The Potential for Undersea Mining

David Dekker & Raymond Binns (CSIRO Exploration & Mining)

The deep sea floor offers new opportunities for minerals exploration. Recent discoveries of high-grade massive sulphide mineralization represent resources whose extent is still unknown. Ferro-manganese nodules formed on abyssal plains are of more modest grade, but very extensive in area. While it is likely that continental shelves may contain seafloor mineralization deeper than deposits already exploited in coastal areas by conventional dredging, the focus of this paper is the hydrothermal vents of island arc and back-arc areas and the abyssal plains of the deep sea. These hold promise of ore deposits quite different from those known on land. Environmental advantages in mining the sea floor include no impact on the surface environment and in some cases opportunities for disposal of tailings back on the seafloor.

Introduction

Manganese nodules were trawled from the deep abyssal plains in the 1960s. Containing significant levels of nickel, copper and cobalt, these represent a huge resource of metal, but they are relatively dispersed. To date, the costs of extracting and treating such deposits exceed their commercial value.

Seafloor hot springs and massive sulphides were discovered near the Galapagos Islands in 1977. Many more such sites have been found since and include the more spectacular black smokers, named after particulate plumes emanating from hydrothermal vents that deposit massive sulphide mineralization in the form of chimneys growing from the sea floor.

In 1991 a CSIRO-led study of submarine volcanic hot-springs in the Manus Basin, Papua New Guinea found exceptionally metal-rich sulphide mineralization (Binns and Dekker 1998). Even richer and larger discoveries since then of copper and gold, such as the "Sunrise" deposit found on a submarine volcano 400 km south of Tokyo by the Japan Marine Science and Technology Centre (Iizasa et.al., 1999) have caused commercial interest to expand rapidly.

As well as forming chimneys, the hydrothermal vents emit a plume of mineral laden water. Much of the metal content is probably emitted into these plumes and deposited over a broad area as sediment. Conceivably, these metaliferous sediments might also be exploitable. While found at shallower depths than the manganese nodule deposits, those hydrothermal vent deposits that are actively forming at high temperature support a unique fauna.

Undersea Resources

Figure 1 shows some of the known undersea mineral deposits. The north east Pacific is regarded as the most prospective manganese nodule deposit area, although other nodule areas as shown in the Pacific and Indian Oceans occur at depths of several kilometres.

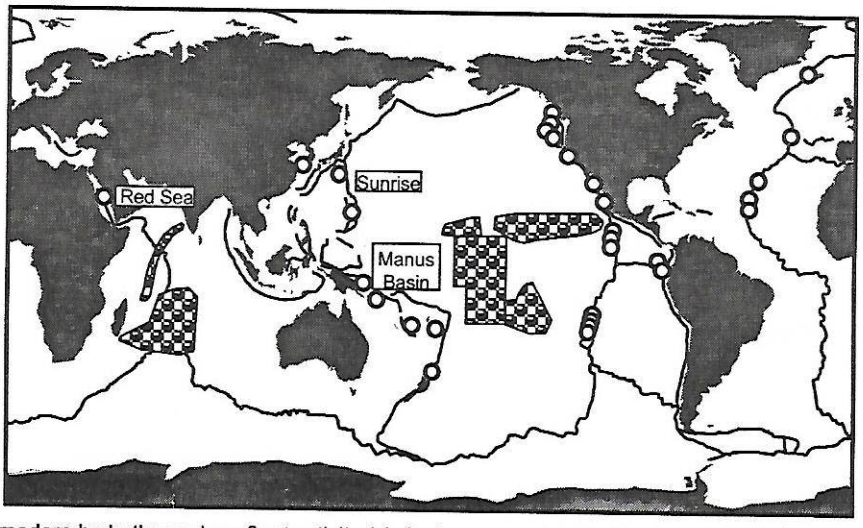


Fig 1: Locations of modern hydrothermal seafloor activity (circles) are associated with plate boundaries and seafloor spreading centres. Manganese nodules (stripes) grow on the surficial sediments of oceanic crust as it spreads from the mid ocean ridges.

The open circles represent known hydrothermal deposits. The Red Sea deposit contains about 90Mt of zinc-rich ooze at 2km depth that received commercial attention in the 1960s and 1970s, but proved difficult to process so was not economic at the time. The deposits of the Manus Basin occur at depths of 1.5 km to 2 km beneath the Bismarck Sea north of Papua New Guinea. These deposits and those at Sunrise south of Japan have the highest indicated grades as shown in Figure 2. In the absence of drilling data, resource estimates for hydrothermal sites are only guesses at this stage. It is likely that many more undiscovered deposits exist along the back arc regions associated with subduction of oceanic crust on the western rim of the Pacific. The territorial waters of Indonesia include several such prospective areas. The key to economic mining of any undersea deposit will be very high value per tonne.

Mining Potential

For manganese nodules, United Nations (1987) estimated that 25 potential manganese nodule mines occur in the Clarion-Clipperton Zone (north-east Pacific), each being a 214Mt of ore resource of which 35% might be recovered.. Frazer and Fisk (1980) concluded that in approximately the most prospective 1.2 million square kilometres of the north Pacific there is an average Mn nodule abundance of 12 kilograms per square metre at a grade of 2.27% Cu+Ni. By contrast, average metal contents of massive sulphide samples collected from Manus Basin hydrothermal deposits show high grades greater than 15% Cu+Zn with significant gold and silver. The deposits occur at technologically accessible water depths and their metallurgical properties are potentially favourable. Papua New Guinea government authorities have issued the world's first deep ocean exploration licences over the location to a private company, which is now assessing deposit size and the feasibility of mining.

Mining methods

There are significant infrastructure requirements for mining the deep seabed, which will need to be fully automated. There are currently fewer than a dozen manned submersibles that will operate at even the moderate depths of the Manus Basin deposits. These, while suitable for initial exploration are not suitable for mining operations. In the case of manganese nodule mining the cost associated with surface support ships is prohibitive unless multiple automated miners can be operated from each surface vessel.

Processing should be considered an integral part of mining operations, the key issues being the nature of the deposits, the disposal of wastes and if processing at sea, the provision of services such as power and water.

Methodology

The mining phase consists of the same fundamental processes required for underground mining: breaking ore from the surrounding rock, crushing to transportable size, and hoisting to the surface. The advantage of both nodules and active vent chimneys is that they are easily detached from the surrounding rock. Nodules exist at a readily transportable size, while chimneys are generally friable or at least partially porous so easily crushed. The industry will need the ability to navigate machines accurately in turbid water, and to remotely sense ore grade and geology.

Research will also focus on continuous processes adapted to the particular hoisting method and surface-handling infrastructure.

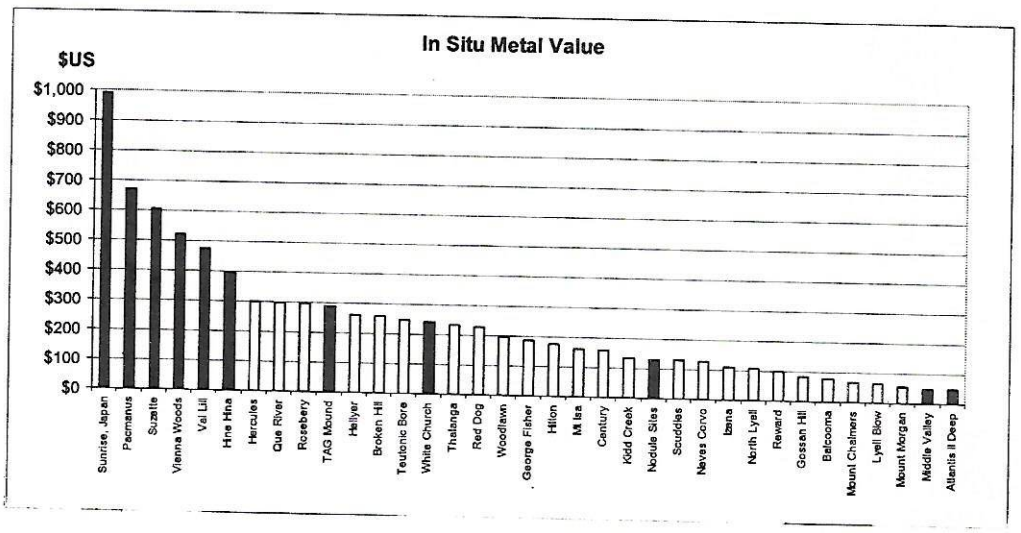


Fig 2: Known seafloor deposits are of equal or higher than average grade, and similar in total contained metal value to land deposits.

Raising

Possible mining scenarios depend on the type of undersea deposit types. Operational constraints favour continuous raising options over batch processes. It takes typically one hour to hoist a load 2km from the seafloor. The difficulty of this process for mining chimneys is evident from Figure 3. Grab and hoist methods are suitable only for shallow depths or extremely high grade and spatially dense deposits, to ensure that every grab counts. The United Nations (1984) suggests the use of hydraulic, airlift or continuous line bucket conveyors for hoisting of nodules.

Either batch or bucket conveyor hoist or continuous hydraulic hoisting can accomplish lifting. Hydraulic hoisting can be driven by introducing buoyancy into the water column within the pipe by injecting air under pressure which expands as it rises reducing the average density and providing buoyancy sufficient to lift rock particles up to a few tens of mm diameter.



Fig 3: The largest complete hydrothermal vent chimney returned to the surface in one piece by dredging was 'snagged' by CSIRO ship RV Franklin in early May 2000. The chimney contains around 50% zinc as sphalerite (ZnS), and about 0.15% silver.

Future Exploration

The United Nations (1984) suggests an exploration sequence for nodule development in four stages: regional appraisal, target area definition, identification of probable economic deposits and delineation of economic deposits. These steps apply equally to any type of deposit although the means of assessment will vary. Mineable deposits must be of sufficient grade, size and ease of access to allow undersea mines to compete with land based mines.

The legal framework for environmental protection, undersea leases and rights is developing rapidly and nations will become more protective of these rights.

Environmental issues for undersea mining will have many issues in common with land based mines.

It is possible that decisions to proceed with undersea mining will be made at lower levels of certainty than would be acceptable on land due, to the cost of drilling. This risk must be offset by higher grades and it can be seen from Figure 2 that very high-grade deposits do exist. This makes the hydrothermal vent deposits of the western Pacific Rim particularly attractive.

An Automated Underwater Vehicle (AUV) or a Remote Operated Vehicle (ROV) is a basic pre-requisite without which many exploration, mining and environmental tasks will not be practicable.

Conclusion

A key objective for the immediate future is to demonstrate economic recovery of seafloor resources. Quite different examples of mining targets have been given to illustrate the techniques required. The first targets are likely to be shallow high-grade hydrothermal deposits due to the high grades indicated.

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In Memoriam: Dr. David Dekker (1951-2000)



David Dekker joined Mount Isa Mines in 1979 as a research scientist and completed a PhD in Geophysics part time through the University of Queensland in 1983. He also spent two years as Mine Equipment Superintendent at Mount Isa Mines followed by five years as Engineering Research Manager.

Dave joined CSIRO Exploration and Mining at the end of 1995 as Mine Equipment Automation Group Leader. In 1996 he was concurrently appointed as Mining Science Co-ordinator responsible for coordination of the Division's mining science activities. Particular areas of expertise were in research management and new mining methods based on automation technologies. Dr Dekker also co-ordinated activities in CSIRO that addressed the Minerals Exploration and Mining industries.

Dave unexpectedly passed away on July 16, 2000. One of the last manuscripts he completed was "The Potential for Undersea Mining", submitted to FOSI's Berita Sedimentologi.