Summary

Literature study on environmental impacts of deep-sea mining on the marine environment

This literature study describes the expected ecological consequences of deep-sea mining on the marine environment. It starts with an overview of national and international environmental investigations carried out in the past decades. Furthermore, the study provides a detailed overview of current international projects, technological developments as well as important legal framework conditions. In addition to some general conclusions, concrete recommendations regarding the work package technologies, environmental investigations, ecological consequences and legal conventions will be derived.
All facts and aspects discussed in this study refer to the following types of marine mineral resources: manganese nodules, polymetallic crusts, massive sulphides as well as metalliferous muds.

Summary by chapter

Key messages of the literature study are summarized within the following sections:

After an introduction regarding the environmental impact of deep-sea mining (**Chapter 1**) details on marine mineral resources are presented within **Chapter 2**.

- For several years now, marine mineral resources have been coming back into the focus of national and international economic interests. The main reasons are the economic growth in a globalized market, the growing needs for high-tech metals, in conjunction with increasing commodity prices and the strong demand for securing the national and global supply of mineral resources.
- **Manganese Nodules** consist of a matrix of manganese oxides and iron-oxyhydroxides, where significant amounts of various other metals are involved Manganese, iron, copper, nickel, cobalt and titanium are of particular economic interest.
- **Polymetallic Crusts are generated** by hydro-genetic precipitation of Vernadit and iron oxyhydroxide and by the incorporation of trace metals sorbing on the surfaces. In contrast to the manganese nodules which grow around a core, polymetallic crusts precipitate within large areas of sediment-free slopes of seamounts reaching thicknesses of up to several centimeters – and in exceptional cases even up to 25 centimeters.
- Hydrothermal **massive sulphide** deposits are formed by fluid circulation in tectonically active areas, where seawater, penetrating into the oceanic crust, is heated by a heat source such as a magma chamber. When rising through the host rock, the heated seawater experiences reactions with a sequence of chemical changes.
  In addition to the high nonferrous metal content, there are also enrichments of Au, Ag, In, Te, Ge, and Se. As a further mineralization, sulfate minerals (barite, anhydrite) and other oxide minerals occur.
- The **Metalliferous Sediments** represent a special case of hydrothermal deposits. They are currently only known as hydrothermal sediments in the so-called "brine pools" in the Red Sea trench. Major relevant resources within the metalliferous sediments are manganese, zinc, copper and silver.

Chapter 3 deals with the main global reserves of marine mineral resources with respect to the current license areas.

- In total the International Seabed Authority (ISA) has issued 17 exploration licenses for marine mineral resources since 2001, including 13 licenses for manganese nodules and 4 for massive sulfides. In addition, 2 license applications were submitted for polymetallic crusts for the first time in 2012. Further applications have been announced.
- **Manganese nodules** are found mainly in the abyssal plains of the oceans in water depths between 4,000 and 6,500 m. The economically most interesting manganese nodule region outside the EEZ is the Clarion-Clipperton Zone (CCZ) in the eastern equatorial Pacific. Most of the license areas for manganese nodules issued by the ISA are located in the CCZ. There are also some other extensive nodule deposits in the central Indian basin and the basin of Peru. Germany has been among the license holders since 2006.
- Similar to nodules, **polymetallic crusts** occur almost everywhere in the world ocean. However, economically interesting deposits are mainly found on seamounts located within the large oceans. According to the current state of knowledge, the most economically interesting occurrences of polymetallic crusts are found in the western Pacific, in particular in water depths between 1,000 and 3,000 m.
  In 2012 China and Japan submitted the first license applications regarding polymetallic crusts to the ISA.
- Hydrothermal **massive sulphide deposits** in general are found at the mid-ocean spreading centers (65%), at oceanic island arcs (12%), at backarc basins (22%) as well as at individual hotspot volcanoes. Since 2011 the ISA has issued 4 exploration licenses to China, Korea, Russia and France.
  The application for a German sulfide license area in the Indian Ocean is in preparation.
- The only known and explored **metalliferous mud deposits** were found in the central trough of the Red Sea. Since the first discovery in 1948, a total number of 18 so-called “brine pools” have been discovered in the Red Sea. But only the largest of these “brine pools”, the Atlantis II Deep, is likely to be economically viable.
  The exclusive rights regarding the exploitation of the Atlantis II Deep deposit belong to the two neighbouring states Saudi Arabia and Sudan in their joint "Exclusive Economic Zone" (EEZ) where this deposit is located.

Chapter 4 deals with the currently relevant deep sea mining technologies for the raw material types examined in this study.

- Already in the period between the second half of the 1960s until the early 1980s, the technological development of the deep sea mining has been strongly promoted. However, during that time the main focus was laid only on manganese nodules. The technological development of procedures for the exploration and mining of nodules ended with some first successful pilot mining tests (PMT) in the deep sea. The first golden age of ocean mining was based essentially on a strong private sector involvement supported by substantial governmental funding.
- As a result of many years of global efforts focused on the development of mining and extraction technologies for **manganese nodules,** a universally accepted system concept has been developed. This general concept comprises the following major

components: self-propelled crawler, flexi-tube, buffer, riser and mining production platform or ship.

- Since the mid-1990s, the technological developments in the field of **manganese nodules** have been strongly influenced by publicly funded projects in China, India, Japan and Korea. For several years now, a growing number of German companies has been engaged in technological developments for nodules mining.
  On behalf of the BGR, the company Aker Wirth elaborated a "Technical and economic feasibility study for the exploitation of polymetallic nodules from the deep sea" in 2010.
- The natural boundary conditions regarding the exploitation of **polymetallic crusts** are extremely difficult. Despite some recent concepts up to now, it has not been possible to find a satisfactory technological solution with respect to the requirement for a cost-effective implementation. Compared to the other marine resource types considered in this study, the mining technology for polymetallic crusts reveals the clearest technological deficiencies.
- The current technological level regarding the development of a commercially usable mining system for **massive sulfides** is determined by the achievements gained by the Canadian company Nautilus Minerals. The preferred system concept, which is partly already under construction, covers seafloor mining tools, a riser system and a production ship together with barges for the temporary storage of the recovered ore.
- The basic technology for the **metalliferous mud** exploitation of the Atlantis II Deep in the Red Sea goes back to the mining concept developed in the late 1970s by the German Preussag AG. This concept is very similar to that of the manganese nodule mining. Major changes are required especially for the collecting technologies. For the so-called Pre-Pilot-Mining-Test (PPMT) the nodule-collector has been replaced by a special suction head to suck up the metalliferous sediments.

Chapter 5 provides an overview of the most important recent environmental studies on deep sea mining projects.

- In recent years and decades, a strong focus of all available studies has been observed on the **potential environmental impact of deep-sea mining in international waters (so called "Area")**. Most of these studies were carried out in the time period from the mid-1970s to about the late 1990s.
- Since the beginning of this millennium, environmental studies have focused more and more on the **exploration licenses for manganese nodules in the CCZ**. These activities are related to the ISA itself, which has carried out a number of studies and workshops since this time, as well as investigations carried out by the licensees.
- For several years, initial environmental studies have also been observed with respect to massive sulfides which are due to the local exploration activities of the mining company "Nautilus Minerals" in the **EEZ** of the state of **Papua New Guinea**.
- Regarding manganese nodules **DOMES/USA** (Deep Ocean Mining Environmental Studies), **Discol/Germany** (Disturbance and re-colonization experiment), the German studies **SEDIPERU, FeMILIEU, MEPARSED and ATESEPP** (Effects of technical intervention on the Ecosystem of the Deep Sea in the South East Ocean) are some of the most important national and international environmental research studies.

- Within the **DISCOL project** a large-scale seabed disturbance experiment was carried out in an area of 10 km^2 within the South-East Pacific.
- Further licensees within the CCZ carried out so-called **Benthic Impact Experiments (BIE)**.
- The **KAPLAN project,** studying the distribution of deep-sea organisms in the CCZ, was also supported and funded by the ISA. It was carried out from 2002 to 2007.
- In addition to these studies, the ISA has introduced a **series of workshops on environmental issues of deep-sea mining** in recent years.

In addition to the description of the current state of the ecological situation within the future deepsea mining areas, **Chapter 6** extensively deals with expected impacts of deep-sea mining on the marine environment.

- After the successful **mining tests for manganese nodules,** German scientists, in the 1980s and 1990s, laid a strong focus on research projects aimed at the expected environmental impact of future commercial deep sea mining (Discol, ATESEPP) in the Southeast Pacific.
- Since the establishment of the ISA in 1994, extensive studies on the genesis, the benthic abundance, the seafloor topography, etc. have been carried out in the license areas of the so-called Pacific manganese nodule belt in the CCZ. These studies were carried out in the course of basic research, prospecting and exploration cruises of international research groups and industrial consortiums. However, new and more detailed work, especially for surveying the seabed regarding geotechnical and hydro-physical conditions as well as environmental challenges of the mining industry, were only started in the last decade.
- **Polymetallic crusts** of economic interest are found worldwide primarily on the top and at the slopes of seamounts. Generally it can be assumed that the seamounts and their immediate environment are very attractive for the benthic and bathypelagic fauna. On the one hand, they offer a great potential for the "pinning" of organisms and good shelters from predators with their highly structured rocky slope topography. On the other hand, there is, compared to the surrounding deep sea, an unusually extensive food supply because of partly strong currents.
- On account of their often singular geographical location in the deep ocean, seamounts generally provide a favorable environment for the formation of endemic species.
- The good shelter due to the seamount's structured slope topography and the high food availability leads to a relatively high population density (compared to the surrounding deep ocean environment). As a direct response to the increased population in some seamount areas, intensive deep-sea fishing activity has developed there over the last few years, currently resulting in overfishing in some areas and the local populations and ecosystems are already endangered.
- Despite the first two license applications in 2012, it can be assumed that due to the difficult conditions (separation of the crusts from the hard substrate and usually extremely difficult geomorphological conditions) the realization of commercial mining is not yet foreseeable.
- **Massive sulphides** are ore deposits which are primarily caused along the spreading or subduction zones of oceanic plate boundaries. Therefore, they are not in the deep ocean basins, but in depths of a few hundred to a few thousand meters.

- The immediate environment of massive sulphide deposits is generally mountainous with a heavily textured topography. Since the ocean floor in these areas is very young, it is rather unlikely to be covered by sediments.
- From an environmental point of view for the potential mining of massive sulphide deposits, a major distinction must be made between active and inactive hydrothermal systems. While the ecology of inactive deposits is not significantly different from the surrounding sea floor, this is completely different in the active hydrothermal systems with their "black and white smokers," and their very high local abundance and bioproductivity.
- The **metalliferous muds** of the Red Sea are a special case of the hydrothermal vents at oceanic plate boundaries. These are sulfidic ores, like the massive sulfides based on a hydrothermal genesis. The fact that the hydrothermal fluids leak in the Red Sea as saturated brine leads to the development of heavy brine pools, which accumulate within closed basins on the seafloor. This results in stable stratified brine bodies, where semi-liquid ore slurry is formed underneath - and no rocky massive sulfides as the black smokers.
- The extreme boundary conditions in the central Red Sea, such as the geographic, arid location, the morphology with the flat sill in front of the Bab el Mandeb, the only connection to the world ocean, the dry weather, the wind regime and the high water temperatures and high salinity have the following effects:
    - the Red Sea is extremely low in nutrients i.e. oligotrophic, and accordingly it is quite hostile;
    - the primary production is extremely low due to the above-mentioned boundary conditions and compared to other marine areas;
    - the population density of the different species is very low in the different pelagic zones
    - the benthic biota has a low population density similar to that of the phyto- and zooplankton due to the prevailing lack of nutrients in the Red Sea.

The major environmental impacts of deep-sea mining on the marine environment in the ore regimes described here are briefly edited hereinafter:

- The **manganese nodule fields** of the deep sea are generally characterized by a small number of individuals per unit area and a wide distribution of species. It may thus be assumed that the alternation of mining areas and undisturbed areas is not likely to cause the extinction of endemic species. However, it should be considered that these deep-sea ecosystems may not be able to respond in short periods on massive environmental changes due to their natural adaptation to long-term stable environmental conditions. Some of these massive changes and influences could be:
    - Direct destruction of habitats and extinction of fauna by the action of the collector and removal of nodules, which serve as substrates for sessile organisms
    - Negative impacts up to the point of the "choking" of organisms due the strip-off of whirled sediment in the close vicinity of the mining area
    - Impact on the food chain by killing certain organisms, change in bacterial composition in sediment and bottom water and re-entry of sediments brought into suspension
    - Release of toxic substances or negative impact of particulate matter on pelagic organisms, if residual material should be returned in the water column.

This should be completely avoided, and, if not avoidable, it should only be released directly at ground level.

- Regarding the **crust deposits** of seamounts, the sedimentary cover is relatively low due to the relatively frequent high flow rates. Owing to this fact, the mining of manganese crusts would cause potentially lower sediment clouds. The mining area would be significantly smaller compared to the mining of manganese nodules.
- The special role of deep-sea mountains as potential hotspots of biodiversity with endemic species and an important breeding and refuge area for many fish species and other marine life must be emphasized.
- The problem of deep-sea fishing with its increasing access to deeper water should be considered as an important environmental stress factor for the ecosystems of seamounts. Therefore, the consequences of a future manganese crust mining must always be considered in context with other possible uses or anthropogenic influences.
- At active **sulfidic hydrothermal vent fields**, the number of individuals is extremely high, and still little is known about the genetic diversity and endemism. Due to these uncertainties and facts, it must be ensured that active hydrothermal fields are largely or even completely excluded from mining.
- Sulphide deposits that have been inactive for a long time, differ not significantly in their benthic composition from the neighbouring environment. Furthermore, the spatial extent of sulphide deposits is of the order of several hundred meters and therefore the field length is very small. For this reason, we may expect a significantly lower impact and a high re-colonization capability of the local biological community.
- With regard to the production and processing of **metalliferous muds** in the Red Sea, the following environmental impacts should be considered:
  - Severe impact on the benthos communities of the trough caused by the very fine-grained suspended matter within the tailings plume and toxic effects of flotation chemicals
  - Toxic effects of remaining heavy metals (zinc, copper, arsenic, etc.) within the tailings
  - Changes in the nutrient content of the deep water.

- In case the tailing plume does not remain beneath 1,000 m water depth, the intake of sediment particles and toxic pollutants by the benthos and zooplankton - and thus adverse effects on the human food chain - cannot be excluded.

The main focus of **Chapter 7** is the representation of the principal legal conventions and agreements that have a direct reference to deep seabed mining.

- The main legal basis is the UN Convention on the Law of 1982 and the supplementary Implementation Agreement, which came together into force in 1994 as a "constitution of the oceans". For deep-sea mining in international waters, which is outside the limits of national jurisdiction, such as the 200 Sm wide EEZ or so-called outer continental shelf (up to 350 Sm), the ISA in Jamaica regulates the licensing, environmental protection and monitoring. For this purpose, the ISA shall adopt a comprehensive secondary law, which consists among other things of mining codes, environmental management plans and protected areas, which are described in this study.

- For deep-sea mining in international waters special particularities are valid, arising from the fact that the deep water resources are seen as "common heritage of mankind". Distributive justice, environmental impact, liability of the company and his home state and judicial litigation are particularly pronounced.
- The current application and licensing procedures (mining codes) and accompanying detailed guidance for applicants include the admission requirements such as reliability, environmental studies, environmental impact assessments, monitoring obligations, reference zones, contingency planning, inspections, etc. This set of rules is updated continuously. Three mining codes regulate to date the exploration of the three ore types. The first code for the exploitation of manganese nodules is now on the agenda.
- In 2012, the ISA summarized the entire environmental protection regime with a large-scale environmental management plan for the 5 million km^2 CCZ and including nine protected areas around the license areas.
- While the environmental protection regime in the jurisdiction of the ISA shows clear outlines, there remains the problem of how to encourage coastal states to establish a ("consistent") jurisdiction to their EEZ and continental shelf zones comparable as possible, because seabed mining is expected also in these huge maritime zones. The relevant environmental protection Chapter XII of UNCLOS does indeed also apply to coastal states, but not the detailed secondary legislation of the ISA with its standards and safeguards. This problem is discussed in workshops and in the literature. There are initial road maps, but still no mandatory law.
- At the end of this chapter a brief look is taken at the evidence arising from the European and national German law.

In the final **Chapter 8,** in addition to the summary, a number of specific recommendations for action are given for the 4 studied work packages: technologies, environmental studies, environmental impacts and legal convention.