Seafloor Massive Sulfides Mining

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On the lightless bottom of the Western Pacific Ocean, tiny volcanoes jet extraordinarily hot fluids into icy water. These "smokers," as geologists coined them, emerge from hydrothermal vents, and are either "white" or "black" depending on the chemicals they emit. Some pour rumbling, acrobatic clouds of metals such as copper, zinc, and gold, combined with sulfur, into the heavy seawater. Fine particles of metal sulfides then precipitate, or fall out, forming "chimneys" of intricate geometries on the seabed. These can be three meters tall and evoke images of stalagmites on a cavern floor.

Whole ecosystems exist in and around fields of these chimneys of seafloor massive sulfides (SMS), including extremophiles—microorganisms evolved to thrive in harsh environments by generating energy from hydrogen sulfide rather than photosynthesizing glucose from carbon and sunlight like most living things. These are the progenitors of astrobiology, sparking speculation that life could have begun near these hydrothermal vents as hot inorganic molecules blended in just the right way. Such peculiar life might exist on Mars and other planets with otherwise-hostile atmospheres.

But this article concerns a more down-to-earth premise arising from these submarine SMS deposits: that one day your child's mobile phone (or perhaps your grandchild's cerebral implant) could contain circuit boards engineered from elements vacuumed from the bottom of the sea.

The saltshaker on the table, your mountain bike, your sister's fleece puffy coat, cars, trains, buses, and aircraft, the building whose roof is above you, the computer on which I write this: most fundamental objects are tools designed to facilitate human life. What is obvious but easily overlooked is that every tangible object we have is made from some resource on this planet. Long before recorded history, Homo sapiens and their ancestors began yanking materials from the Earth and putting them to use.
As you read this article in 2019 and beyond, the most visionary human minds seem capable of almost anything. Juxtapose that against another self-evident fact propounded for decades by keen observers in science, engineering, energy, manufacturing, and environmental circles, and now abundantly plain to anyone paying attention: resources are severely limited. We are especially challenged in our ability to find them, engineer their extraction, and market them economically, all without destroying the planet. This is especially true, of course, for nonrenewables like oil and gas, coal, and hard-rock minerals. And it is why doing what once was considered the stuff of science fiction—like landing on asteroids to assess their rare metals or mining the moon—is now soberly debated. *See, e.g.*, Scot W. Anderson et al., *The Development of Natural Resources in Outer Space,* 37 J. Energy & Nat. Resources L. 227–58 (2019).

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Although space was the "new frontier" of the last century, it has now in many ways been eclipsed by the deep sea, an uncultivated wilderness full of promise. The ocean remains infused with mystery, even as the 300 quintillion gallons of seawater are our constant companion, ubiquitous, manifest, more often than not taken for granted. In this present age of human population growth that drives an unparalleled demand for resources, it is hardly surprising that an entrepreneurial urge is upon us: to take a gigantic deep breath and dive to the ocean floor in search of the stuff we need to make new gadgets. In this article we discuss how that impulse created SMS mining, and how governments, investors, and the legal community have reacted.

A Brief History of Undersea Mineral Exploration

Although deep-sea mining depends on cutting-edge technologies honed to the demands of a largely unexplored world, it is not a new endeavor. For one thing, extracting some kinds of submarine resources is commonplace: offshore drilling for oil and gas became an industry standard in the 1900s, and now fossil-fuel companies regularly withdraw petroleum from ocean depths as great as 2,700 meters. World Ocean Review, *Oil and Gas from the Sea* (2014), https://worldoceanreview.com/en/wor-3/oil-and-gas/. Such production is one-third of all that occurs worldwide. *Id.* Underwater resource extraction is not limited to oil and gas. De Beers and other companies take diamonds from the seabed off the coast of Namibia, for example. And minerals like cobalt are targets in the Clarion-Clipperton Zone, or CCZ, located in the Pacific Ocean east of Hawaii.

The concept of deep-sea, hard-rock mineral extraction arose in the 1870s, around the time when the HMS Challenger, a British research vessel, embarked on a scientific enterprise to circumnavigate the globe and study the ocean, including locating mineral deposits. The Economist, *Race to the Bottom* (Mar. 8, 2018), www.economist.com/technology-quarterly/2018/03/19/race-to-the-bottom. SMS deposits likewise are not recent objects of exploration. Although SMS are found in oceanic crust, this same mix of compounds also exists on land, where the ancient Greeks mined it, followed by many others. John W. Jamieson et al., *Seafloor Massive Sulfide Resources* 1 (2017). In the 1960s, mining engineers and resource companies began to visualize exploiting marine SMS deposits as a viable commercial pursuit. Now, profitable deep-sea SMS extraction is beginning to look more like reality as technology opens the hatch to opportunities miles below the ocean's surface.

Discovery of Seafloor Massive Sulfide Deposit Fields

SMS deposits occur where one tectonic plate moves under another, in "subduction zones," and where tectonic plates pull away from each other along "divergents." Subduction-zone SMS deposits draw attention from prospectors like Nautilus Minerals Inc. (Nautilus), and they commonly occur in areas of volcanic activity associated with the Western Pacific portion of the Ring of Fire, from the southwestern Pacific to Indonesia and north to Japan. Oceanographers discovered SMS deposits in the late 1970s near the Galapagos Islands, and found the first active black smoker along the East Pacific Rise just beyond the mouth of the Gulf of California. In 2005, the first commercial SMS survey occurred in the Western Pacific near Papua New Guinea in the Manus Basin. Raymond Binns, *Seafloor Massive Sulfide (SMS) Potential within and beyond National Jurisdiction in the Asia-Pacific Region* 4 (2011). For a thought-provoking narrative on the discovery and impacts of SMS mining, *see* Simon Winchester's illuminating book, *Pacific* (2015).

Engineering Challenges Presented by Deep-Sea Mineral Extraction

Extracting minerals from SMS deposits presents a bevy of technological challenges. SMS deposits are often found 2,000 meters below the surface of the ocean, in heated seawater that approaches 400 degrees Celsius (but ironically is accessible only by traveling through frigid ocean), in the pitch dark, under pressures reaching a bone-crushing 3,000 pounds per square inch. Kristi Birney et al., *Potential Deep-Sea Mining of Seafloor Massive Sulfides: A Case Study in Papua New Guinea* v, vi, 22–30 (2006). All the tools required to drill for samples, extract sediments, separate ore, transport it to waiting ships, and process the SMS have to be customized to overcome these obstacles, either through new developments or by adapting equipment from oil and gas production or other industries.

Fortunately, mining companies generally excel at engineering economically beneficial solutions to complex problems, and the same clarion call for human ingenuity sounds at over 300 fathoms below the surface. Glencore's Onaping Depth Mine in Ontario, Canada (albeit on land), exemplifies the steady advance of mineral-extraction engineering. The Onaping Depth Mine accesses an ultra-deep nickel-copper-platinum-group-elements deposit 2,500 meters below the Sudbury Basin. The find is highly valuable, but its depth makes ventilating the site prohibitive. Rather than walk away, Glencore is creating an electric-vehicles fleet for the mine. Admittedly, upfront costs will be higher than traditional diesel. But Glencore expects that its electric fleet will cut expenditures on ventilation and refrigeration by half. International Institute for Sustainable Development, *Innovation in Mining: Report to the 2018 International Mines Ministers Summit* (Mar. 2018), www.iisd.org/library/innovation-mining-report-2018-international-mines-ministers-summit.

Similar to solving for the extremes of the Onaping Depth Mine, undersea mining requires innovative solutions to overcome novel, complicated problems. Nautilus, for instance, has been working on an integrated system for seafloor extraction and production. It involves using several specialized vehicles to prepare the rugged seafloor, cut and gather the SMS deposits, and then collect the broken material in seawater slurry that would be pumped to a ship uniquely designed for dewatering, storage, and shipment to shore. Nautilus Minerals, Technology Overview, www.nautilusminerals.com/irm/content/technology-overview.aspx?RID=329 (last visited July 17, 2019).

Jurisdictional Stumbling Blocks in the Race to the Bottom of the Ocean

The physics of deep-water mining of SMS present challenges, but the law also poses significant hurdles. Not surprisingly, companies bent on excavating the seafloor also must navigate jurisdictional problems. The United Nations Convention on the Law of the Sea (UNCLOS), which became effective in 1994 with its ratification by 60 nations, divides the ocean into legal zones. The "territorial sea," extending up to 12 nautical miles from coastlines, is the sovereign territory of each coastal nation. UNCLOS, Dec. 10, 1982, 1833 U.N.T.S. 397, art. 2–3. The "exclusive economic zone" (EEZ) extends beyond the territorial sea up to 200 nautical miles from the coastline and gives coastal states sovereign rights and jurisdiction for exploring, exploiting, managing, and conserving natural resources here, in waters of what geologists call the continental shelf. *Id.* at art. 55–57. Coastal states "have the exclusive right to authorize and regulate drilling on the continental shelf for all purposes." *Id.* at art. 81. Papua New Guinea, Sudan, and Saudi Arabia have already issued permits and licenses to exploit minerals in the seabed below their EEZs. Kathryn A. Miller et al., *An Overview of Seabed Mining Including the Current State of Development, Environmental Impacts, and Knowledge Gaps* (Jan. 10, 2018), at 7. But emerging regulatory frameworks for deep-sea mining near certain states, along with pushback from local communities and nongovernmental organizations (NGOs) raising environmental and other concerns, have disrupted some EEZ mining plans.

Beyond the EEZs extend the seemingly infinite high seas and, under their crushing weight, the seabed known in UNCLOS as "the Area," "the common heritage of mankind" over which no state may claim sovereignty. *Id.* at art. 136–37. The International Seabed Authority (ISA), an autonomous international organization established by UNCLOS, governs resources development in the Area. The ISA considers applications to mine deep-sea resources located within the Area, and it has approved 29 15-year contracts for exploration of polymetallic nodules, polymetallic sulfides, and cobalt-rich ferromanganese crusts. International Seabed Authority, Deep Seabed Minerals Contractors, www.isa.org.jm/deep-seabed-minerals-contractors (last visited July 17, 2019). But states that have not ratified UNCLOS, such as the United States, may not apply to the ISA for deep-sea mining permits. Such states thus find themselves at a comparative disadvantage in what will inevitably become a competition to explore for and extract minerals from the seafloor.

Environmental Considerations

Although mining SMS deposits will occur only where the metal-sulfide chimneys are "dead"—i.e., otherwise finished producing SMS and often collapsed in heaps on the seafloor—mining nonetheless will take place in the proximity of active vents and their dynamic living systems, creating obvious environmental implications. Birney et al., *supra* at v, 23. Recall the ubiquitous front-page news of the Deepwater Horizon oil spill that began with an explosion on April 20, 2010. Equipment malfunctions, high pressure, deep water, volatile heavy machinery, and human error all led to the catastrophe that spread quickly through the churning seas and coated the Gulf Coast with oil, leaving lasting physical and biological impacts, and leading to years of costly litigation resulting in some of the largest damages settlements in history. Concerns here are not dissimilar. For example, mining SMS could lead to silt and sediment plumes (some toxic), and destruction of delicate (often rare) marine ecosystems. Interference with light availability (natural or anthropogenic), increased noise, changes in temperature, and other pollution, along with damage to the seafloor itself, all would play a role. Compounding these issues are numerous problems already impacting the ocean: climate change, acidification, overfishing, and large-scale pollution by plastics and other contaminants. Perhaps of greater concern is what makes the ocean a mysterious frontier in the first place: all that we do not know and could harm as a result. Current assessments of potential environmental impacts cannot account for our general ignorance of the deep sea as humankind continues to discover flora and fauna—85 percent of which are considered endemic—living near hydrothermal vents at a rate of two new species each month. Miller et al., *supra* at 11–18.

Other Controversies

Environmental issues are not the only controversies. Competing interests from other industries, along with fights over resource availability and access, also present substantial challenges. In New Zealand, for example, Trans-Tasman Resources' (TTR) plan to extract seabed iron sands has been suspended following legal challenges from both local and international entities. In 2017, the New Zealand Environmental Protection Authority approved TTR's proposal to mine in New Zealand's EEZ. *Trans-Tasman Resources Appeals High Court Decision on Seabed Mining*, New Zealand Herald (Sept. 24, 2018), www.nzherald.co.nz/environment/news/article.cfm?c_id=39&objectid=12130799. Several groups, including international NGOs like Greenpeace, local environmental groups such as Kiwis Against Seabed Mining, and commercial fishing interests all challenged that decision. *Taranaki Seabed Iron Sand Mining Decision Reversed*, Stuff (Apr. 19, 2018), www.stuff.co.nz/business/103221820/taranaki-seabed-iron-sand-mining-decision-reserved. An increasing number of NGOs are focused exclusively on seabed mining. The Deep Sea Mining Campaign (DSMC) (www.deepseaminingoutofourdepth.org/), for instance—an association of NGOs and citizens from the Pacific Islands, Australia, Canada, and the United States—combines grassroots community development and science-based advocacy to fight it. DSMC's active opposition against commercial extraction of SMS off the Papua New Guinea coast demonstrates just how potent and focused legal resistance can be.

Nautilus Minerals Saga

Such resistance, along with a host of other obstructions, has plagued Nautilus Minerals. Its venture into SMS mining is a cautionary tale for deep-sea miners of all kinds, but especially for those seeking to explore for and extract SMS under license in a state's territorial waters.

Nautilus, a Canadian underwater, mineral-exploration company, holds itself out as the first commercial operation to consider seriously mining seafloor SMS. Nautilus tried to adapt offshore oil-and-gas technologies to do so. Although the company initially focused on SMS deposits near Papua New Guinea and Tonga in the Southwest Pacific, it expanded to explore the CCZ in Central Pacific international waters, where researchers discovered substantial deposits of polymetallic manganese nodules. Nautilus Minerals, CCZ, www.nautilusminerals.com/irm/content/ccz.aspx?RID=261 (last visited July 17, 2019).

The precursors to the Nautilus story began over three decades ago, when in 1985 researchers discovered SMS deposits in Papua New Guinea's territorial waters. Twelve years later, the nation granted Nautilus the country's first commercial Exploration License tenement for these SMS deposits. Nautilus Minerals, PNG, www.nautilusminerals.com/irm/content/png.aspx?RID=258 (last visited July 17, 2019). At first, Nautilus thrived due to financial support from key mining-industry players. In November 2006, Anglo American PLC invested $25 million in Nautilus. *Anglo Investing US $25 Million in Nautilus for 11.5% Stake*, Northern Miner (Nov. 20, 2006). Placer Dome, a subsidiary of Barrick Gold, also invested heavily in Nautilus, putting $12.2 million toward earning a 40 percent joint-venture interest, which it later converted into a 9.59 percent equity stake in the company. *Id.* Buoyed by these investments, Nautilus launched large-scale commercial explorations for high-grade SMS deposits in Papua New Guinea's EEZ. Nautilus Minerals, *Exploration 2007–2013*, at 7. In 2009, Papua New Guinea's Department of Environment and Conservation granted a final environmental permit for a 25-year term for Nautilus's Solwara 1 project. Press Release, Nautilus Minerals Inc., Solwara 1 Environmental Permit Granted (Jan. 5, 2010). Just over a year later, Papua New Guinea signed an investment agreement with Nautilus under which it took up to a 30 percent stake in that project. Press Release, Nautilus Minerals Inc., PNG Government Confirms Investment in Solwara 1 (Mar. 29, 2011).

But the tide quickly turned. In June 2012, Nautilus reported a dispute with the Papua New Guinea government over the investment agreement, asserting that the country had exercised its option to acquire a 30 percent interest in the project but was claiming Nautilus had not satisfied certain conditions precedent. Press Release, Nautilus Minerals Inc., Nautilus Dispute with the State of PNG (June 1, 2012). The company's stock price crashed and Nautilus was forced to delay the project. An arbitrator ultimately ruled for Nautilus, finding that Papua New Guinea breached the option agreement by failing to complete the purchase of its interest. Nautilus received $113 million released from escrow in December 2014. Peter Koven, *Nautilus Minerals Inc Says It's Poised to Begin Undersea Mining Following Dispute Settlement*, Financial Post (June 25, 2014).

But the company never fully recovered from the setback. In 2017, nearby community members, represented by the nonprofit environmental and human rights organization Centre for Environmental Law and Community Rights Inc., complained to the government of Papua New Guinea about environmental concerns related to Nautilus's project, seeking permitting documents, environmental studies, and agreements between the government and Nautilus. In May 2018, Anglo American divested from Nautilus, leaving the company with few key investors. By December 2018, Nautilus appeared to have lost the nearly completed custom-built ship it had chartered when MAC Goliath, which was overseeing the ship's construction, defaulted on a payment and Nautilus was unable to step in to make up for it. The shipyard then sold the ship to a subsidiary of MDL Energy, an Indian shipping-investment company. Nautilus likely cannot replace the ship, designed specifically to extract SMS deposits in the Southwest Pacific. Nautilus's future in SMS exploration and extraction is uncertain. On February 21, 2019, the company filed for and was granted creditor protection under the Canadian Companies' Creditors Arrangement Act. Subsequently, on April 3, 2019, Nautilus was delisted from the Toronto Stock Exchange. The company reports that it remains in control of its business, but it is exploring recapitalization options, including the sale of its SMS business unit. *Nautilus Delisted from Toronto Exchange*, Papua New Guinea Post-Courier (Apr. 2, 2019), https://postcourier.com.pg/nautilus-delisted-toronto-exchange/. Deep-sea mining companies may find themselves caught in a web of unclear regulations and corporate uncertainty, trying to find a foothold in a shifting legal and political landscape. Nautilus is perhaps an extreme example of this, but one that companies should not overlook as they consider their options for SMS exploration and development.

Underwater Hard-Rock Mineral Mining in the Future

The need for metals will only increase as more people inhabit the planet, living new-tech lives. Just one of the elements entrained in SMS—copper—is used to generate and transmit power, make industrial machinery, and manufacture vehicles of all kinds. Heating, cooling, telecommunications, and car parts depend on copper, every ounce of which we have taken from terrestrial mines. Mining on land will continue, of course, but likely will experience tougher regulation, more resistance in various forms (whether due to environmental consequences, land-use conflicts, or political controversies), and market variations that will significantly affect economic incentives to continue operating current mines or open new ones.

Although many of these factors are associated with seafloor mining as well, they have different connotations underwater. Because industrial-scale seafloor mining has not yet been attempted, and because the scientific, economic, and legal challenges facing this nascent industry are just emerging, it is difficult to predict the future of the business. One thing seems certain, however: when demand for the metals that are also found on the seafloor exceeds the ability of land-based mining interests to supply those elements, the major mining companies will be swift to follow the entrepreneurial pluck of their upstart and intrepid deep-ocean counterparts.

New efforts at deep-sea mining will take place against a backdrop of laws, regulations, guidelines, and even general "best practices" that are fledgling, moving targets. Even the terms vary—what may be a lease or a permit in one jurisdiction could be a contract or a charter in another. Indeed, the legal infrastructure is as turbid and unstable as the windswept high seas.

What seems clear, however, is that the International Seabed Authority is critical to the future of deep-sea SMS extraction. Exploration and exploitation in the Area can only happen by contract with the ISA, and the draft rules addressing exploration for deep-sea deposits pursuant to these contracts were first promulgated in 2007. The draft rules mimic, at least in part, some of the United States' (and other countries') environmental laws and regulations. For example, they require an environmental impact assessment to precede mining activity. Miller et al., *supra* at 7. Finalizing these rules has stalled, however. This is due to a lacuna of scientific research on deep-sea marine habitats, combined with quickly advancing deep-sea mining technologies. A draft "Regulations on Exploitation of Mineral Resources in the Area" was published on March 25, 2019. *ISA Release Draft Proposal of Exploitation Regulations for Deep Sea Mining,* ECO Magazine, www.ecomagazine.com/news/regulation/isa-release-draft-proposal-of-exploitation-regulations-for-deep-sea-mining. But shortly thereafter, the ISA announced in a "Proposal of Draft Exploitation Regulations Released by ISA Legal and Technical Commission" that the draft rules would be reviewed again in July 2019.

Numerous nonprofits and NGOs have voiced strong opinions on—and objections to—the ISA's draft rules, including the DSMC, the International Union for Conservation of Nature, the International Marine Minerals Society, and The Ocean Foundation. Although NGOs such as the DSMC radically oppose SMS mining, others take a more nuanced approach, asking for more transparency into the ISA's regulation discussions and for an ISA environmental committee.

Regional nonbinding guidelines and best practices also contribute to the global governance of deep-sea mining. These include the MIN-Guide initiative for the European Union's member states, and the Deep Sea Minerals Projects for the larger Pacific Ocean region (which promulgated in 2012 a Regional Legislative and Regulatory Framework). Miller et al., *supra* at 7–9. Deep-sea SMS extraction within the Area is truly the new legal Wild West of the mining world, and leaves much to be resolved.

Looking Forward

Those who are willing to tackle seafloor mining can be de facto first movers in this embryonic market, and the draw of reserving the most lucrative mineral deposits and securing valuable patents will continue to lure investors willing to accept the physical, environmental, economic, and legal risks. Undoubtedly, seafloor mining is not obviously better, easier, or more attractive than mining on land. For example, the cost of removing tons of overburden to access ores on land is met by the expense of negotiating miles-deep saltwater to get to otherwise unburdened deposits on the seafloor. And, along with project-crippling environmental litigation, an undefined regulatory structure, and unknown technical challenges, there are many reasons to hold back from digging in the sea. But there is hardly a doubt that a market will emerge to make it worthwhile. It is almost certain that private companies will not be the only players, either. Spurred by the prospect of greater resource independence, nation-states with large budgets will have a strong incentive to tap into seabed resources, and actively participate as well.

Whether or not mining companies or governments can successfully realize the benefits of SMS mining depends on the creation and impact of future regulations, an increased understanding of environmental issues and how to mine SMS sustainably, and, most importantly, humanity's future demand for metals weighed against the costs of extracting them. That demand created this burgeoning industry in the first place, and it very likely will overcome today's numerous challenges to drive seabed mining into the future.