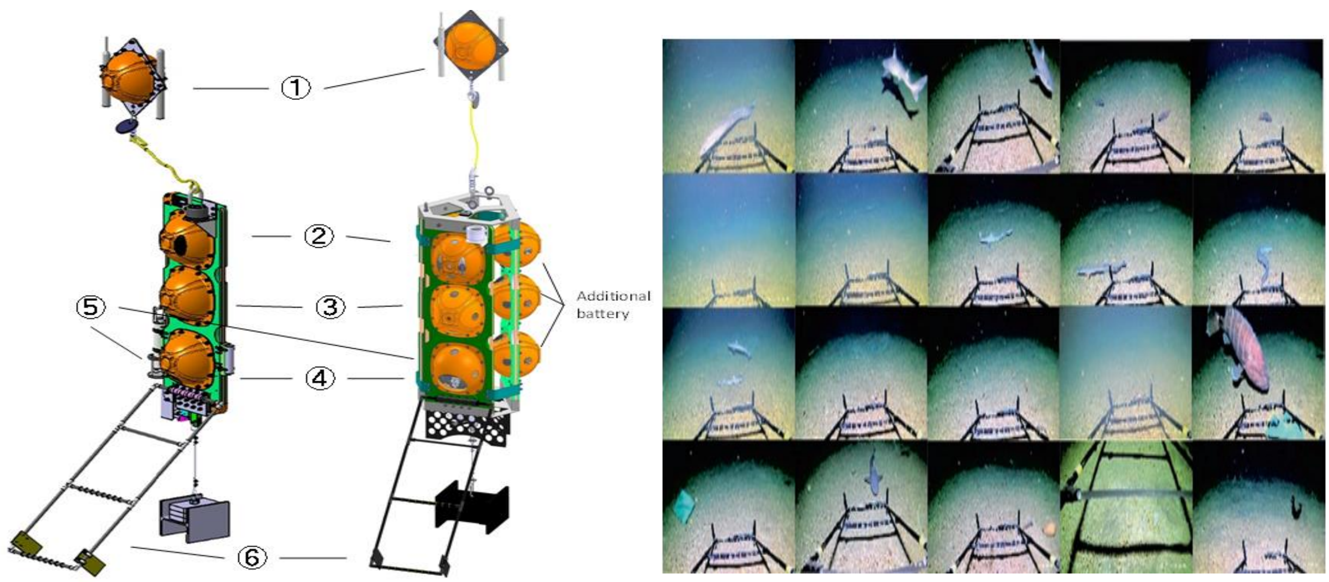


Figure 11: A) External view of edokko mark 1. The left side is a lightweight model. The right side is a long-term observation model.

From top, it consists of **offshore communication balls used for collection (1), transponder balls used for detachment (2), illumination balls used for led lighting (3), and photographing balls by time-lapse camera (4). Ctd measurement is installed (5). Shooting will observe the bottom of the sea from the altitude of 1 m (6), b) screenshots observed at the seabed. From the upper left to the lower right, a photo of each of the 1 h has been placed.**

5.5 Deep-Sea Mining Technology

Polymetallic nodules are the most explored resources comparing to the other deep-sea minerals due to their easy collecting feature. These nodules unattached to the seabed and found at the upper sediment of abyssal basins. The biggest and metal abundance reserve of PMs is the "Nodule Belt" in CCZ of Northeast Pacific. Thesekinds of metals are known as the energy metals of the future which are widely use in energy transportation, energy transition, energy storage in Electric vehicles, batteries, and other kind of new green technologies.

Removal of polymetallic nodules on the seabed is a very complex and difficult process and new technologies are needed. The following questions must be answeredto ensure the technological feasibility of this process. How can we extract ore fromthe seabed?

How can we transport the extracted ore to the sea surface? What technologies can we use to implement these processes? Can we reduce unwanted by-products? How can we reduce sediment plume and manage dispersion? What are the impacts on the environment, potential damage, and how can we manage them?

Other critical factors of using this equipment and technologies are the wear and tear due to corrosion, collision, friction, and fatigue in extreme environmental conditions (150-600 bar pressure, completely dark environment, and complex geological conditions such as abyssal plains (nodules), mid-oceanic ridges and back-arc regions(sulfides), and seamounts (crusts)) in deep-sea at the depth of more than 2000-5000meters. Because of this the regular inspection, maintenance, and repair are mandatory. There are not fully tested and proven technologies and equipment for deep-sea mining anywhere in the world for now and those technologies are developed by countries or private companies individually in special areas under the control of ISA contracts.

In order to obtain a sustainable mining concept for the harvesting of polymetallic nodules and transport them to the sea surface, the following sequence must be followed **dredging-and-collecting → buffering → lifting → separation → treatment-and-tailing** and this concept would consist of the following subsystems:

- Seafloor dredging robot
- Buffer station
- Lifting system
- Seawater separation and treatment facility
- Nodule handling and offloading system
- Tailing treatment facility
- Mining platform

A schematic view of continuous mining is shown in **Figure 12.**

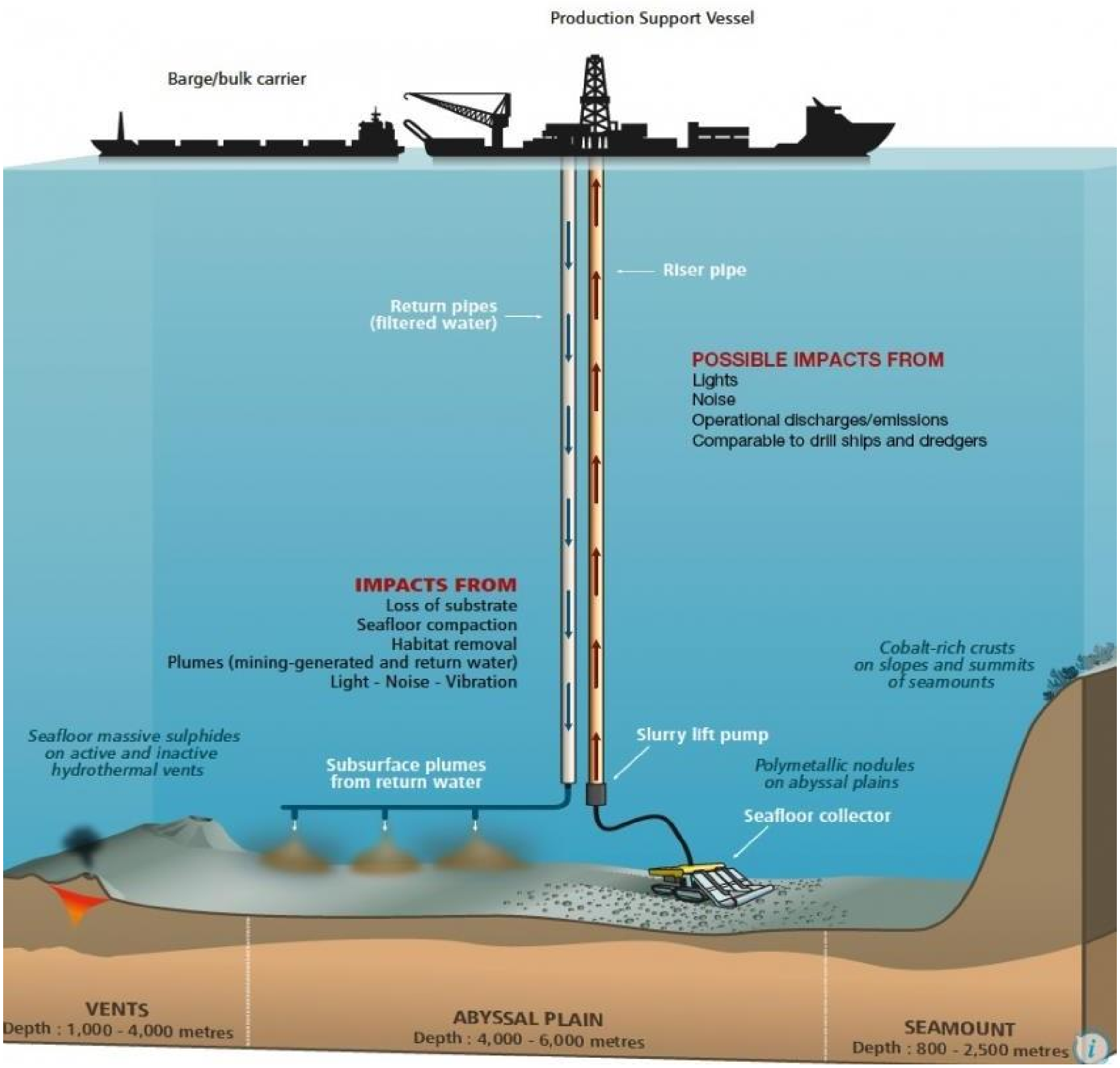


Figure 12: A schematic view of continuous mining.

➢ Seafloor Tools

Seafloor tools are instruments that mine the unattached or half-buried seafloor nodules from the ocean basin. Although the general concept of these tools is the same, there would be additional functions or designs for different goals on the deep- sea. There are here different remotely controlled machines for excavation and collection of deep-sea ores depend on the topography of the mining site with its relatively steep slopes (up to 20°) including the auxiliary miner, the bulk miner, and the gathering machine **(Figure 13).** The digging machines are used to prepare the seabed for a more bulk cutter (BC) using an auxiliary cutting (AC) device, and then the 2.5 cm diameter cut ore is collected using a collecting machine (CM). These processes are mainly used in the extraction of sulfide ores and were first carried outby Nautilus Minerals project in Solwara 1 in Papua New Guinea (Schriever and Thiel, 2013).

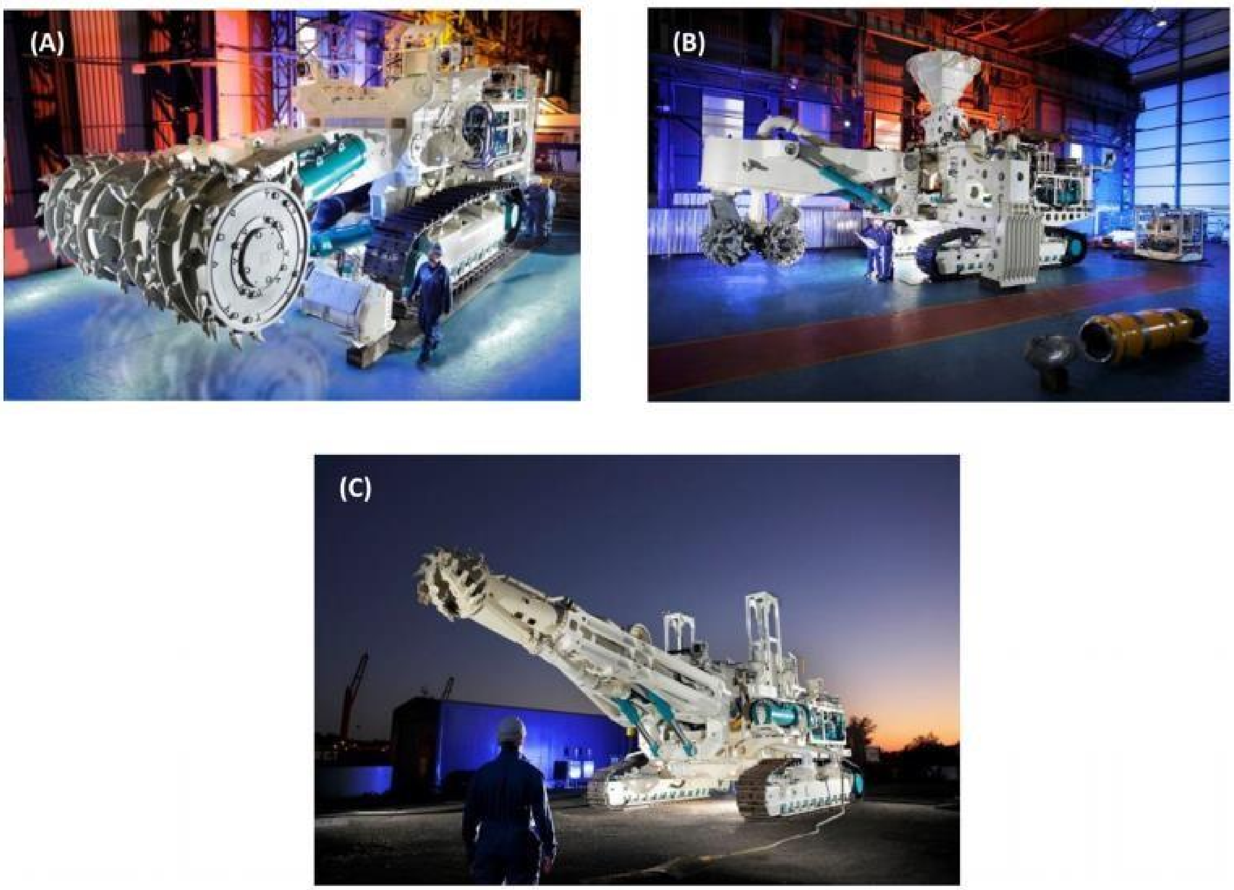


Figure 13: Machinery for the exploitation of resources of the seabed, owned by nautilus minerals company (a: bulk cutter (bc), b: auxiliary cutter (ac), c: collection machine (cm)) (modified from Nautilusminerals, 2019).

Two of three mining tools are using for the excavation of ores from the seabed during production operations. The auxiliary miner (AUX) is important for the beginning ofthe process, as it prepares the seabed for the Bulk miner and the Collecting machine for landing, as well as removes edge sections of benches that cannot be mined by theBM and are inaccessible. The cut and collected ores will then be pumped into the Riser and Lifting system by a flexible riser as slurry.

Among the seabed mining machines, the most interesting one for us is the collection machine, which consists of several major subsystems. These include the collecting system, the electro-hydraulic system, the movement system, the power supply system and the control system.

-Collecting system: The collection vehicle used to collect the ores scattered on the seabed is equipped with an auger device. Thus, when passing through the mining area, this device channels the ore to the inlet of a large centrifugal dredge pump. Also, this device equipped with a special tool which is known as a cutter head that extracts the soil before it is sucked up by the subsea pump. The key element of this auger device is to convey the mined ore to the pump inlet. Due to (SRK Consulting,2010) the total system head for the collecting machine to the centrifugal pump is estimated with 18 bars. This discharge pressure will require centrifugal pumps in series that are used to overcome larger system head losses than one pump can handle alone as shown in **Figure 14**.

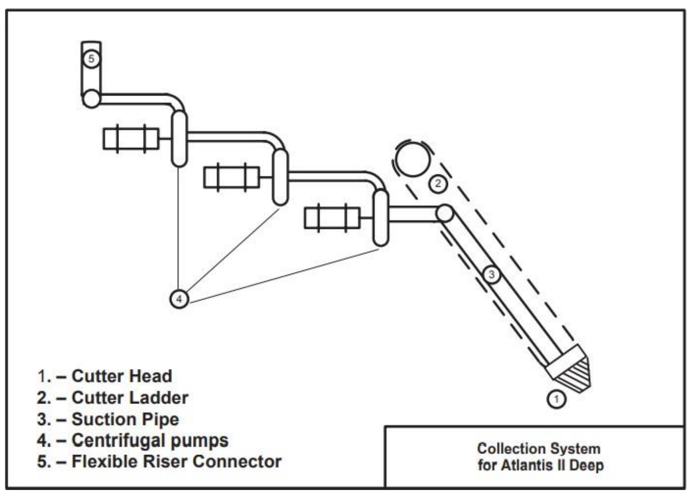


Figure 14: Schematic Of The New Collection System

Figure 14: The type of cutting head depends not only on the technical parameters but also on the type of soil (hard soil, non-cohesive soil, cohesive soil) to be dredged (Eisma, 2006).

-The electro-hydraulic system:

In a hydraulic machine, the hydraulic fluid is transmitted along with the machine tovarious hydraulic motors and cylinders, and this fluid is automatically controlled automatically by control valves which are distributed along with the hoses and pipes.Electro-hydraulic equipment has very high advantages, including high maneuverability, high accuracy of equipment, easy handling, rotation ability, high speed, low vibration, etc.

-Movement System

The collecting machine is a surface-operated device that also moves on a pair of tracks powered from the surface. An azimuth thruster consists of propellers placed in pods that can rotate in all horizontal directions, which gives it a high maneuverability.

-Power Supply System:

The energy needs of the collection machine are provided by electrical energy from the shipboard. The total power demand of this machine is 2 MW, and the length of the cable that provides this power is more than 2000 meters, and this varies depending on the area and should be taken into account in the complexity of transmission. A high-voltage 6600-volt power supply system has been selected to provide long-distance transmission.

-Control System:

The collection machine is equipped with a camera, various types of sensors and detectors for effective control by the vessel operator. It is important to provide reliable means of transmitting control signals from ship to vehicle and vice versa. Optical cables are used for this purpose and the power supply is transmitted through these cables.

- Materials Transportation

Nodules obtained in deep-sea mining, along with seawater and sediments, are transported from the collection machine to the floating vessel by a subsea lift pump and a vertical riser system hung from the floating vessel. Nodules are our main target material, while others are considered unwanted by-products. When sediments and seawater mix, they form a sediment plume. Part of the sediment plume is spread horizontally in the benthic zone, the rest is lifted into the vessel along with the nodules.

The horizontal dispersion of the sediment plume resettles to the seabed again at a certain distance over a period of time. It should be noted that the vertical transport of the sediment plume should be minimized as much as possible before it reaches the water surface. In addition, sediments should be cleaned to reduce the environmental impact.

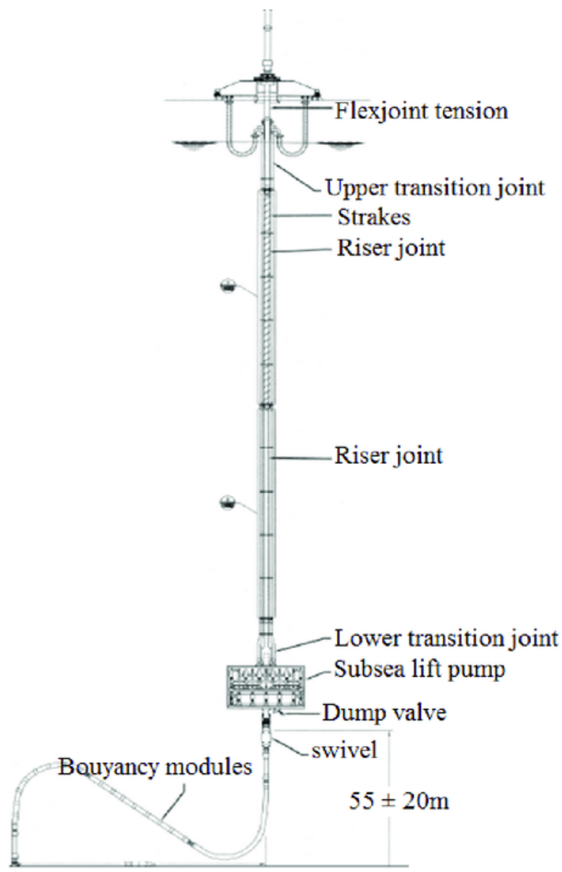


Figure 15: Nautilus: riser and lift system

The most energy-intensive of all mining operations is the vertical removal of nodules. There are the following types of lifting: Hydraulic lifting, air-lifting, and mechanical lifting. Among them, hydraulic lifting and airlifting are commercially leading in terms of durability, reliability and safety. Hydraulic lifting has higher efficiency but has some disadvantages, including durability and maintenance-and- repair of underwater pump stations. Airlifting, which is more advantageous in termsof maintenance and repair, also has less water volume but is relatively inefficient and very noisy. There may also be some durability and safety issues due to the severe expansion of injected air bubbles and consequent impacts and collisions.

The efficiency of hydraulic lifting depends on the maximum volume concentration of the ore transported in the pipe, the energy consumption used for its transportation and the number of by-products.

The rate of nodule collection (ton/hour) willnot remain constant because nodule abundance (kg/m^2) is not uniform. Inparticular, the very complex topography of the seabed, non-homogeneity of sediment properties, does not stabilize the collection rate of these nodules, and as a result dredging efficiency will not be constant as well. For this reason, a buffering mechanismis used to ensure the efficiency and sustainability of the process between collection and lifting operations. This improves the flow assurance, and reduces the lifting of sediments into the vessel, prevents pipe clogging, increases the efficiency of lifting pumps.

Extracted slurry from the seabed reaches thefloating vessel and goes through the dewatering process. The ores are transferredto a transport barge for shipment to shore and the filtered return water is sent to a subsea lift pump to be returned to the mining site. The riser and lift system consist of the parts shown in the **Figure 15.**

The riser and lift system have the following functions:

-The ore slurry obtained from the collection machine is lifted vertically by means of a riser system to a dewatering plant located on the deck.

-Send the return water to the seabed.

- Surface vessels

Floating support vessels are similar to offshore drilling and equipment used in the oil and gas industry. The main technical parameters for such floating production vessels are the deck space, accommodation up to 140 people, enough energy to carryout the process, etc.

Using a dynamic positioning system, the floating support vessel can maintain its position over the seabed mining area and support the safety and sustainability of bothon-board processes and subsea operations. Crew changes are usually made by crew change boats or helicopter. They are also used for emergency evacuation purposes. The ships designed by Nautilus consist of a barge, a heavy lift transportation vessel and a bulk carrier.

Vessel is mainly equipped with the following two types of tanks:

1. A dewater ore storage bin used to store ores extracted during one-day production.
2. A dewater ore out of specification bin for storage ores that is not considered convenient to transport and needs to be re-fed.

5.6 Processing/ Refining

Figure 16 shows the typical processing and refining stages of polymetallic nodules.It should be noted that although the mineralogy of polymetallic nodules is very different from that of dry ores, their processing is based on the same common methods. The flow chart below is provided by HATCH, one of the world's leading process engineering companies.

The first half of the process is considered **pyrometallurgical**, and the process is very close to the pyrometallurgical processing of nickel laterites. Manganese silicates, which contain 40% manganese, are obtained as an intermediate output of the pyrometallurgical process and shipped to an alloy plant to be converted to silicomanganese, and very small amounts are converted to manganese sulfate, whichplays a major role in the production of NMC-811 battery cathodes. Another output obtained in the process of pyrometallurgy is an intermediate matte containing nickel, cobalt, and copper.

Then nickel-cobalt-copper matte is processed by **hydrometallurgical** method. Thus,the matte is first leached and then each metal is separated from the other. The separated metals are then refined into their final forms. Copper is electrowinning toobtain 99.99% copper cathode, while nickel and cobalt are each extracted, refined,

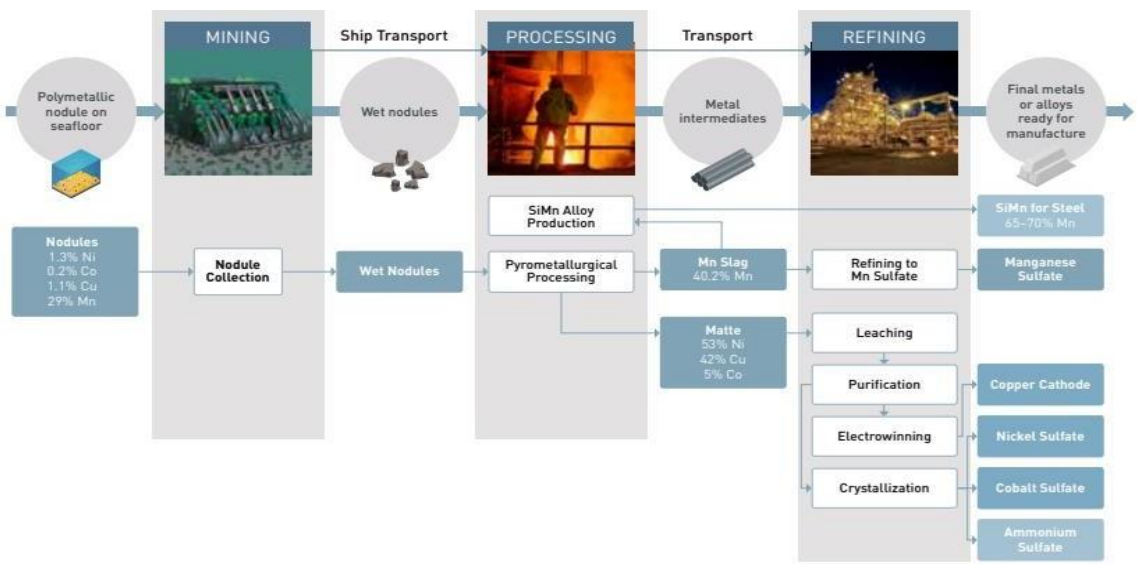


Figure 16: Processing polymetallic deep-sea nodules.

and crystallized into sulfates. In addition, a large amount of ammonium sulfate, which is used in the production of fertilizers, is produced.

The high-level material flow pattern for the polymetallic nodule processing is shownin **Figure 17** by DeepGreen, a Canadian deep-sea mining company. The processingand refining steps will result in gas emissions and a certain amount of water consumption, as in the case of land-ore processing, but after these steps, zero solid waste is produced.

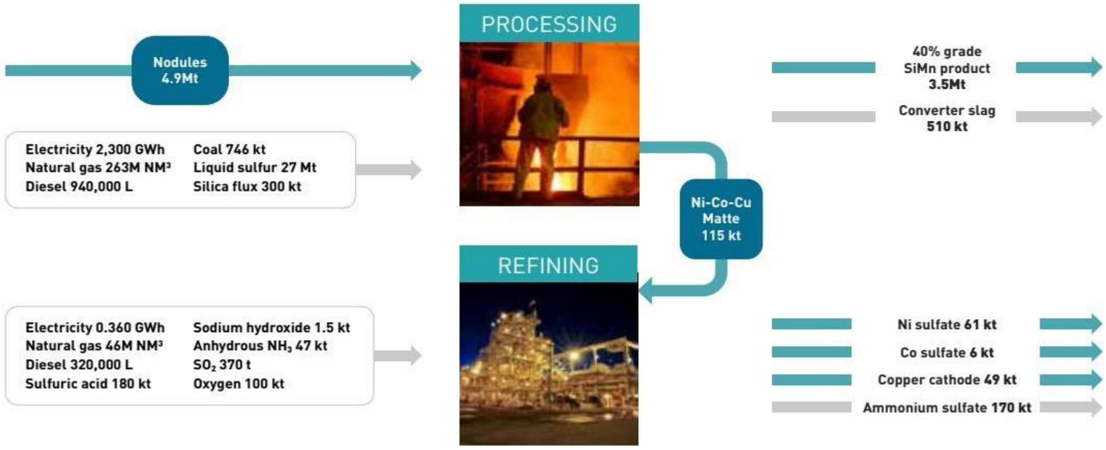


Figure 17: Sample material flows for 4.9 mt/year nodule processing and refining plant.

5.7 Key Metal Production Process Differences for Land Ores And Nodules

The table below compares all the procedures from the initial stage of exploration of both the ore and the nodules to the final stage of production. As a result, we can clearly see the risks, positives and negatives for each stage, and compare them to see which base ore is more appropriate.

		LAND ORES	NODULES
MİNİNG	EXPLORATİON	• Prospecting is considered very risky for this type of mining in recent years, as no major discoveries have been made about tier I mining assets in the last decade. • Prospecting is based on the drilling of hard rocks to be able to remotely sense geological structures of the mining site and collect drill cores to test their composition.	• Prospecting is considered less risky. Because in recent years, research has shown that such deposits are very rich and abundant in metals. For example, CCZ alone contains about ten times more manganese, three-and-half times the nickel, one-third of the copper, and six times the cobalt which can be obtained from economically suitable terrestrial deposits. • The study of the seabed, seabed environment and biodiversity are carried out by means of sensors attached to the vessel hulls or autonomous underwater vehicles.
	DEVELOPMENT	• If the mine site is located in a remote area, new infrastructure must be built for it, including roads, bridges, electricity, water, miner accommodation etc. • Underground mines require the establishment of networks between tunnels and access shafts. • Open-pit mines cause deforestation, clearing of vegetation and topsoil removal to reach the ore body, which has a huge impact on the environment. • The development of a mine can vary from 5 to 10 years, which is a very long time.	• Development requires surface vessel, vertical lift system, seabed collection machines as an offshore production system. • The manufacture of each offshore production system can take up to two years, which does not include the initial system design stages and the development of mining systems implemented under pilot projects, which take 3 or 4 years. A full-scale system design can take an additional year.
	ORE EXTRACTİON OR COLLECTİON ORE	• The most commonly used method for terrestrial drilling of metal-rich ore bodies is to drill holes in hard rock and blow them up with various chemical explosives. The resulting rock fragments are then reduced in size by crusher to enrich the ore. • Mining disrupts tracts of land at the mining site and for connecting roads. • Mining of base metals has recently begun to increase in areas with high biodiversity due to declining resources on the planet. • The extracted ores are transported by trucks to remote places. • Harmful particles and dust generated as a result of the mining process are released into the atmosphere, which harms the health of miners and surrounding communities. • As a result of the mining process, a significant amount of fresh water is drawn from lakes, streams, and groundwater sources. • Groundwater pollution causes various diseases and death in human life and wildlife. • Pollutants from coastal mines harm marine animals. In addition, the disposal of deep-sea tailings causes great damage to the seabed environment and wildlife. • Society can both benefit and harm from such mining. For example, when such mines are located close to local settlements, this can lead to direct physical damage or cultural disruption. On the other hand, such mining can bring development and industry to remote areas that society can benefit from. • As the amount of mining waste exceeds the amount of ore extracted from mining and concentration, this endangers the environment, local habitats and wildlife.	• The nodules are spread over the seafloor in an unattached form in the top 5 centimeters of sediment. Their removal from the seabed is carried out by means of collecting machines using a curved nozzle head based on the Coanda effect. Inside the collection machine, the nodules are partially separated from the seawater and sediments, and then lifted into the vessel with the help of vertical lifts. After the nodules are completely separated from the seawater from the dewatering facility on board, the seawater is returned to the sea at 1000 meters and deeper. • The collection of nodules leads to the disappearance of their hard substrate. Some wildlife needs these hard substrates to survive and for critical life functions (e.g., egg-laying). The collection of nodules can lead to a decrease in the population of these organisms and their extinction. • Discharge of plumes (i.e., suspended seabed sediment) during the movement of the collection machine can smother, kill, and disrupt wildlife in the impacted area, depending on the blanketing thickness. • Transportation of ores is mainly carried out by ship. • The impact on the atmosphere is limited to ship emissions during operation. • There is little direct freshwater impact. • The main effects of deep-sea mining mainly include the effects and turbidity that occur during the re-discharge of slightly warmed, decompressed seawater into the mining site, possibly harming ocean wildlife as well as ship emissions. • Nodule collection has no effect on local communities as it is located far from human settlements. The collection of nodules means new jobs, economic benefits, with the potential to aid developing nations who act as sponsoring states for ISA contractors, new sources to meet the demand for metals.

	CLOSURE AND RECLAMATİON	• Mine closures are economically very expensive. Often these processes are postponed indefinitely or incomplete or left to the state. • Unrestored land further pollutes habitats and has long-term effects, affecting human health and hindering the redevelopment of future habitats. • Improper disposal of waste or the collapse of dams can lead to the mixing of toxic substances into groundwater, the release of toxic dust into the air, and the resulting disease and death of humans and animals. • Environmental protection measures and enforcement vary from country to country. It varies greatly depending on the strength of national and local governments, especially in developing countries.	• Collection of nodules can be stopped at any time with limited associated cost. In addition, due to our lack of knowledge about the seabed, its biodiversity, and the environment, reclamation of the seafloor poses significant scientific and logistical challenges. • Leaving the nodules without restoring the collection sites does not lead to any disaster, nor does it cause human illness or death. • Leaving 15% of the nodules behind in the collection sites will help to natural habitat restoration process there, but this process will likely take a very long time. • Environmental protection measures are carried out in consultation with many stakeholders and are implemented by ISA.
PROCESSING		• Processing plants are mainly located far from the mining area, and as a result, they need to be transported by vehicles. These are mainly used in developed countries for bulk ores that cannot be easily concentrated in the mining area, and the process is powered by local electricity grids that often rely on coal. • Because ores are mainly composed of heavy toxic elements, they need to be separated and stored during the process. At this stage, dams need to be built to reduce the impact of large volumes of tailings and residues on the environment and require ongoing monitoring and maintenance indefinitely into the future. • The physical footprint includes the occupied area where the process takes place, tailing dams, residual storage facilities, and the infrastructure (roads, bridges, residences, maintenance) required for this process. Some processing is constrained to the mine site while some is more distant. • İmpacts occur as a result of pyrometallurgical and/or hydrometallurgical processes and vary depending on the type and composition of the ore. As a result of the process, a significant amount of waste and pollution is thrown around from standard techniques.	• Processing plants can be located anywhere in the world. The energy required to carry out the process can be optimized using energy sources such as renewable hydropower. • There are no tailings, residues, or solid wastes because nodules do not contain toxic levels of heavy elements. • Physical footprint consists of land occupied by a processing plant, as well as road building and maintenance. • Impacts result from pyrometallurgical processing, optimized for low waste and emissions along with hydrometallurgical refining due to the unique mineralogy and location flexibility.
REFINING		• There is a need to build additional refining facilities, which will require additional transportation and land use. There will also be a need for an additional power supply to carry out the process. This means additional costs. • Tailings and residues can be produced mainly at this stage. • Refinery locations are mainly optimized for areas that can be transported to the market.	• Hydrometallurgical refining is located in the same area with processing, and additional plants can be built for other final products, which require additional costs and energy. • Intermediate products can be processed without generating any tailings or residues. • Transport to the market minimizes transportation costs because it is close to a port to access the international market.

Table 11: Summary of key process differences for land ores and nodules (Paulikas, 2020)

CHAPTER 6

ENVIRONMENTAL ISSUES OF DEEP-SEA MINING

The commercial exploitation of marine resources began in the 1960s, but little attention was paid to environmental damage in those years. In recent decades, in parallel with the sharp increase in interest in deep-sea mining and metals in international waters, scientific research on marine ecosystems, marine ecosystem services and biodiversity has also begun to increase.

The rapid extinction of marine life has been observed in recent years, which in turn has led to relevant discussions on conservation mechanisms to prevent climate and physical changes in marine ecosystems (Miller, 2018). Environmental changes at the seabed, as well as other concerns, have been studied through experiments, such as the German project DISCOL (disturbance and recolonization experiment) and the follow-up study by MIDAS (managing impacts of deep-sea resource exploitation). MIDAS was a multidisciplinary program across 11 countries, partially funded by the European Commission and completed a three-year study in October 2016 (MIDAS, 2016).

Within the framework of the MIDAS partnership, scientists, industry, social scientists, legal experts, NGOs, and SMEs from all over Europe were invited to study the nature and scale of the potential impacts of mining. These include 1. Physical destruction during seabed mining, creation of mine tailings, 2. Particle-laden plumesin the water column and their impact on the environment, 3. Toxic chemicals generated during the mining process and their effects on the deep-sea environment.It should be noted that information on the biological diversity of the deep seabed, the connectivity between them, and how much they are affected by this mining, and the period of ecosystem recovery is limited and not fully understood.

- Nodule Removal from the Abyss

The physical recovery of manganese nodules will take millions of years because the formation of these nodules is due to the deposition of sediments that occur over a long period of time (Miller, 2018). One of the first studies on biota renewal was carried out at CCZ in 1978, as nodules were removed experimentally (this is calledthe OMCO experiment) and a long time later, in 2004, the area was revisited to assess changes in benthic habitat. Although 26 years have passed since the process,the roads created by the movement and collection of mining machinery were still clearly visible, and the variety and biomass of nematode worms in the excavated areas was reduced compared to the untouched areas (Miljutin, 2011). Most ofthe experiments to date have focused on the commercial assessment of the seabed, and very little has been done on the self-regeneration of nodules after seabed drilling.Vanreusel, (2016), explored the way mining was done 37 years ago. It was concluded that the fauna of this area, once rich in nodules, could not be recovered, despite the passage of years. This proves that nodule mining causes permanent damage to the seabed and leads to the destruction of significant amounts of biomass **Figure 18.**

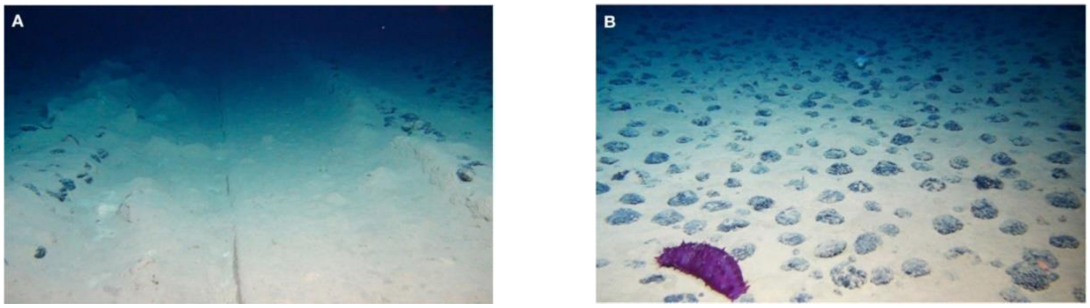


Figure 18: Examples of seafloor morphology and disturbance. (a) thirty-seven-year-old omco track (ifremer license area); (b) nodule landscape (ifremer license area) (Miller, 2018)

- Seafloor Massive Sulfides from Hydrothermal Vents

Remote-controlled machines have a direct physical effect on the seabed and cause achange in topography through suction or drilling of the substrate. Because sulfides are obtained from hydrothermal vent chimneys, these chimneys are completely eliminated, leaving a flatter topography with a more uniform surface and compressed sediment. This causes the destruction of living things in the area and that could be unsuitable for habitat recovery and recolonization. Van Dover (2010) suggests that the mining of hydrothermal vents could change their distribution. However, he suggested that if these hydrothermal chimneys were active, then the mineral components of the chimneys would reform over time. Miller (2018) said some placesin the Eastern Pacific Rise have grown 40 centimeters in five days. However, in general, there is no exact information on how long the recovery of vent-associated species will last. Van Dover (2014) assessed those anthropogenic impacts around hydrothermal chimneys include light, noise pollution, discarded materials, crushing of organisms by seabed machines, and heavy vehicles compacting the seabed.

- Removal of Cobalt-Rich Crusts from Seamounts

Mining CRC deposits on seamounts will directly lead to the death of sessile organisms there. Levin et al. (2016) suggest that such mining will lead to the extinction of benthic, mesopelagic (200–1,000 m), and bathypelagic (1,000–4,000 m) fish. The extent of this mining in the deep sea causes it to expand its sphere of influence. Intensive mining will lead to the destruction of pelagic species aggregations due to the extraction of benthic fauna, the spread of sound, light, and suspended sediments due to the presence of machines. Miller et al. (2018) compared the potential impacts of mining from a fishing context, especially trawling. Trawling, which removes substrates and associated organisms from seamounts. Although verylittle is known about the recovery of this species after intensive periods of trawling,the negative effects of deep-sea fishing have been well studied with a decrease in faunal biodiversity, cover, and abundance (Clark, 2016). Many seamount creatures are thought to develop very slowly, such as sessile corals (from a few micrometers to ~1 mm per year), long-lived (up to millennia), and are thought to besensitive to physical influences. Therefore, there is a need for global protection of seamounts, such as VMEs (Vulnerable Marine Ecosystems). (Miller et al, 2018). The impact of deep-sea mining is greater than that of trawling because the removal of substrata will be complete.

➢ Sediment Plumes

Deep-sea sediment plumes are generated by offshore production vehicles, especially during their movement and collection, as well as by risers and by the discharge of wastewater from dewatering from support vessels to the water (Van Dover, 2014).

Dewatering waste may consist of fine sediment and small amounts of heavy metalsthat may be resuspended when discharged into the water. Dewatering waste, side cast sediment, and sediment that releases during the mining process are known as main wastes that may consist of fine sediment and small amounts of heavy metals that may be resuspended when discharged into the water. In deep-sea mining, it is important for us to deliver economically important ores from the seabed to the ship.Therefore, in order to increase the concentration of ores and prevent the transportation of waste to the ship, they are partially separated from the waste in the collection machine and buffer station. As a result, a sediment plume is formed, which will cause significant physical changes and suffocate the benthic habitat. At Solwara,one of the sulfide extractions projects, Nautilus Minerals state that about 240,000 tons of waste sediment and rock will be generated by the mining process. The returned slurry is returned 25-50 meters above the seafloor. The returned slurry may contain suspended particles (smaller than 8μm) and be warmer than sea temperatureat that depth and high concentration of metals if leaching occurs from ore during mining. This type of toxic plume affects habitats not only in the mining area but also miles away from the mining area due to ocean currents and the amount of sediment discharged, and there is no clear idea about the plume's distribution or volume. In some models, sediments released near the seabed are in some cases confined to deep water due to differences in water density and not move into the upper water column.

According to Nautilus Minerals (2008) a sulfur test in Solwara1 causes the release of plumes from the mining area and resulted in the sedimentation of up to 500 millimeters of sediment within 1 kilometer of the discharge area, as well as the spread of some materials over an area of up to 10 kilometers. But natural sedimentation in the abyssal and seamount reaches a few centimeters per 1000 years.For example, in hydrothermal chimneys, the natural sedimentation rate is 0.2 in some places and less than 0.03 millimeters in others.

➢ Increased Noise

Submerged remote control devices used in the deep-sea will increase the noise of the underwater ambient environment. Most deep-sea species generally have adaptedto very low levels of noise, and such anthropogenic sounds, especially if this soundoccurs continuously, will lead to an increase in the ambient noise level of the seabed(Bashir et al, 2012). Studies have shown that some deep-sea fish communicate usingvery low sound frequencies (<1.2 kHz; Rountree, 2011), and other benthic species are thought to detect food up to 100 meters using sensitive acoustic systems(Stocker, 2002). Increased anthropogenic noise causes behavioral changes in a number of marine fish species and marine mammals, leading to communication andcausing temporary threshold-shifts in hearing or permanent damage depending on the species, type of noise and received level (Miller et al, 2018).

- Anthropogenic Light

It is very easy for sunlight to penetrate the euphotic zone, up to about 100 meters above the ocean, and provides photosynthesis in that region. However, the penetration of light into the dysphotic zone (200-1000 meters) is very little. Areas deeper than 1000 meters are known as aphotic, where sunlight penetrates to some extent but is not completely dark. Weak light in the deep sea has been shown to originate from bioluminescence (Miller et al, 2018) and geothermal radiation(Beatty et al, 2005), and organisms in the area have adapted to this condition. Continuous mining activities of surface support vessels and seafloor mining tools lead to a long-term increase in light levels, which will change the current situation in the mining sites. For example, studies have shown that deep-sea shrimp living in hydrothermal vents in the Mid-Atlantic Range have suffered permanent retinal damage as a result of floodlights on manned submersibles (Miller et al,2018), or other mobile organisms might migrate away from the mine site. Artificial lighting on ships at night causes seabirds, particularly fledglings, to change direction, fly toward the light source, and collide with man-made objects (Troy et al, 2013).

- Increased Temperature

The heating of the machines used during the seabed mining operations and the dewatering waste that is returned to the deep sea at a certain temperature will generate some heat and cause the seabed temperature to change in the mining area. Thus, the temperature of the waste materials is expected to be 11 degrees warmer than the surrounding seawater, which is in line with estimates by Nautilus Minerals,which will cause the return water to warm up to 5.8–11.4◦C degrees on the seabed (Nautilus Minerals, 2008). There are very little research and information on the effects of temperature increases on the seabed. However, such temperature changes are thought to affect the growth, metabolism, reproductive success, and survival of some organisms that adapt to a constant temperature (Bashir et al, 2012).

- Possible Conflicts

Seabed mining impacts have the potential to conflict with subsistence and commercial fishing, and shipping activities. Another reason for the growing commercial interest in seabed biota is the novel chemical compounds that are widely used in the pharmaceutical industry. There are several legal aspects to considerin deep-sea mining. Thus, if the plume formed during the mining process crosses itsborders and interferes with the internal waters of any state, or goes beyond the contractor's territory, violates the marine environment of that state, that state or institution could bring legal cases. There may be a number of disputes that could arise regarding seabed mining if the exclusion zones around seabed mining operations impede access to fishing areas or change shipping and navigation routesin the EEZs or in the Area. The deep sea is considered to be the largest genetic resources facility, and many companies have already hold patents for the production of pharmaceuticals found there. For example, the French company Sederma has been using enzymes derived from deep-sea bacteria for several years to make commercial skin protection products (Miller et al, 2018). This market for marine genetic resources isvery large and reached several billion dollars in 2010 (Leary et al, 2010). Deep-sea mining is damaging this industry and destroying unexplored genetic deposits.

CHAPTER 7

LEGAL ENVIRONMENT

This section will examine the regulation of seabed mining activities in marine fields in national and international waters, focusing on the protection of the marine environment. Therefore, the exploitation of marine resources requires a comprehensive analysis of the geopolitical and socio-legal context.

The United Nations Conventions on the Law of the Sea (**UNCLOS**, 1982) is aninternational agreement that harmonizes domestic and global uses of the oceans as well as balancing competing uses of the marine environment as well as balancing competing uses of the marine environment, while simultaneously striving to protect and preserve the marine environment, defines the guidelines, rights and responsibilities of nations regarding the worlds' oceans and its marine environments (United Nations Convention on the Law of the Sea, 1982).

UNCLOS creates different maritime zones, including internal waters, territorial sea,contiguous zone, exclusive economic zone, continental shelf, high seas and the international seabed (i.e. "the Area"). Each zone is characterized by different formsof prescriptive and enforcement jurisdictions.

A coastal state's **territorial sea** (Art. 3 ff) extends from the coast to 12 nautical miles (22 km) in accordance with the United Nations Convention on the Law of the Sea (UNCLOS), and includes the airspace and the water body to the seabed and thesubsoil. The **contiguous zone** (Art. 33) may extend the territorial waters line to another 12 nautical miles. Coastal states have the sovereignty and jurisdiction to exploit the natural resources within their 200-nautical mile (370 km) **exclusive economic zone (EEZ)**. In some countries, there may be an expanded continental shelf outside the EEZ, which they have sovereign rights over the seabed and any mineral resources, though not over the water column. The high seas are generally defined as a maritime area outside the exclusive economic zone (EZZ) and cover the seabed territory that is not subject to international jurisdiction (or "**Area**") (i.e. beyond the continental shelf of coastal states).

Three sections in UNCLOS are particularly relevant to deep-sea mining:

UNCLOS Article 136—Common Heritage of Mankind:

The Article states that:

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

UNCLOS Article 137.2—Legal Status of the Area and Its resources:

The Article states that:

"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."

UNCLOS Article 145—Protection of the Marine Environment:

The Article states that:

"Necessary measures shall be taken in accordance with this Convention with respectto 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:

(a) 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;

(b) The protection and conservation of the natural resources of the Area and the prevention of damage to the flora and fauna of the marine environment."

Responsibility for the protection of the marine environment, navigation, research and the regulation and control of mineral-related activities in the region outside the continental shelf (Area) and thus beyond the limits of national jurisdiction is regulated by the **International Seabed Authority (ISA)**, established by UNCLOS in 1982 and is an autonomous intergovernmental body with 167 members. In addition, ISA considers contractors' applications for exploration and exploitation of deepsea resources, assesses environmental impact assessments, and monitors mining operations in the Area. Currently, ISA has signed 17 contracts for the exploration of polymetallic nodules in various oceans, in an area of 75,000 km^2, 7 for polymetallicsulfides in 10,000km^2 and 5 for ferromanganese / cobalt-rich shells in an area of 20 km^2. Contracts are valid for 15 years, after which the contract can be extended for 5 years further.

CHAPTER 8

IMPACT DRIVERS

In the above-described chapters, we compared the mineralogy of land-based and deep-sea ores, analysing their extraction and production technologies, the environmental impacts and legal environment--related aspects. In Chapter 8, we described the results of an approach of effects -analysis based on the comparisons in 5 different categories, including Climate Change, Nonliving Resources, Biodiversity, Social Impacts, Economic Impacts based on the spheres of influence. It should be noted that the information reported, comparisons, graphs and their scope in this section come from the LCA, which was calculated and described in Paulikas et al, 2020. In each category, the production of 1 billion EV of land-based and deep-sea-based ores based on calculations performed is compared with their effects.

Figure 19 shows a comparative "spider chart" of the estimated relative ratings of the impact zones for categories for land ores (dark gray) versus nodules (blue). In general, the greater the area, the greater the negative impact footprint.

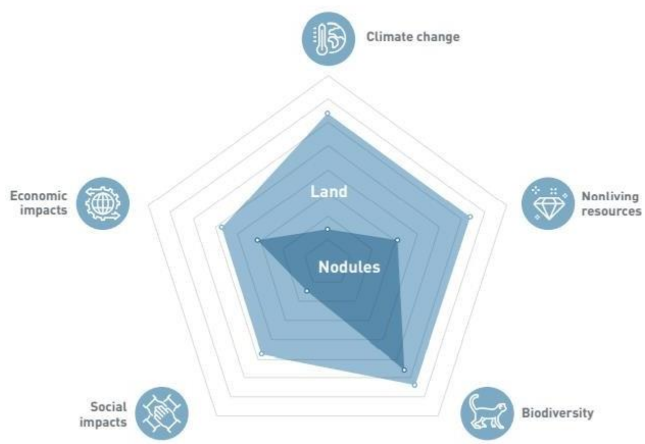


Figure 19: Summary of category impact ratings (Paulikas et al, 2020).

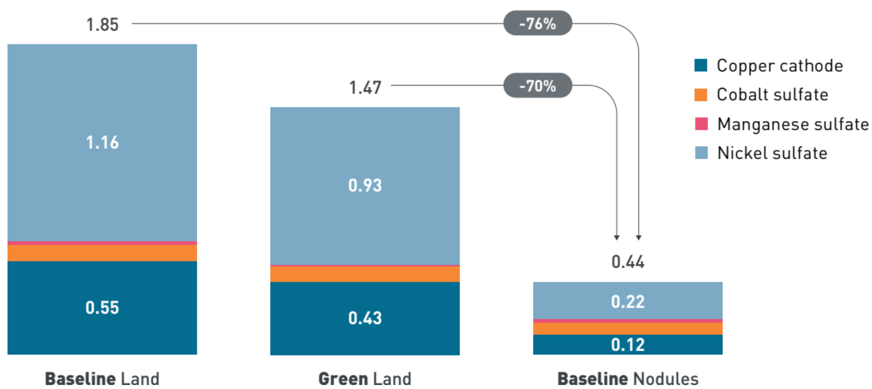
8.1 CATEGORY 1: Climate Change

Metals produced from nodules are characterized by 70% lower GWP than metals produced from land ores. In addition, the carbon sequestration impacts associated with land mining are riskier than the potential disruption of carbon stored in deep-sea sediments and water, as the use of nodules reduces this risk by 94%. In this section we look at two impact sub-categories reported in Paulikas, 2020—Global Warming Potential (GWP) and Carbon Sequestration—each of which can exacerbate the ongoing climate crisis.

- Global Warming Potential (GWP)

Extraction of ore from land requires a significant amount of energy, effort, infrastructure and transport, which in turn leads to the release of significant amounts of emissions and waste production. Based on different scenarios, it is possible to comment on the amount of this land-based waste and compare them. The typical LCIA indicator for GWP is CO_2e (CO_2 equivalent) emissions per kilogram of output. For example, in the base-case scenario, cradle-to-gate life cycle emissions are estimated at 1.85 gigatons of CO_2e by 2047 for the production of one billion electric batteries, including Ni, Co, Mn and Cu, and their compounds required for the battery. Under the optimistic "green" supply scenario, the figure is estimated at 1.47 gigatons of CO_2e.

The collection and processing of deep-sea nodules generate less CO_2e life cycle impact, with only 0.44 gigatonnes of CO_2e produced by the planned nodules projects baseline scenario due to the low-impact mining phase, lower transport costs and easeof access of the power supply to renewable energy (e.g. hydropower). Even compared to the optimistic green land-mining scenario, the amount of CO_2e cradle-to-gate emissions from nodules based on baseline scenario production is 70% less, andunder mass-based sensitivity analysis, this reduction is close to 90% (**Figure 20).**



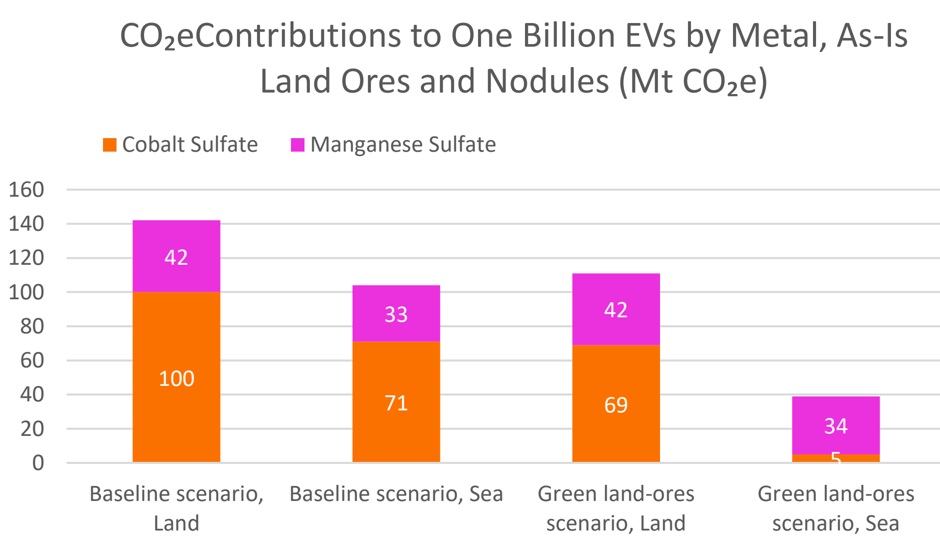


Figure 20:CO_2e attributable to production of battery metals and copper, 1 b evs, 2017–2047 (gt) (Paulikas et al, 2020).

1 EV battery contains 56.2kg (36%) NiSO4.7kg (5%) $CoSO_4$, 6.6kg (4%) $MnSO_4$ and 85 kg (55%) Copper. In the production of nodules, all of these compounds are obtained as a final product, in addition to which ammonium sulphate is obtained, which is used in the production of fertilizers. That is, the amount of waste during theproduction of metals from nodules is very small. During the production of 1 billionEV batteries, according to the primary analysis of the land, 1750 kg of CO_2 emissionsare generated, of which 51% falls on the mining and concentration step, 29% on

processing and 20% on refining. During the production of these same metals from the nodules, 445 kg of CO_2 is generated, of which 13% falls on the mining and concentration stage, 65% on the processing stage and 22% on the refining stage. It should be noted that during the production of nodules, such a large amount of emissions in the pyrometallurgical stage is associated with a manganese processing,but the high amount of manganese obtained can compensate for this.

➢ Carbon Sequestration

On land, in addition to the processing phase, significant amounts of carbon are released into the environment as a result of forests, vegetation and soil degradation. For example, one billion EV batteries are at risk of releasing 9 gigatons of carbon toproduce metals.

When using deep-sea nodules, the total amount of stored carbon at risk is less than 90%. Seabed sediments contain very lower amounts of carbon, and if the sediment is disturbed, very little can reach the ocean surface. However, as a result of deep pressurized seawater pumping to the surface, CO_2 has a small effect on the atmosphere, but the modeling has shown that this risk is very low. For onshore processes, the location of processing plants can be flexible, so it can be built in areas with areas of minimal trees and vegetation, which will reduce the risk of carbon **(Table 12).**

For 1 billion EV batteries, carbon Sequestration Impact from…	The amount of CO_2 is atrisk of release. (gigatons)	Area which is impacted by mining for 1B EVs. (km^2)	The amount of stored organic carbon km2 ofmining area. (tonnes)
Terrestrial Mining and Production	9,30	156.000	~16.200
Nodule Offshore Operations	~0 (from pumping water or disturbing the seabed sediments) ~0,00015 (from depressurization of deep seawater pumped to surface)	508.000	~424
Nodule Onshore Processing	0,54	9.200	~16.200

Table 12: Potential sequestered carbon release from terrestrial mining and production, nodule offshore operations and nodule onshore processing for 1b evs (Paulikas et al, 2020).

8.2 CATEGORY 2: Nonliving Resources

Land mining industry uses and significantly alters nonliving resources. Land mining industry is characterized by substantial physical land alterations in the soil during mining, water pollution, chemical pollution, air pollution with toxic dust obtained because of the process, and high quantities of waste. It is very difficult to restore mines, and this work is often not done. Mining disasters and the collapse of dams domore damage to the environment. In addition, the use of large amounts of water cancause many problems on local scales. Thus, to obtain land ores, it is necessary to carry out drilling operations using various mining methods, going to adepth of hundreds of meters, even kilometers underground (e.g., copper and nickel sulfides), or several-meters thick flat sheets covering a much larger land area (e.g., nickel laterites) or with land ores, a large amount of waste rock needs to be drilled and blasted just to gain access to the ore body—this is particularly true in the case of open-pit mines with spiraling terraced access for mining trucks. In contrast, nodules present as a thin nodule field- 90% of the nodules are in the top 5 cm thick of the sediment over the sea and can be collected directly. Although the area wherethe nodules (508,000 km^2) are distributed is larger than the area of the land mine (156,000 km^2), therefore more habitat can be affected, but the damage to the environment during their collection is relatively small.

One ton of polymetallic nodule contains 290 kilograms of manganese, 13 kilogramsof nickel, 11 kilograms of copper and 2 kilograms of cobalt. To obtain the same amount of metal from land ores, three different types of ore bodies - nickel-cobalt, copper-cobalt, and manganese ores - must be discovered and extracted. When average grades of mined ore on land are applied (35% for manganese, 1.25% for nickel, 0.5% for copper, and 0.08% for cobalt as a byproduct of nickel and copper mining) the need in soil ores, about four times as much (4068 kilograms) of ore needsto be extracted from the land to get the amount of metal in 1000 kilograms of nodules. As a result, the extraction of such metals from nodules effectively reduces the required tonnage of the total ore by four times.

Extraction of land ores generates a significant amount of waste and tailings (64 gigatons of waste and tailings for one billion EV batteries), which leads to substantial amounts of chemical pollution. If the process design as smart-processing, no waste (~0 gigatons of waste and tailings for one billion EV batteries) is generated during the production of nodules, because all the products obtained can be recycled into the processing, converter slag can be reused as a raw gravel material by the market, and fertilizer-grade ammonium sulfate is produced as a useful byproduct.

The consumption of fresh water in soil mining (45 km^3 of freshwater are withdrawnfor mining operations) is mainly used for milling, flotation, and separation of ores, hydraulic and slurry transport, dust suppression, leaching, heating, cooling, electrorefining, tailings management, granulation, revegetation, wastewater, and ofcourse, employee needs. In contrast to land mining, there is no direct need for fresh water in the collecting of nodules but the need for water in processing and refining stages, particularly for heating and cooling, granulation is 5 km^3.

Land mining is a source of contamination of freshwater resources, which harms both humans, animals and vegetation. Contaminants can enter the water at any stage of land mining and contaminate surface water and groundwater with acid-mine drainage, toxic-metal leachate from pits, waste-rock piles, tailing ponds, and flooding of underground tunnels. Unlike soil mining, nodule collection does not contaminate freshwater.

With land-ore mining, air pollution poses a significant risk to the environment, nearby communities and miners due to the amount of harmful compounds released into the atmosphere. The main compounds that pollute the air during land ore miningcan consist of airborne emissions, toxic dusts from blasting, evaporated tailings ponds, and soil contaminated by leachate from waste-rock piles. Air pollutants can irritate the eyes, skin, and respiratory tract and lung diseases such as asthma, silicosis, chronic obstructive pulmonary disease, and lung cancer may result from prolonged exposure. Gases that pollute the air during deep-sea mining are consideredto be CO_2, SO_x, NO_x, and they are formed during the combustion of bunker fuel, andthere are only some human-hazardous risks for the ship's operating personnel. For the production of one billion EV batteries, it is estimated that 173 megatons of SO_xwill be generated from the production of metals from land ores and 17 megatons ofSO_x from nodules. These figures are 8 megatons for NO_x gas from metals extractedfrom land ores and 1 megaton for metals extracted from nodules (Paulikas et al, 2020)

8.3 CATEGORY 3: Biodiversity

There is a variety and richness of species affected by land mining. As a result of landmining, habitats are being destroyed and biodiversity is being disrupted, including the development of new mines to meet future demand for metals and the expansion of mining sites to biodiverse regions of the planet, home to rare species of animals and plants. Although the rehabilitation of mines is mandatory in some countries, it is not strictly observed in countries where cobalt and manganese are mined.

Due to a low flux of particulate organic carbon from the surface, there is few nutrients on the sea surface in the CCZ region. That is why the abundance of life in the abyssal sea waters is low and the fauna is limited, and the flora does not exist. Some organisms attach to the surface of the nodules, while others need the hard surfaces of the nodules for critical life functions. Removal of nodules from the seabed will lead to the destruction of such wildlife populations. If the disturbed sediment extends beyond the plume collection areas, the risk area of deep-sea miningwill expand. There is a need for more study on solving these problems and future impacts of nodule collection on ecosystem function and recovery. Estimated risk to megafauna and biomass during mining and processing of one billion EV batteries: For metals produced from land ores - 47 trillion megafauna (including 0.6 trillion vertebrates and other mobile megafauna) and 568 megatons of biomass, for metals produced from nodules: 3 trillion megafauna (including 0.04 trillion vertebrates and other mobile megafauna) and 42 megatons of biomass (Paulikas et al, 2020)

On the abyssal seabed, “megafauna” describes organisms longer than two centimeters, but on land it commonly refers to animals weighing more than 40–44 kilograms (90–100 lbs.), while in soil science, the term is used for animals such as earthworms and small vertebrates (e.g., moles, mice, hares, rabbits, gophers, snakes, and lizards). On the abyssal seabed, “macrofauna” describes organisms smaller than two centimeters and retained on a sieve of mesh size 250 µm, but on land it describes organisms longer than one centimeter. “Meiofauna” describes the very small (<1 mm) organisms that live in spaces between sediment particles. “Microfauna” on the abyssal seabed describes organisms that pass through a mesh size of 32 µm (0.032 mm), whereas on land it describes soil animals smaller than one millimeter (https://www.isa.org.jm/scientific-glossary/m).

8.4 CATEGORY 4: Social Impacts

Land-ore mining has several inherent dangers, and today Mining remains one of the most dangerous occupations in the world, with 50-100 deaths per 100,000 workers globally. (Statista, 2019) Throughout history, mining has caused deaths, illnesses and financial costs. Vulnerable populations are disproportionately affected, including children exploited by artisanal mines and underprivileged people indeveloping countries (especially in Africa, DRC) and dozens of children are victims of this kind of artisanal mining every year. For example, in the Republic of Congo, according to statistics for 2014-2015, at least 82 people died in cobalt artisanal minesin 13 months. In 2019, the figure was 63 (Amnesty International, 2016). The main reason for this was the country's monopoly, dictatorial regime, wars, and internal unrest, which weakened control over such mining.

Analysts believe that DRC will remain the main source of cobalt in the near future.To this end, car makers and technology companies such as, Apple, Microsoft, and Tesla, want to provide secure future cobalt supply to ensure the metal used in rechargeable batteries is sourced ethically (Cobalt Investing News, 2018). Such mining also affects local cultures. For example, in Indonesia, 29 villages were critically affected by tailings from the world's second-largest copper mine, Grasberg Mine.

The production of metals from ocean nodules eliminates or reduces the risks associated with land ores. Risks associated with nodule production may arise primarily from operating production vessels at sea. No deaths were reported in deep-sea mining. Because the collection of deep-sea nodules from a commercial point of view has not started there yet. However, there is a reason to believe that the rate of fatalities, illness, and injuries will be less for deep-sea nodule collection. If there is an accident, the only vulnerable population affected may be countries whose GDP is highly dependent on cobalt, manganese, or nickel. There is no risk of cultural displacement.

8.5 CATEGORY 5: Economic Impacts

Land-ore mining is characterized by high prices, greater underlying uncertainties, timelines for prospecting, high prices of metals in the global market, depletion of high-grade ore mines, and disruptions in operations related to disasters. Land-ore mining means more jobs than nodules. However, many of these jobs are considered dangerous, and some are exploitative. For example, while 600,000 workers (if including artisanal: 2.3 million) are required to extract land ore to produce 1 billion EV batteries, the figure is 150,000 for metals produced from nodules which is fewer but safer and higher-quality jobs (Paulikas et al,2020).

The extraction of metals from nodules, which are important for the production of EV batteries, could lead to a sharp drop in their prices on the world market, especially the manganese market. The main reason for this is the high content of these metals in the nodules, their quality, short production time and the presence of a single international regulator (ISA), which can reduce all the risks associated with production. In general, collecting nodules will create fewer though safer jobs that are, in aggregate, likely higher paying.

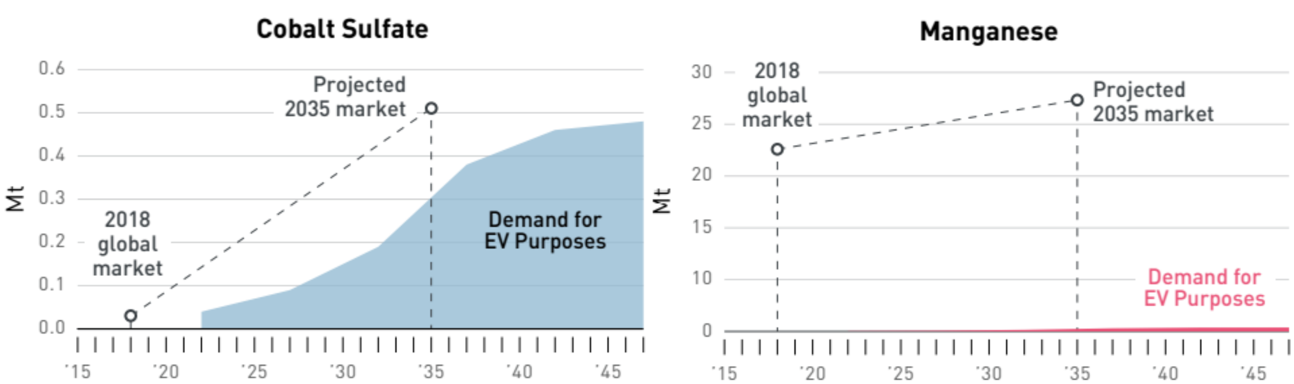


Figure 21: METAL DEMAND (Stanley, 2017).

To better understand the potential impact of nodule supply on metal cost, it is necessary to look at demand forecasts and market volume. **Figure 21** shows the $CoSO_4$ and Mn 2018 production volumes and 2035 projected requirements for battery production.

As it is clear from the graphs, cobalt production is of great importance in the EVmarket, and the demand for it continues to grow every year. If we look at **Figure 22**, it is clear that existing land-based capacity begins to become constrained in 2020, and 8,000 tons of additional products will be required to meet the

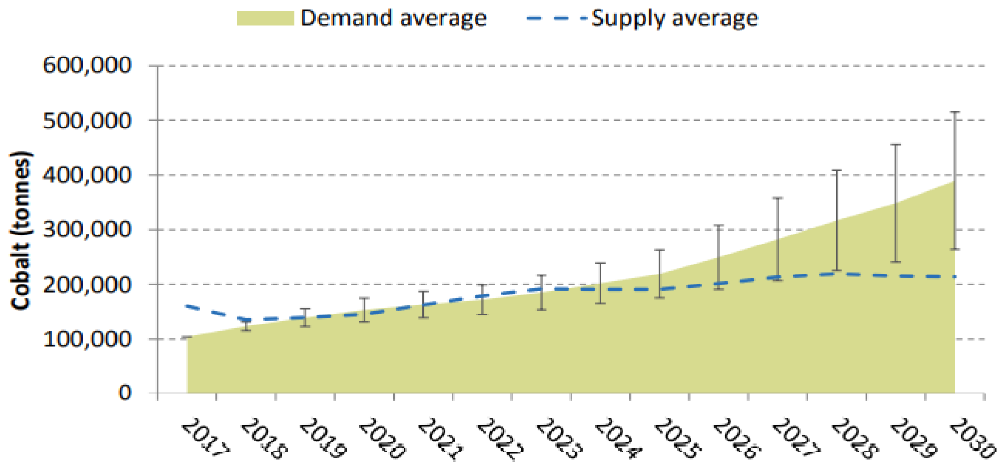


Figure 22: Year on year cobalt surplus/deficit in average mine supply and demand scenarios.

In the coming years, this figure will increase sharply, for example, in 2030 it will increase to 175,000 tons.

One of the main reasons for the increase in demand for this metal is the high rate of demand for EVs, especially in the Netherlands, China and the United States, these countries are investing significantly in the trend towards electrification. Thus, the size of the EV fleet is estimated at 9 million electric cars in 2020, and in 2030 this figure will increase to 56 million. In general, many scenarios have been put forward for the development of the EV industry, each scenario is projected to increase the demand for EVs, and this demand cannot be met by land ores alone. The cobalt content may vary depending on the type of battery and EV. However, in general, an average of 9-11 kg of cobalt is required for an EV.

Demand for cobalt sulfate in 2018 was 29 kilotons. This demand is growing every year by 510 kilotons, and in 2035 the demand for cobalt sulfate is projected to increase 17 times. This is within the context of an overall cobalt market of 121 kilotonnes in 2018, projected to grow to 640 kilotonnes in 2035. Thus, over 18 years,cobalt sulphate will dominate the cobalt market, accounting for 80% of the market, due to increased demand for sulfate batteries. By 2035, Five nodule extraction areaswith three active projects will produce about 80 kilotons of cobalt sulphate and it will account for 16% of the cobalt sulfate market. Forty typical operations supplyingthe nickel sulfate demand gap could produce 215 kilotonnes of cobalt, or 42% of thecobalt sulfate market.

It should be noted that the demand for LIB is associated with the growth of the EV industry, and cobalt consumption in this market is increasing with the use of NMC (nickel-manganese-cobalt) cathode materials. According to (Darton Commodities, 2016), most manufacturers of electric and hybrid vehicles (BEV and PHEV) have recently increased their interest in replacing cathode chemistry NMC with a non- cobalt chemical material, mainly LMO (lithium-manganese). More and more manufacturers are choosing NMC chemistry, which has such a high energy density and thus a long charge to cover long distances. In **Figure 20**, the reason for the relatively low demand for manganese for EV is that it is widely used as a raw material in steel production, and this trend is expected to continue to dominate the industry in the future. There remain many uncertainties concerning how fast the growth of manganese consumption in batteries will be, and which manganese products and production processes will be required to fulfill the demand from lithium-ion batteries.

The manganese market is projected to grow from 21.1 megatons in 2018, with an annual growth rate of 1.4%, to 26.8 megatons in 2035. Due to the high content of manganese in polymetallic nodules, their removal from deep-sea will significantly increase the production of manganese. For example, a single nodule project will produce 1.4 megatons of manganese by 2035, which will cover 5% of the market alone. In 2035, five nodule-extraction areas, each with three fully operational production systems are planned, with a total manganese production capacity of 19 megatons, which is 69% of the manganese market or forty operations satiating the nickel sulfate demand gap would produce 50 megatonnes of manganese, or 185% ofthe market.

8.6 Recycling

Another way to meet the demand for cobalt and manganese is to recycle expired batteries. Batteries usually reach the end of their life after 8 years and are ready for reuse.

The amount of metals recycled in the world is estimated to vary between 79,000 and96,000 tons per year. Globally, the potential recoverable amount of cobalt from oldscrap EV reserves was 452 tonnes in 2020. This figure is projected to be 4,800 tonnesin 2025 and 38,000 tonnes in 2030, depending on the type of battery collection andrecycling processes **(Figure 23).** This could provide about 10% of European cobalt consumption in the recycling EVs sector by 2030.

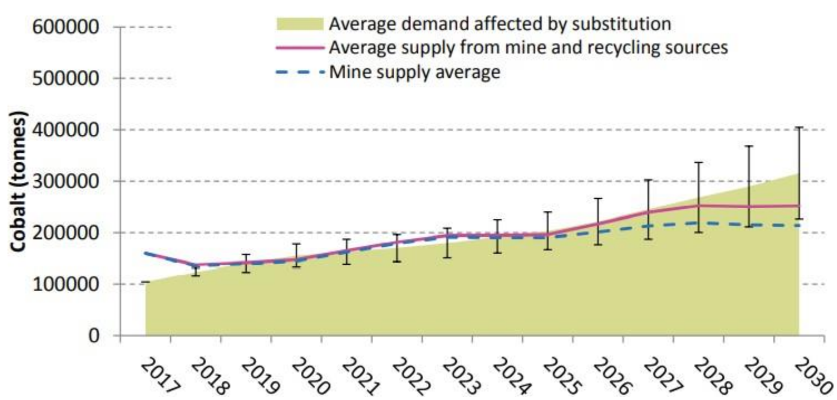


Figure 23: Average global demand/supply balances including the effects of substitution over demand and EV batteries recycling over supply.

The recycling of Li-ion batteries in the European Union is carried out by 10 specialized companies with a total processing capacity of 38,000 tons / y, the largestof which is Valdi (20,000 tons per year) with the participation of the French group ERAMET. Then Belgium's UMICORE is considered to have a capacity of 7,000 tons / year, which enables the treatment of around 250 000 000 mobile phone batteries, 2 000 000 E-bike batteries, 200 000 HEV batteries and 35 000 EV batteries (Umicore, 2017).

In January 2019 the US department of energy launched a 15 million dollar research and development initiative near Chicago Illinois called Argonne **Recell (**https://recellcenter.org/about/facilities/**)** center the first advanced battery recycling RD facility in America designed to help businesses develop new recycling methods that can out perform hydrometallurgy and pyrometallurgy and so enable the US to compete in the global recycling industry and reduce their reliance on foreign sources of battery materials. A similar initiative exists in the UK called **ReLib** (https://relib.org.uk/). It is a consortium led by the university of Birmingham in collaboration with all these UK institutions. Their aim is to establish not only a technological infrastructure but also a legal infrastructure to optimize what iscurrently a very underdeveloped and badly regulated industrial sector.

Manganese can be recovered together with iron from slag from generated during the production of iron and steel. In fact, such recycling of manganese is considered insignificant because it is recycled incidentally as a constituent of ferrous and nonferrous scrap.

It should be noted that both cobalt and manganese are obtained from the scrap recycling process rather than from the recycling of Li-ion batteries. The advantage of this process is that it slows down the depletion of land resources, consumes less energy than the production of metal from ore, prevents the production of mine waste and prevents the release of precious metals into the environment. Most recycled cobalt is recovered by recycling alloy scrap. It is made into alloy similar in composition to the scrap. Approximately 10,000 or 15,000 tons of cobalt are obtained from the recycling of such scrap.

Despite the recycling, this area is not yet well developed and there are several problems. According to (Umicore, 2012) report: “Current levels of lithium collectionin the EU are very low. In case of batteries, these amount to an estimated 5% of thelithium-ion batteries put on the European market. Most of the current lithium is either dumped in landfill or incinerated, contributing to Europe’s dependence on lithium supply”. Therefore, the development of technologies for the extraction of cobalt from nodules can prevent such problems in the future.

CHAPTER 9

CONCLUSION

The urgent transition from fossil fuels to EVs is leading to an increase in transitional demand for basic metals. One of the critical issues is to ensure the supply of these large amounts of base metals ensuring minimal environmental, social and economic impacts. The thesis focused on the two main base metals needed to electrify the global passenger fleet and compared the impacts of the two sources of these metals: including conventional land-based ores and deep-sea minerals. It has been deepened the EV batteries sector, nevertheless such metals are very important for use in many areas, including renewable technologies: very significant benefits will be obtained if these metals are obtained from less-impactful sources.

Based on different sources, it has been performed an in-depth comparison of the effects of cradle-to-gate impacts of producing metals from two different sources considering all the main categories of impact. These categories include climate change due to global warming and carbon emissions, biodiversity, social, and economic impacts. This analysis shows that the production of metals from polymetallic nodules, which are widespread in seabed minerals, especially in the CCZ region, can have significant advantages over land ores in each category. In addition, large-scale research is needed to assess the environmental-impact assessment of nodule collection on the seabed wildlife and ecosystem function.

A large transition base metal demand requires the development of new land mines and increasing the production capacity of existing mines. Recently, the extraction of land-based ores is considered very risky, both in terms of technology and resource depletion. This, in turn, will lead to the extinction of wildlife in some of the most biodiverse places on this planet, more disruption of forest habitats, long-term local land disruption and pollution, social displacement and the creation of additional gigatonne-sized greenhouse gases, more fresh water usage, more groundwater pollution; more human death and decades-long human-health impacts and a substantial amount of stored carbon at risk. At a time when countries and companies are struggling to reverse the relentless upward trend in the world's emissions, this problem will deepen. Deep marine nodules are considered less dangerous in this regard because the deep sea is very rich in industrially important metals, and also prospecting of nodules is not based on the drilling of hard rocks to be able to remotely sense geological structures of the mining site or collect drill cores to test their composition the mining of these metals. Nodules are collected from the sea surface with the help of special autonomous underwater vehicles, which carry special sensors attached to the vessel hulls to explore the seabed environment and biodiversity. Unlike terrestrial mining, deep-sea mining is not carried out in rural areas and does not require new infrastructure, roads, bridges, establishment of networks between tunnels and access shafts. Also, unlike open-pit mining, there are no cases of major environmental impacts such as deforestation, clearing of vegetation and topsoil removal to reach the ore body. The development of a land mine can vary from 5 to 10 years, which is a very long time, while for deep-sea mining this figure is 3 or 4 years.

To prevent the above-mentioned negative effects of land mining, there is a need to increase investment in energy and water efficiency, electrification, mechanization, and automation of mining equipment, increase the efforts to search for high-grade ores, and invest in existing production methods. However, all these processes require a long time, extra costs, and control.

In areas with high biodiversity (i.e. Indonesia, DRC), such mining activities or the expansion of their sphere of influence poses direct and indirect threats to large numbers of species, including high-visibility vertebrates (mammals and birds) as well as reptiles, amphibians, and fish. Many of these species are considered endemic, and some are threatened by other factors, including rapid loss of forest areas, climate change and the impact of other mining operations. High-visibility marine invertebrates, such as reef corals, already face serious threats from climate change. Besides, any harm from terrestrial mining can compound that challenge, not only to corals, but to the rich fish and invertebrate communities that depend on them. Air pollution from land-ore mining can consist of airborne emissions, toxic dusts from blasting, evaporated tailings ponds, and soil contaminated by leachate from waste-rock piles which pose great risk to miners and nearby populations. Exposure to these dusts and other air pollutants can irritate the eyes, skin, and respiratory tract and cause lung diseases such as asthma, silicosis, and lung cancer. Land mining often causes pollution of freshwater sources, groundwater, and harmful impacts that can include illness and death in humans and wildlife. Pollutants can enter the water at every stage of land mining. Contamination of surface water and groundwater can be caused by acid-mine drainage, toxic-metal leachate from pits, waste-rock piles, tailing ponds, and flooding of underground tunnels, among other mechanisms. Also, water pollution becomes more catastrophic when tailings dams collapse which can cause hundreds of deaths.

The mining sector is becoming more difficult over the years. One of the main reasons for this is the decline of ore classes, the shift of production is moving to more biodiverse places, accessing ore bodies requires either breaking or tunneling through the significant tonnage of waste rock and the richness of land ores with heavy toxic elements. One of the advantages of soil ore mining is that mining takes place in a smaller area. For example, because polymetallic nodules are spread on the sea surface in the CCZ-zone, it takes three times more area for the same amount of metal to collect. Although it requires three times as much land, the damage caused by deep-sea mining to biomass, ecosystems, and carbon storage is still less than that of land- based ores.

The development of deep-sea mining can have a negative impact on countries whose economies depend on the extraction of certain metals (such as cobalt, DRC), leading to unemployment. However, deep-sea mining means safer jobs with higher wages.
Thesefore, in the thesis it also has been explored in detail the distribution of seabed minerals, their exploration and extraction, transportation and processing technologies, as well as the environmental impacts of deep-sea mining. The compositions of each deep-sea mineral, the ore grade of the transitional metals required, and their economic importance were noted. The legal environment of deep-sea mining was studied, and detailed information was provided on its control by ISA. The ISA aims to protect the deep-sea environment and biodiversity by instructing each contractor to set aside 10- 30% of the contract area as no-take zones. It is believed that this will restore the ecosystem and protect the wild environment.

It has been seen above that the role of deep-sea minerals in creating the greenest and most ethical EVs in the world will be enormous. There is a great need for further research into the deep-sea ecosystem, and for investments in more suitable technologies for exploration, collection, and transportation. All this will lead to the further development of this sector and the commercial use of deep-sea minerals in the near future, and as a result, the development of a more ethical and greener EV battery industry will play a role in solving all these environmental problems.

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