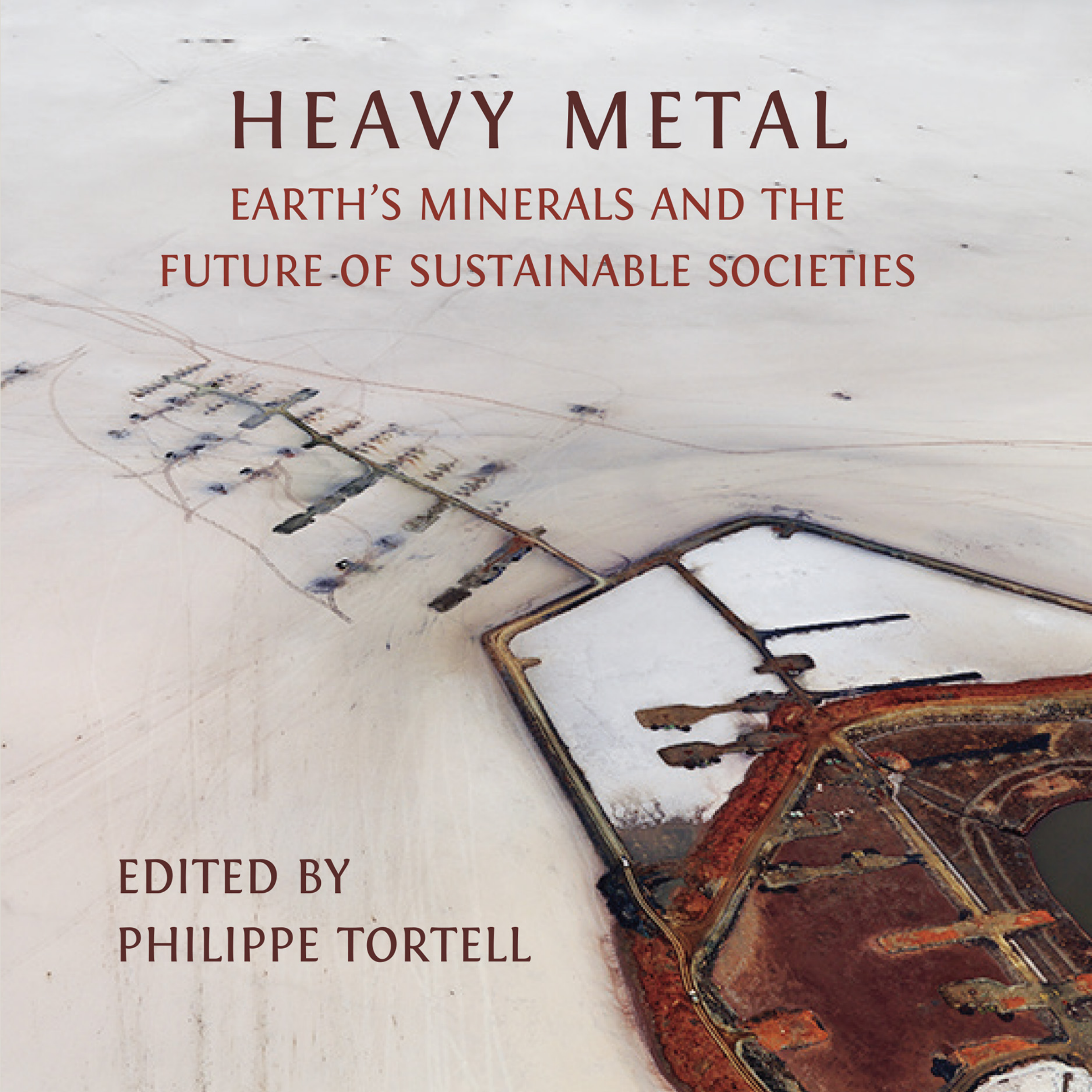
HEAVY METAL

EARTH'S MINERALS AND THE FUTURE OF SUSTAINABLE SOCIETIES



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Ocean Minerals

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In Jules Verne's 1870 novel *20,000 Leagues Under the Sea*, the ocean explorer, Captain Nemo, describes vast treasures in deep-sea mines of zinc, iron, silver and gold. At the time, Verne could only imagine what lay beneath the great ocean depths. That began to change, however, just two years later, when the HMS *Challenger* set sail from England on a nearly three-year scientific expedition to map the global oceans. The ship's crew brought back thousands of samples, describing many new species and providing the first glimpses of the ocean floor. The expedition report described golf-ball sized sedimentary 'nodules', rich in manganese oxides and other associated metals. This was the first tangible evidence of significant metal deposits in the ocean. Yet, it remained unclear what quantity of minerals might be supplied from the deep sea, or how they might be extracted in a commercially viable manner.

About half a century later, as Germany struggled to pay its massive World War I reparations, the chemist Fritz Haber devised a plan to concentrate gold from seawater. Haber, who had recently won the Nobel Prize in Chemistry for his method of ammonium production, believed that large quantities of gold could be extracted from ocean waters using electrochemical methods. He was not the first to suggest this possibility. In the late 1880s, two men from Edgartown, Massachusetts, Prescott Jernegan and Charles Fisher, published a pamphlet, entitled *Gold from Sea Water at a Profit: The Facts*, in which

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they described a revolutionary new method to extract ocean gold using a copper plate and a thin layer of mercury. After duping more than a few investors, the two men were exposed as frauds, and the idea of ocean gold mining faded from public attention until Haber took up the cause. Based on Haber's recommendation, the Germans undertook a survey of seawater gold concentrations on the 1925 ocean *Meteor* expedition. Initial results seemed to support Haber's assertion, but he eventually discovered an error in his calculations, realizing that he had overestimated seawater gold concentrations by a factor of one thousand.

Modern interest in deep-sea mining was re-ignited a century after the first discovery of manganese nodules during the *Challenger* expedition. By the mid-1970s, undersea exploration technology and marine chemistry had advanced sufficiently to allow accurate determination of potential deep-ocean metal sources. In 1974, ocean floor manganese nodules were first test mined in the Pacific Ocean, while deep-sea hydrothermal vents—metal-rich geothermal fluids rising to the seafloor—were discovered in 1977. Back then, deep-sea mining was largely undertaken as a proof of concept, driven more by scientific curiosity than economic imperatives. At the time, atmospheric carbon dioxide (CO_2) was 25% lower than present-day levels, the world's population was about half the current value, and global warming was not embedded in the public consciousness. And in the pre-digital age, humanity's requirement for mineral resources was significantly smaller than it is today.

Fast forward about fifty years, and things look rather different. As the world now has over eight billion citizens who hope to be wealthier and live longer than their predecessors, it is anticipated that we will require large quantities of minerals to supply our renewable energy needs if the worst impacts of climate change are to be mitigated. Is it now time to rip a page from our past and reconsider exploiting the ocean's potentially vast mineral wealth?

The question of when and how ocean mining might be developed is both a scientific and philosophical one. With current technology, it may now be possible to mine almost every major deep-sea mineral deposit.[1] And while the environmental cost and legal regimes are currently hotly debated, this has not stopped the expansion of potential ocean mining activities in recent years. Indeed, the United Nations International Seabed Authority (ISA),[2] which regulates mining in international waters, has already issued more than twenty ocean mining licenses, and approved mining exploration over more than one million square kilometers, an area twice the size of Texas. In the face of this rapid expansion, there are fundamental questions remaining to be answered.

While there are many types of marine mineral deposits, including specialty sands, phosphates, diamonds, gravel, shells, hydrates and silts, three types of deposits have been the primary focus for ocean mining activities: manganese nodules, polymetallic sulfides (black smokers) and manganese crusts. The nodules are found on the deep seafloor in depths ranging from about four to six kilometers below the surface, while the crusts are somewhat shallower, located on the top and sides of seamounts. The sulfides are found on hydrothermal ridges at tectonic plate boundaries and other geologically active seafloor spreading areas, such as the mid-Atlantic ridges first identified during the *Challenger* expedition.

The idea of sustainable ocean mining is a controversial one. On a global scale, the ocean is generating minerals at a greater rate than we would most likely mine them. But this is a moot point, as any realistic mining operation would be concentrated in a relatively small region, where the rate of removal would vastly exceed the rate of generation. In the case of manganese nodules, for example, the mineral deposits grow through a continual process of hydrothermal input and precipitation on the seafloor. These are slow processes, with nodule growth rates of only a few millimeters per million years. A golf ball-size nodule lying on the seafloor and containing rare-earth metals could be tens of millions of years old. In practice, ocean minerals should be considered as a non-renewable resource.

From a purely economic perspective, the mining of ocean manganese nodules offers the best hope for development in the next decade.[3] This mining is essentially a gathering operation, not unlike picking fruit. The nodules simply sit on the seabed waiting to be harvested; there is no tunneling, blasting or digging—simply collecting. A machine, not unlike a golf ball collector at a country club, picks up nodules from the bottom and conveys them to a lift system for transport to the surface. To a first approximation, the technology seems mundane. The technical complication comes from the fact that the nodules can be found in water depths exceeding six kilometers, and the lifting of mined ocean minerals to the surface is not a trivial endeavor. The lift can occur through buckets, or using pipes that operate like a home vacuum cleaner, using water rather than air to generate the necessary suction. Alternatively, the nodules can be mixed with seawater to create a slurry, which is pushed to the surface with high-pressure mining pumps, analogous to those used in many land-based mining operations. The amount of material in question is enormous. A single mining vessel would release between 2–3.5 million cubic feet of effluent from the slurry every day, a volume equivalent to about three thousand twenty-foot shipping containers. This process could run continuously for thirty years at one mining location.

Despite the obvious challenges of mining manganese nodules, they have the advantage of being relatively widespread across the seabed, covering about 15% of the ocean floor (approximately 10% of the planet's surface). This means that ecologically sensitive nodule areas could be set aside, and that nodule mining operations could be widely spaced from each other, in contrast to terrestrial mining activities, which must be highly concentrated in the specific area of an ore deposit.[4] By comparison with manganese nodules, the two other main ocean deposits, polymetallic sulfides and manganese crusts, are much more restricted geographically, and they must be excavated from the ocean sediment, making their extraction significantly more expensive and complex. As a result, it is likely that ocean-mining activities will focus on manganese nodules for the foreseeable future.

Although technologically feasible, there remain major problems in opening up the deep sea for mining. Historically, the deep ocean was considered remote and largely devoid of life. It was also believed to have an inexhaustible capacity to absorb human pollution. We now know, however, that deep-water ecosystems are complex, diverse and fragile. Beyond their huge potential mineral wealth, these ecosystems may also hold highly valuable biological resources. For example, scientists have discovered thousand-year-old deep-sea corals, and microbes that can treat cancer and infectious diseases, and convert sulfur and methane into energy. These organisms offer a rare glimpse into the origins of life on earth and could provide biologically inspired solutions to a range of critical problems facing humanity.[5]

There are several significant ecological impacts associated with deep ocean mining. First, and perhaps most obviously, the heavy machinery used to collect manganese nodules moves across the seabed like a steam roller destroying all non-motile organisms in its path. There are also significant indirect effects, as the sediment is churned up into a fine-grained plume, blanketing bottom-dwelling organisms within a few hundred meters of the collector. Experiments revisiting test ocean-mining sites have shown only marginal ecological recovery after thirty years, indicating that the impacts on the ocean floor are profound and long-lasting.[6]

The ocean water column above the sediments is also subject to significant mining-related disturbances. On average, the ocean depth is around four thousand meters, more than twice as deep as the deepest point of the Grand Canyon. This vast expanse includes more than 90% of the planet's life-sustaining habitats, and is home to an immense array of creatures, from microbes and worms to jellies and giant squid. When a nodule is vacuumed from the seafloor and pumped to a surface ship, the minerals are separated from a so-called 'dewatering plume', a muddy, metal-enriched fluid that is pumped back into the sea. Heavier particles in this plume sink to the seafloor, passing through thousands of meters of intervening water before settling. An unknown amount of material including heavy metals is dissolved in this plume, and this material will be carried indefinitely by ocean currents. Finer materials within the plume can drift for months, carried over great distances by the ocean currents. This drifting material could have a severe impact on open-water ecosystems thousands of kilometers away from the site of the mining operations.

Deep-sea organisms have adaptations that make them especially susceptible to mining impacts. Many of these organisms feed on a meager diet of small particles that sink down from the surface, and they are extremely sensitive to excessive particle loads, which can clog their feeding systems. In addition, more than half of deep-sea animals generate their own light through bioluminescence to find mates and prey and as camouflage to avoid predators. This system requires clear water to be effective. The challenge of navigating through plume-clouded waters, along with additional gill clogging and feeding disruptions would compound other ongoing stresses experienced by deep-sea organisms, including ocean acidification and deoxygenation. It is reasonable to believe that further disturbance associated with mining activities could push some deep-sea organisms over the edge to extinction. Cumulative ecological effects may be much larger than any site or time-specific problem. What is most worrisome is that the deep-sea environment is so poorly known, we have few baselines against which to compare potential future changes.

Beyond the potentially significant ecological impacts of deep-ocean mining, there are also social and geopolitical realities to contend with. The companies and governing agencies that stand to profit most from mining activities are based in the United States, Canada, Australia, Europe and Asia. In most cases, they are geographically, politically and economically removed from the small island nations that will bear the greatest environmental impact of mining. The governments of these small island states may welcome mining for economic gain as a partial replacement for lost tourist revenue. But if history is repeated, it will be Indigenous peoples and local communities on these islands who may first bear any problems coming from this new industry, with few long-term benefits.

The question appears to be not whether there will be deep-ocean mining, but how this activity should be regulated. In this respect, the ISA is releasing seafloor mining regulations, and seabed developers are waiting for these regulations before mining permits can be issued. Over the last ten years, numerous working groups have had input into the development of a deep-sea mining regulatory system, and there has been progress toward consensus. But the final regulations, initially supposed to be released in July 2023, have just been delayed until 2025. This delay is partly attributable to a desire to protect land-based mining, particularly in developing countries, and by calls for greater deep-sea research to support better environmental protection standards. It is unclear how soon mining on the international seabed might start after regulations are finalized.

The regulatory vacuum surrounding international seabed mining has created an opening for two countries, Norway, and the Cook Islands in the South Pacific, to use existing national legislation to propose mining within their two-hundred-mile exclusive economic zones (EEZs). The Cook Islands, in particular, are moving forward in the development of their own mining industry under the oversight of a local minerals authority, with the goal of exploiting more than ten billion metric tons of manganese nodules that are estimated to lie across an area of about 750,000 km^2 of the country's EEZ. There are currently three companies actively exploring new mining exploration licenses and conducting tests around the Cook Islands, including the deployment of seafloor mining pumps and pipe handling and riser equipment. Proponents of this work argue that it will provide a significant opportunity for long-term sustainable development, with suitable attention to environmental protection. Sensitive areas have been set aside as protected, including fifty-mile buffer zones around sensitive coral reefs. However, such measures will likely be only partially successful, as sediment plumes may travel hundreds of kilometers, and will not respect the neat boundaries defined by a permit.

As exploratory deep-sea mining activities move ahead, more discussions about potential environmental impacts will continue, and could help inform ISA's regulations and decision process. In the best-case scenario, the regulations could address both environmental and economic interests, for example by setting aside large undisturbed areas to protect fragile ecosystems and as a reference against which to gauge mining impacts. As an alternative, mining companies could be required to shoulder the additional expense of depositing their effluent as close to the original seafloor disturbance as possible. Doing so will minimize harmful effects of sinking and drifting plumes on the water column and ocean sediments. At the same time, new innovations in ocean mining technology could help offset some of the worst environmental impacts. For example, modifications to lift systems, using buckets instead of suctioning, could solve much of the surface plume problem. Much can be done, assuming that mitigations are incorporated in equipment design before it is finalized and deployed at a wide scale over the coming decade. Over the next few years, there is still time for considerable improvement.

The future development of deep-sea mining operations will be shaped by a complex interplay of many competing factors and motivations. The demand for cobalt and other green industry metals will loom large, as will the desire to prevent the industrialization of the ocean. While the ISA will certainly be a key regulator in the future, other factors will also likely come into play, such as the growth of the environmental movement in the Pacific, geopolitical realities (such as increasing Chinese control of critical metal markets) and the rapid expansion of new mining technologies. This Gordian Knot of competing issues will be difficult to unravel, but we can only hope that strong science and good governance prevail in the future of ocean mining.

Endnotes

1 Rahul Sharma, ed., *Deep-Sea Mining: Resource Potential, Technical and Environmental Considerations* (Cham: Springer, 2017), https://doi.org/10.1007/978-3-319-52557-0

2 *International Seabed Authority*, https://www.isa.org.jm/ (website includes publications and further resources).

3 Sebastian Volkmann, Thomas Kuhn and Felix Lehman, 'A Comprehensive Approach for a Techno-Economic Assessment of Nodule Mining in the Deep Sea', *Miner Econ* 31 (2018): 319–36, https://doi.org/10.1007/S13563-018-0143-1

4 See also 'Where We Find Metals' by Shaun Barker in this volume.

5 Jessica Volz, Laura Haffert, Matthias Haeckel, Andrea Koschinsky and Sabine Kasten, 'Impact of Small-Scale Disturbances on Geochemical Conditions, Biogeochemical Processes and Element Fluxes in Surface Sediments of the Eastern Clarion–Clipperton Zone, Pacific Ocean', *Biogeosciences* 17.4 (2020): 1113–31, https://doi.org/10.5194/bg-17-1113-2020

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