POLICY FORUM: ECONOMIC GEOLOGY

Lessons Learned from Deep-Sea Mining

G. P. Glasby

When published in 1965, J. L. Mero's *Mineral Resources of the Sea* (*1*) painted a picture of an essentially limitless resource of more than 1 trillion metric tons of manganese nodules on the Pacific deep-sea floor that were growing at a rate faster than could possibly be exploited, a literally inexhaustible supply of metals such as Mn, Co, Ni, and Cu. This book literally launched a hundred ships (or rather a hundred research cruises). An era of vigorous attempts at deep-sea mining ensued that resulted ultimately in very little return on investment. An examination of this history provides several lessons for planning complex international projects and regulations involving developed and developing countries and for the future of deep-sea mining and exploration.

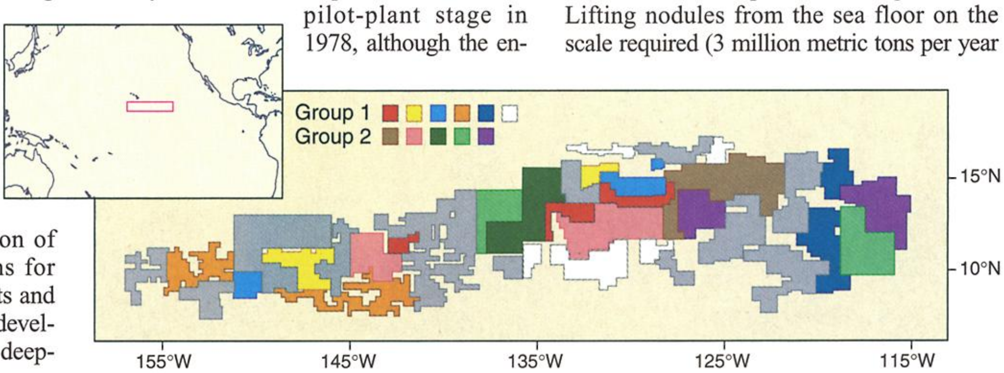
Historical Development

The initial phase of investigating the possibility of deep-sea mining lasted from 1972 to 1982, shortly after the widespread abundance of metal nodules in the oceans was recognized. A major factor in initiating this research was the prediction of global mineral shortages.

Initial investigations on the possibility of deep-sea mining focused mainly on the area between the Clarion-Clipperton fracture zones (CCFZ) in the equatorial North Pacific. The United States funded 30 to 40 cruises, Germany 26 cruises, and France 42 cruises, mainly to this area, and the Soviet Union about 100 cruises worldwide. In 1977, Mero (*2*) calculated that the nodules from this North Pacific high-grade area covering an area of about 6 million km^2 would contain only about 11 billion metric tons of Mn, 115 million tons of Co, 650 million tons of Ni, and 520 million tons of Cu. He assumed that Mn nodules would be "in full-scale economic production within the next 5 to 10 years." The most recent resource estimate indicates that this area is not quite as rich but still contains about 7.5 billion metric tons of Mn, 78 million tons of Co, 340 million tons of Ni and 265 million tons of Cu (*3*).

The author is in the Department of Economic Geology and Geochemistry, University of Athens, Panepistimioupoli, Zografou, Athens 157 84, Greece. E-mail: glasby@geol.uoa.gr

Seven consortia were set up by companies, mainly from the United States, Germany, France, Britain, and Japan, to investigate the possible commercial exploitation of nodules. This work culminated in the successful testing of a system to mine deep-sea nodules at the pilot-plant stage in 1978, although the entire mining system was lost over the stern of the ship after about 800 metric tons of nodules had been recovered from the sea floor.



Mining claims in the Pacific Ocean. Schematic map showing the disposition of the registered areas of the pioneer investors in the CCFZ (*13*). Key: Colors represent the following in order listed. Group 1, Registered Pioneer Investigators: Russia, Japan, France, China, Interoceanmetal Joint Organization (IOM), and South Korea; Group 2, Consortia: Ocean Mining Associates (OMA), Ocean Minerals Co. (OMCO), Ocean Management Inc., (OMI-I and OMI-II), and Kennecott Consortium (KCon); gray, International Sea Bed Authority.

A further development raised false hopes: The Lockheed/OMCO consortium claimed to have developed a system using the Hughes *Glomar Explorer* as mother ship, for which sea trials were carried out in 1976 and 1978. A huge bay (82 m long) could be opened and closed in the ship's hull, through which a large, remotely controlled mining system could be deployed and retrieved at depths of 6000 m. Pipe handling and deployment were automated. However, it was subsequently revealed that the *Glomar Explorer* had been built by the U.S. Central Intelligence Agency primarily to recover a sunken Soviet nuclear submarine at a cost of about US$500 million in current dollars. Because this fact was not known at that time, a widespread impression was created that deep-sea mining was more viable than turned out to be the case.

A more sober assessment of deep-sea resources eventually prevailed. In the case of deep-sea nodules, criteria for economic deposits of a combined Ni, Cu, and Co content >2.5% and an abundance on the deep-sea floor >10 kg m^{-2} meant that only a small percentage (<5%) of nodules could be considered potentially economic. These are mainly diagenetic nodules from the CCFZ in the Pacific Ocean and from the Central Indian Basin in the Indian Ocean. In addition, world metal prices have remained depressed since the beginning of the 1980s and land-based mines are working at less than full capacity. High-quality sources of metals on land proved abundant enough to meet the projected demands for Ni, Cu, and Co for at least several decades. This meant that only those marine mining operations that were capable of operating without subsidy would be viable. Economic-grade manganese nodules are generally found in the middle of the ocean in water depths exceeding 4500 m. Lifting nodules from the sea floor on the scale required (3 million metric tons per year for 20 years at an individual mine site covering an area >6000 km^2) is a formidable proposition. Although technically feasible, it remains debatable whether this can be done at a cost lower than that of mining land-based ore deposits within the foreseeable future.

Thus, by 1982, the initial enthusiasm in manganese nodules had waned with the realization that nodules were not going to be exploited in the near term [as had been predicted by Medford (*4*)]. The exploration programs of the United States, Germany, and France essentially ended. From the early 1960s to 1984, more than US$650 million (in 1982 dollars) had been spent on developing technologies and exploring for deep-sea manganese nodules with little return (*10*). For most of the firms involved, this was a relatively small investment (about 5 to 7% of their annual budget on exploration and R&D on average during the peak spending period). This analysis begs the question of whether further investment in deep-sea mining is worthwhile.

Deep-Sea Mining and the Law

Concurrently with the commercial investigations of the deep-sea floor, the United Nations Conference on the Law of the Sea

(UNCLOS) was being undertaken as the largest-ever forum for international diplomacy. Ultimately, the International Seabed Authority (ISA) was set up to regulate deep-sea mining outside the 200–nautical mile Exclusive Economic Zones (EEZs) of individual nations.

Because of the presumed possibility of huge revenues from deep-sea mining, the Third World countries (Group of 77 in the UN) wanted to ensure that they were not denied a share of the wealth. On the basis of false expectations, a number of provisions were proposed that were considered to be so onerous by potential nodule mining companies as to make nodule mining inviable (*5*). These included a parallel system of deep-sea mining in which a mining company would be required to explore two mine sites of approximately equal value and relinquish one to the ISA. During the initial phase of nodule mining, contractors would also be required to transfer technology to the Enterprise, the deep-sea mining arm of the ISA, on "fair and reasonable commercial terms and conditions" over a period of 10 to 20 years. The international community would also be required to furnish the funds for one initial commercial-scale mining project by the Enterprise. The assumption in all this was that nodule mining would be so profitable that the mining companies (representing the industrialized countries) would be able to make substantial transfers to support nodule mining by the Enterprise (representing Third World countries). The controversy surrounding these requirements eventually led to the refusal of several industrialized countries with an interest in nodule mining (including the United States, United Kingdom, and Germany) to sign the initial Law of the Sea treaty in 1982. Instead, the United States unilaterally declared an EEZ in 1983 with the intention of leasing minerals such as manganese crusts (*6*). At least one consortium (INCO) ended its involvement in deep-sea mining because it believed that no private company could compete against the Enterprise.

Cobalt-Rich Manganese Crusts

The invasion of the Shaba province of Zaire by insurgents from Angola and Zambia in 1978 led to a sharp increase in the price of Co (*7*). As a result of the perceived threat of a disruption to the supply of metals to the west from unstable regions in the Third World, a number of metals, including Co and Pt, were considered to be strategic metals. This idea took particular hold in the United States. Co-rich manganese crusts occur at depths of 1500 to 2500 m on the flanks of seamounts (*8*). Four German cruises were undertaken to the Pacific and one to the Atlantic. Eight cruises were also undertaken by the U.S. Geological Survey (USGS) and one per year by Japan.

The requirement for economic-grade crusts was that the crusts should be at least 40 mm thick and contain >1% Co on average. The total resource of Co-rich Mn crusts within the U.S. EEZ was calculated to be about 300×10^6 metric tons of crust material containing 2.7×10^6 tons of Co, 1.5×10^6 tons of Ni, and 74.1×10^6 tons of Mn. According to Mangini *et al.* (*9*), many seamounts meet the tonnage requirements for a commercial mine site, namely, 500 km^2 of prime nodule tract with about 4×10^6 tons of nodules recoverable during each year of mining. Other metals such as Pt were considered possible by-products. Many crusts were found within the EEZs of individual nations. These deposits were under national jurisdiction and therefore not under the control of the ISA. They are also found in shallower water (1500 to 2500 m) compared with depths for deep-sea nodules (>4500 m). However, the problems of separating the crust material from the underlying substrate in situ on the slopes of seamounts have not been properly overcome, and they remain technically more difficult to mine than nodules. Therefore, there appears to be no immediate prospect for the commercial mining of Co-rich manganese crusts.

The New Phase

The new phase of commercial interest in deep-sea nodules, which has developed over the last decade or so, has involved Japan, China, Korea, and India. The main factor driving this development is the perceived shortage of resources in these countries. The eventual ratification of UNCLOS in 1994 led to the setting up of the ISA in Jamaica to supervise deep-sea mining. Those countries and organizations that have accepted pioneer investor status are obliged to fulfill a work program within their registered mine site areas (see figure, p. 551). However, world metal prices have remained depressed, so that there can be no hope of deep-sea mining being profitable. The commercial viability of nodule mining is therefore by no means assured, and no consortium is contemplating building a nodule mining system at present.

The discovery of the Voisey's Bay Ni-Cu-Co deposit in Newfoundland in 1994 has reinforced this assessment. This deposit is considered to be the largest mineral discovery in Canada in the last 30 years and one of the great nickel finds of this century. The future of deep-sea mining therefore lies elsewhere.

Submarine Hydrothermal Minerals

There has been sporadic interest in the resource potential of submarine hydrothermal minerals from divergent plate margins. Of these, the metalliferous sediments from the Atlantis II Deep in the Red Sea remain the largest known marine sulphide deposit rivalling the largest volcanogenic massive sulphides on land in size and was estimated to have a value of about $5 billion in 1985 prices. However, there are no plans to mine even this deposit in the forseeable future.

Recently, attention has switched to submarine hydrothermal deposits at convergent plate margins. Prospective deposits appear to be those with high gold and base metal contents located close to land in water depths of less than 2000 m. In 1997, Papua New Guinea issued exploration licenses to the Nautilus Minerals Corporation to explore two areas in the Central and Eastern Manus Basin for Au-bearing sulfide deposits. Another promising prospect is the crater of Conical Seamount situated on the Tabar-Lihir-Tanga-Feni forearc chain east of Papua New Guinea, which occurs at a water depth of 1050 m. Sulfides from there have been shown to have an average Au content of 26 parts per million (ppm) with a maximum content of more than 230 ppm based on the analysis of 40 samples (*11*). This deposit may become the first marine gold deposit to be mined (*12*). The shallow water depth and proximity to the Ladolam gold processing plant 25 km away on Lihir could favor its exploitation.

Assessment

This brief history shows how false economic forecasts and poorly designed laws based on overoptimistic assessments ultimately led to much wasted effort and money in an attempt to mine deep-sea minerals. Hopefully, the advent of a new phase of exploration for submarine hydrothermal deposits will not result in the same mistakes in the future.

References

1. J. L. Mero, *The Mineral Resources of the Sea* (Elsevier, Amsterdam, 1965).
2. J. L. Mero, in *Marine Manganese Deposits*, G. P. Glasby, Ed. (Elsevier, Amsterdam, 1977), pp. 327–355.
3. C. L. Morgan, in *Handbook of Marine Mineral Deposits*, D. S. Cronan, Ed. (CRC Press, Boca Raton, FL, 2000), pp. 145-170.
4. R. D. Medford, *Mining Mag.* **121** (no. 5), 369 (1969); *Mining Mag.* **121** (no. 6), 474 (1969).
5. V. E. McKelvey, *Science* **209**, 464 (1980).
6. F. F. C. Earney, *Marine Mineral Resources* (Routledge, London, 1990).
7. F. T. Manheim, *Science* **232**, 600 (1986).
8. J. R. Hein, A. Koschinsky, M. Bau, in *Handbook of Marine Mineral Deposits*, D. S. Cronan, Ed. (CRC Press, Boca Raton, FL, 2000), pp. 239–279.
9. A. Mangini, P. Halbach, D. Puteanus, in *Marine Minerals Advances in Research and Resource Assessment*, P. G. Teleki, M. R. Dobson, J. R. Moore, Eds. (Reidel, Dordrecht, Netherlands, 1987), pp. 205–220
10. J. M. Broadus, *Science* **235**, 853 (1987).
11. P. M. Herzig, personal communication.
12. ______, *Philos. Trans. R. Soc. London A Math. Phys. Sci.* **A357**, 861 (1999).
13. R. Kotlinski, Proceedings of the ISOPE Ocean Mining Symposium, 21 to 22 November 1995, Tsukuba, Japan, pp. 5–7, 9 (1995).