DEEP-OCEAN MINERAL RESOURCES

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The mysteries and promise of the deep ocean rose to attention on the heels of military interest and technology after World War 2. Despite accounting for 70% of the Earth's surface, almost nothing was known about the deep-ocean seafloor. That changed dramatically over the following 60–70 years, although our knowledge still remains patchy at best.

On land, exploration and discovery of mineral resources was led by prospectors and mining companies. Governments and researchers supported this process through mapping and via geophysical and geochemical surveys, which provided the basic data to guide exploration; only rarely did governments and academic researchers participate directly in land-based discoveries. By contrast, governments and researchers played a significant role in seafloor discoveries. Although polymetallic nodules were first discovered in the late 19th century, it was only from 1950 onwards that researchers discovered the Red Sea brines, black smokers, accumulations of massive sulfides, and polymetallic crusts. The nature of these discoveries attracted public, and eventually commercial, attention.

International expeditions led by Australian, Canadian, European, Japanese, US and other researchers developed new technologies and methods, including submersible equipment, to explore the deep ocean. This eventually led to ocean drilling expeditions that are ongoing to this day, a recent example being the drilling on Brothers Volcano in the southwest Pacific Ocean by the International Ocean Discovery Program. Research has increased our knowledge of numerous Earth and biological processes and our understanding of land-based analogues to these mineralizing systems, especially volcanogenic massive sulfide deposits.

With ocean research well established, several phases of resource exploration and evaluation on the seafloor followed. The first phase in the 1960s to 1980s was focused on polymetallic nodules in the Pacific Ocean and predominantly involved major mining companies. Although many technical issues were solved, declining metal prices and uncertainty over ownership eventually curtailed activity.

The second phase followed the numerous discoveries of hydrothermal systems and massive sulfides in the deep ocean during the 1990s and early 2000s, especially in the complex arcs and basins of the southwest Pacific. Declining metal prices post-2009 took a toll on this effort, although one company, Nautilus Minerals, continued to advance the Solwara deposit (in the seas off Papua New Guinea) through engineering, permitting, and ownership negotiations with the government of Papua New Guinea. Solwara is an extinct hydrothermal system that contains base- and precious-metal-rich massive sulfide; it is located in the Manus Basin within the national waters of Papua New Guinea, a country with an established mining framework.

The commodity boom that occurred during this second phase, also generated renewed interest in polymetallic nodules, particularly in the Clarion–Clipperton Zone of the eastern Pacific. Unlike the first phase, ownership issues were largely solved by the formation of the International Seabed Authority and the associated regulatory framework. This work involved nations, technology companies, and small resource companies, but major resource companies were largely absent.

Each phase of seafloor resource exploration faced four challenges: 1) the discovery and efficient assessment of resources; 2) the recovery of minerals from the deep ocean and how to process complex ore to produce metals; 3) the assessment of baseline environmental conditions and local biodiversity, including strategies to minimize and monitor mining-related disturbance; 4) the demonstration of economic viability, which had to be equivalent or better than conventional land-based mining and extractive processes.

Increasing activity in the deep oceans has also attracted concern and attention. Mining's historical reputation, combined with heightened sensitivity to oceans, is a potent mix, something that is further exacerbated by our limited knowledge of roughly 90% of the deep oceans. Inauguration of the International Seabed Authority may help, although trust in government and international agencies is generally not high.

So, what does the future look like for deep-ocean mineral resources? Accepting the ongoing demand for metals and minerals to meet societal needs for water, sanitation, clean energy, transportation, and communication, what role will the seafloor play compared to conventional land-based mining?

There are advantages of deep-ocean resources: mining on the seafloor can be more selective than land-based mines; a ship-based plant that moves from deposit to deposit will be far more efficient than multiple land-based mines; there will be no mine workers facing safety issues; the lack of waste rock and tailings significantly decreases the potential for long-lasting acid drainage; and, the absence of (human) communities removes pressure on local water, agriculture, and culture.

Conversely, although working in the deep ocean is entirely feasible, developing an understanding of complex ores that contain multiple metals is challenging. Similarly, processing these complex and variable ores and finding the appropriate facilities on tidewater will not be easy. A further challenge will be to establish an environmental baseline dataset at an appropriate, but yet to be determined, scale.

Arguably the greatest challenge is that new seafloor sources of base, precious, and critical metals must compete in the market with established mining. For example, the major product in polymetallic nodules is manganese; but there are sufficient resources of this metal in land-based mines to last many decades. Similarly, the cyclic base-metal market and volatile prices of minor metals makes major investment decisions difficult for land-based mining, and such decisions will be even more challenging for new ventures in the deep ocean.

There is little doubt that the deep oceans contain major resources that could meet the needs of humans well into the future. An improved understanding of the deep-ocean environment will prepare us for more benign mining and extractive techniques and for better protection of the seafloor ecosystem. Based on our land-based experience, however, none of this will guarantee successful economic seafloor operations unless major efforts are made to explain and transparently document all of our work on the seafloor. Open and engaged collaboration between industry, governments, regulatory agencies (such as the International Seabed Authority), nongovernmental organizations, and researchers will be a vital prerequisite.

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