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MINING OF THE DEEP SEABED IN THE YEAR 2010

*Conrad G. Welling**

The challenge to write an article with the above title was accepted with trepidation. I say this because the experience of the last twenty years shows that great risks are involved in any attempt to forecast industry development for twenty years ahead. The task becomes more difficult with time, principally because of the rapidly developing technology, as well as the changing markets. There is an interrelationship between the two that can be difficult, if not impossible, to define with reasonable accuracy. Our deep ocean mining development work started in the early sixties. At that particular point we divided the risks into four categories: technical, economic, legal/political, and environmental. We made the assumption that the markets were not the primary risk. Our time scale was such that we planned to have a deep-sea operational manganese nodule mining and processing system by the late seventies or early eighties.

The major reason we were confident of our planning was that we had the exploration tools to define the quantity and quality of the manganese nodule deposits and that the scientific community had accomplished sufficient exploration work to give high confidence that the deposit was extensive. This is not the case today for other recent scientific discoveries such as the polymetallic sulfides and the manganese crusts. Both the scientific community and commercial activities lack the necessary exploration tools for the rapid development of most non-fuel ocean minerals with the exception of the manganese nodules and perhaps phosphate nodule deposits.

Given the time scale of exploration tool development and other exceptions, such as a rare discovery of a very rich deposit such as gold or platinum, the time scale for ocean mining is a reasonable two thousand to two thousand and ten A.D. period.

Having been previously involved in long range planning, operations research, and systems analysis, I believe that one can outline development risks in great detail so that the allocation of development funds can be accomplished with acceptable efficiency. In the period of twenty years, over one hundred million dollars was spent to reduce development risks to acceptable levels. Being for the most part successful, the approach and methodology have merit. In fact, with research and development

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dollars being dear, it was vitally important that risk analysis be fully utilized. Nevertheless, it was the assumptions on markets that proved to be wrong.

A very important factor in mineral and metal markets is the recent rapid development in new materials. The requirements for structural and energy efficiency have placed great demands on metals and materials. In particular, the great increase in the cost of energy has increased the need for materials of higher strength for given weight as well as higher strength at higher temperatures. At the present state-of-the-art many so-called super alloys have reached performance limits that prompt the search for new materials. Since some of these new materials are starting to displace metals in increasing volume, it is necessary to study their development to have any reasonable understanding of the future markets.

It may be assumed that many metals do not have adequate characteristics for the structural demands, present and past, that have been placed upon them. The new materials will fill some of the voids. This will enable the designer to design more efficient systems because he will be able to decrease the use of materials that are not adequate for the tasks, thereby increasing the desired performance of the system in which the material is employed.

The period following World War II, up to the sixties, witnessed a healthy growth of the minerals industry, with an average annual growth rate of three to four percent. Some metals, such as nickel, were averaging six to seven percent yearly compounded growth rate. The world population growth rate, plus the industrial development of many Third World countries, in addition to the industrial world growth, led to the conclusion of a continued healthy mineral industry growth. Extrapolation of data requires an understanding of the basic reasons for the trend. In order to be conservative, we projected lower future growth rates than historical. However, the growth rate of the minerals industry in the latter part of the nineteen seventies and early eighties was essentially zero. One can place the reasons for the zero rate on the oil crises and the world-wide recession. However, the economic recovery in the United States in the early eighties did not place a greater demand on the majority of minerals. The growth rate of demand on the majority of the metals derived from these minerals has been essentially flat, leading to an oversupply of most metals. Since it takes about seven to ten years lead time to develop a new mine, corporate decisions made to invest in new mine development in the early seventies resulted in an overcapacity in the early eighties. How soon this overcapacity can be absorbed by the market is not known. Perhaps a world economic recovery, especially among the developing countries, will absorb the oversupply in the late eighties. This may provide the necessary incentive to the mineral industry to raise the investment capital necessary for further development.

The United States as a Primary Mineral Producing Country

Some distinct patterns have developed over the past two hundred years in the development of the modern mining industry. While one

can trace the development of mining over a few hundred years, it is the last one or two hundred years that have had the greatest impact.

First, one has to recognize that minerals are not equally distributed throughout the world, or even within a country. This applies even to such common commodities as sand and gravel. As a rule of thumb, one can say that eighty percent of any mineral is produced by approximately twenty percent of the countries of the world. In the extreme, eighty percent or more of some minerals are produced by only two or three countries. Thus some countries are known as oil producing countries or copper producing countries. Another factor shown by historical trends is the passing of phases of mining of a particular country. First, as a country develops its resources, the number of mines will grow to a maximum after approximately fifty to one hundred years. However, the production will continue to grow even after the number of mines decreases, the larger mines becoming more efficient and the smaller inefficient mines being closed. However, exploration activities do not result in finding ever larger, richer ores to keep up with production. The large mines have to produce from ever decreasing ore grade. When a peak in economic ore production is reached the historical decline in production is the result. Once the production of a given mineral peaks and starts decreasing in a particular country, imports will start to increase to support the industries established because of the domestic availability of the mineral in the previous years. In the final phases the industry of a country becomes dependent upon the import of a commodity that was once readily available domestically.

At the present time the mineral production and number of mines in the United States are declining, having reached peak production a decade or two ago. As an example, United States copper production decreased by thirty-one percent during the period from 1970 to 1983. During the same period, United States lead production, as a percent of world production, decreased from twenty-three percent to nineteen percent. During the same time total world production increased by twelve percent. In the case of zinc, United States production decreased from seventeen percent to five percent of world total during this same period. The reasons for these declines were primarily economic and environmental. One could say that no nation mines out all its minerals; only the grade of known resources becomes too low to be produced on an economical basis. The economics can be affected by wages, price of capital, cost of environmental regulations or a combination of these major factors.

From an historic point of view we should expect an ever increasing level of imports to keep the United States' industrial activities at what may be considered adequate growth levels. Other countries such as England and Japan passed their maximum mine production fifty or more years ago. Canada's mineral production is near the historical peak and may start declining in a decade or two. It is estimated that Russia, because of the vast deposits in Siberia, may not reach a peak in mineral production for another twenty-five to fifty years.

There are many factors that may change the trends indicated above. The first is development of technology, the second is the increased knowledge of the sea floor. Up until the period following World War II, very little non-fuel mineral deposits were found by indirect means. Practically all deposits were found by surface observations of rock outcrops. Sampling by borehole and laboratory analysis is, of course, absolutely essential regardless of where ores are found. However, localization of sampling has been greatly aided not only by increased knowledge of geology and morphology, but also by use of such instruments as the airborne magnetometer, and now by Landsat, the earth observing satellite systems. As discussed later, improved oceanographic instruments are providing man with extensive increased knowledge of the ocean floor.

By the use of the new knowledge and advanced instrument development a nation may be able to reverse the historical trends in mineral development, or at the very least, slow the rate of decline of mineral production.

New Materials

The rapidly advancing technology associated with materials and the scientific knowledge derived from the development of solid state physics are bringing forth a rapid development in new materials. One may divide these developments into four areas: polymers (plastics), composites (fiber matrix), high-strength ceramics, and fiber optics.

There are many examples of the impact of polymers on metals by substitution. Steel and copper pipe are increasingly being replaced with plastic pipe and tubing. Composites are replacing aluminum in aircraft. Fiber optics are replacing copper in communications, and ceramics are replacing high strength metals where high strength and temperature are required, such as turbine blades.

Composite Mateirals

Composite materials are not new; for example, straw in clay bricks was used by man thousands of years ago. Today, fiberglass is probably the best known modern composite; another well-known composite is reinforced concrete.

The development of special fibers that increase the tensile strength of composites is causing a revolution in materials. New aircraft are using increasing amounts of composites as part of the structure. Some new general aviation aircraft now in development have a structure, wings, fuselage, and tail made almost completely of composites, replacing aluminum. The high strength fibers used in the new composites are ultra-fine filaments of tungsten, carbon, boron and beryllium. In the laboratory at the present time are almost flawless crystalline structures of such materials as aluminum oxide (sapphire) with strengths up to one thousand five hundred tons per square inch. Another possibility is the use of ceramic fibers as a metal composite. This may be commercially possible with aluminum and be very

competitive with some of the composites that are replacing aluminum. It is not known at the present time how long it will take to produce such fibers on a commercial scale. Nevertheless, successful development of composites made of these materials could produce another great advance in material development.

High Strength Ceramics

These new ceramics are called high-technology ceramics. They are made from extremely pure, composition controlled ultra-minute particles formed, sintered, and treated under closely regulated conditions.

There is a great contrast between conventional ceramics and the new technology ceramics. The raw materials for conventional ceramics are clay and silica, while those for the new technology ceramics are so-called artificial raw materials such as silicon, alumina, silicon nitride, and so forth. The manufacturing processes are different as well as the end product. Both ceramics are able to withstand high temperatures. However, conventional ceramics found in pottery and brick fracture easily. The high strength ceramics have high strength comparable to metals.

The market demand for these new high technology ceramics will not only depend upon their physical characteristics, but the price at which they can be produced. It is estimated that at forty dollars a pound (1984) the market volume would be somewhat limited; however, below fifteen dollars a pound the market could be extensive.

Much development has yet to be done, but it is considered that by the year 2000 the market could be extensive because of the potential wide use in automobile engines alone. Another factor is the potential use of ceramic fibers in a metal composite as discussed in composite materials.

Fiber Optics

Last but not least, one cannot ignore fiber optics and the impact their development has and will have on other materials, especially copper. For the same size, a fiber optics cable can carry many orders of magnitude more of information than a copper cable. As an example, the latest fiber optics cable can transmit the same information in one second that an equivalent size copper wire transmits in seventeen hours. Fiber optic lines are already becoming competitive with communication satellites for fixed installations. It is considered that tapping a fiber optics line is practically impossible, therefore communication through fiber optic lines is more secure than through copper lines. Present installations of fiber optic lines are over a considerable distance between major metropolitan areas. However, the associated development of lasers that provide the light input will make the economic communication distance shorter and shorter so that it will be used within a city, followed by large buildings, where the communication traffic is large.

One should not conclude from the above discussion that because of the many new materials being developed the demand for traditional metals

will decrease. As an example, copper demand world-wide is actually increasing notwithstanding the substitution by plastics in many traditional uses. At the present time there is essentially no substitution for copper in electrical power. If the world continues to develop at a reasonable rate, electrical power growth is essentially assured.

This discussion of minerals and materials has set the stage for a long term look at the seabed as a source of minerals and materials.

The Seabed

The last twenty to thirty years has produced a revolution in the knowledge of the seabed. In spite of this knowledge, we are still in the pioneering stage of exploration of this very large area of the earth's surface.

The basic reason for the great disparity in knowledge of the ocean floor, as compared to knowledge of the dry land surface, is the physical characteristics of seawater. Seawater is essentially opaque to electromagnetic energy as well as having sufficient viscosity and mass to greatly limit the motion of bodies through it. This is in great contrast to air. In addition, seawater is hostile to man's existence. Thus the data rate of information flow through seawater is many orders of magnitude less than through air.

There have been many technical developments in the last thirty or more years that are helping to increase the data rate of information from the sea floor. A few of those which have had a significant impact are: deep sea drilling developed by the offshore oil industry; improved acoustics developed by the United States Navy; greatly improved underwater electronics, and sensors, including television and data handling; underwater lighting and photography; and, last but surely not least, the manned submersible.

It was not until the development of sonar in World War I for anti-submarine warfare that anything other than primitive means existed to determine ocean floor depth. Turning the sonar beam downward, oceanographers in the 1920's discovered that the topography of the ocean floor contained far more features, such as sea mounts, than previously thought. It was not until many years later that repeated crossings of the Atlantic with precision depth sonar showed the existence of a North-South continuous ridge, now known as the Mid-Atlantic Ridge. Data gathered in the Pacific and Indian Oceans produced information that the ridge was a continuous world-wide phenomenon. However, obtaining a detailed topography of the ocean floor by precision depth sonar is virtually impossible, therefore such maps or charts have had to await further sonar developments.

The last few years have seen great improvements in sonar techniques that allow detail topographic surveys previously not possible. These are known as seabeam and side scan sonar. With the aid of computers these instruments are providing real time topographic maps of the ocean floor from approximately one hundred meters to a thousand meters or more in width. With instruments such as these, we are beginning to realize that contrary to previous thinking of an essentially featureless ocean floor, we

are discovering a topography at least as varied as that of dry land. In fact, the sea floor could well be even more varied than on land. New ocean floor is being formed on a continuous basis; none is more than two hundred million years old. Therefore there is less time for erosion or coverage by sediment.

As is well known now, the ocean floor is divided into large tectonic plates that are moving relative to one another and the land masses. And while the great detail of the geological features of the ocean floor is discussed elsewhere, it is important from a minerals point of view that the basic geology be well understood. I think one can safely say that currently the geology of the ocean floor is not well understood, at least from the point of view of mineral exploration.

Non-Fuel Minerals

Since our concern is primarily with non-fuel minerals, it may be worthwhile to look at some of the main factors associated with this industry. There are more than one hundred non-fuel mineral commodities. The world value of these minerals is in the order of forty to fifty billion dollars (U.S.). Of the more than one hundred non-fuel minerals used, nineteen are considered very important; they are aluminum, chromium, cobalt, copper, industrial diamonds, fluorspar, iron ore, lead, manganese, mercury, nickel, phosphate rock, platinum, potash, silver, sulfur, tin, tungsten and zinc. Other metal such as gold can be included. About half of these have been found at sea with sufficient grade that indicates a future potential; they are chromium, copper, industrial diamonds, lead, manganese, nickel, phosphate rock, sulfur, tin, and zinc. Diamonds, sulfur and tin are being mined in shallow water at the present time. Because these deposits exist in shallow water, existing techniques associated with dredging and offshore petroleum are used.

Looking at the long-term availability of minerals, it is considered by some that the distribution of chemical elements in the Earth's crusts sets limits to man's supply of metals which are more important to man's future than energy limits. We can divide the earth's crust into two regions: the continental crust and the oceanic crust. All of the eighty-eight natural elements are available in both crusts. Our knowledge of the concentration of these elements in the continental crust is much greater than our knowledge of the concentration in the oceanic crusts. The continental crusts are richer in silicon, aluminum, and alkali elements, while the oceanic crust is richer in iron, manganese, and calcium. From available information there are only twelve elements that are present in the crust in amounts greater than 0.1%, and these account for 99.23% of the continental crust. The remaining seventy six elements account for only 0.77% of the crust. It will probably take extensive future exploration to learn how much the oceanic crust differs from the continental crust.

The two major elements in the continental crust are oxygen (almost half) and silicon (approximately one-quarter of the mass of the crust). The

remaining one-quarter, in decreasing abundance, consists of aluminum, iron, calcium, magnesium, sodium, potassium, titanium, hydrogen, manganese, and phosphates. These can be considered geochemically abundant elements; all others can be considered geochemically scarce.

Geological processes have concentrated minerals far above the average, some as much as one hundred thousand times or more. The miner has always sought out these concentrations. The problem for the exploration geologist is to develop more efficient methods for finding them. However, many deposits that have been found have proven to be economically inaccessible at the present time. Be that as it may, the average grade of ore mined has steadily decreased and this decline will almost certainly continue. Discoveries on the ocean floor could help lessen the rate of decline or even temporarily increase the average grade mined of a few metals. It is the expected long term increase in the use of minerals, combined with the present large use that tend to blunt the impact of the few rich deposits found.

As the grade of ore mined decreases and as the discoveries are made in more difficult terrain, such as tropical forests, mountains, and arctic regions, the energy to produce an equivalent amount of metal from land sources increases. Eventually, energy requirements may prove to be the limiting factor in the availability of many minerals. Lower grades, as well as difficult terrain, require more energy to transport and process the minerals. How strong a part the ocean floor will play in the future as a supplemental mineral source is not known at present; only by extensive exploration, which in itself must be made far more efficient, can we know.

Ocean Floor Exploration

The development of the theory of plate tectonics is having a profound effect upon the general knowledge of geology and morphology, both land and sea. We now know that the creation of new ocean floor is accompanied by the creation of new ore deposits. Besides the activities at the ocean ridges, where new sea floor is being formed, are those associated with volcanic activities. Nevertheless, the great majority of all non-fuel mineral exploration in the recent past has been associated with manganese nodule deposits. The reasons for this, besides having attractive amounts of nickel, copper, and cobalt, is that the nodules were exposed on the ocean floor over large areas. They were found over a hundred years ago by primitive exploration tools. A weighted line with a sticky substance, when lowered to the ocean floor, would occasionally have a manganese nodule stuck to it. They were difficult to miss. Nevertheless, efficient exploration of the manganese nodule deposits required advanced tools, such as the deep towed camera and television equipment, as well as the free-fall "bounce-grab" sampler. This latter device allowed the exploration ship to deploy a number of these samplers in series at a station. These samplers required approximately two hours to make the round trip to the ocean floor. They were designed to grab a small sample, approximately one to

two square feet of ocean floor, hopefully containing some nodules. The bounce sampler is the key manganese nodule exploration tool and was developed specifically for this purpose. Many more exploration tools will have to be developed specifically for different deposits, otherwise exploration will be too costly for the proper commercial development of many different types of sea floor mineral deposits. Several examples can be given. Specifically, what is needed is a family of different types of coring tools. From the alluvial deposits of the shallow waters of the exclusive economic zone (EEZ) to the newly discovered polymetallic sulfides in deeper waters, both within and outside of the EEZ, new and improved sampling devices are needed, not only for the commercial developer but for the scientific community as well.

The new navigation tools such as the satellite earth positioning system (about to be deployed), as well as the side scan sonar and seabeam, will provide the necessary navigation accuracy. This is especially important, as in the past many expensive hours at sea were lost in establishing a reasonably accurate position of the exploration ship. Last, but not least, are improvements planned and being made in exploration ships. These include twin-hulled ships that not only have greater stability, but greater assistance in the launching and recovery of large objects such as discussed in the following paragraphs.

Another development that is necessary for efficient ocean floor exploration for both the scientific and commercial communities is a family of remotely controlled, unmanned vehicles. Depending upon the function, these vehicles can vary in size from approximately one hundred kilograms to a hundred tons and be either attached to the surface ship by an umbilical cable or completely free. A limited number of these vehicles either are developed or being developed. Most are small, single function vehicles. It will be another ten or twenty years before there may be a sufficient variety of these vehicles to perform the necessary exploration and sampling tasks necessary for an extensive development of the world ocean non-fuel resources.

Manganese Nodules

Manganese nodules were first discovered by the H.M.S. *Challenger* on February 15, 1873. Since this first scientific oceanographic effort, oceanographers have repeatedly discovered manganese nodules throughout the world's oceans. It was not until after World War II, when oceanographic exploration was increased extensively by many countries and scientific organizations, that the vast extent of manganese nodules became apparent. The manganese nodule deposits are unique in that they are essentially two dimensional, a few centimeters thick over areas of many thousands square kilometers. Commercial interest began to increase in the early sixties when published scientific papers indicated that sufficient commercial grades of nickel, copper, cobalt and manganese existed on the deep ocean floor.

At that time these metals had exhibited an excellent growth rate, and the mining companies were expanding existing land mines as well as developing new mines. The reported ore grades of the manganese nodules compared very favorably with the ore grades of not only existing land mines but also with planned new mines.

Most mines produce a product that contains more than one metal that can be economically extracted. The name of the metal that produces the greatest revenue is usually given to the mine. A copper mine may also be the source of silver or cobalt or both, but in general, copper is the major source of revenue. Even though the manganese nodules contain large quantities of manganese-about twenty-five percent as compared to about one and a half percent of nickel and less copper and cobalt—many consider the mining of manganese nodules to be a nickel business. This is because expected markets would make nickel the major revenue producer. The potential revenue from all the metals estimated to be obtained from the manganese nodules would be equivalent to that obtained from a pure nickel mine if the grade of the nickel ore were two and one half to three percent. Very few land nickel mines approach a grade this high. Because of this, a number of mining companies decided to initiate detailed exploration of the most promising manganese nodule deposits. Examination of the scientific reports indicated that the so-called Clarion-Clipperton area of the North Central Pacific was most promising. This section of ocean floor is bounded by five and twenty degrees north latitude and approximately one hundred and twenty-five to one hundred and sixty degrees west longitude. During the period of the seventies and early eighties, six international consortia were formed, not only to explore the promising deposits but to develop techniques for mining and processing the nodules. The effort was extensive. It is estimated that in excess of one half billion U.S. dollars was spent by all parties combined.

The results of this effort gave confidence to those involved that the mining and processing of the manganese nodules was technically feasible, but that extensive development work was required before a practical mining operation could begin.

The development of a large scale commercial system can be conveniently divided into three phases; the research and development (R&D) phase, the pilot plant phase, and the engineering and construction phase of the commercial production system. The early 1980's saw the completion of the R&D phase of the deep ocean manganese nodule system. Each consortium had spent approximately one hundred million U.S. dollars on the R&D phase over a period of a decade or more. It is believed that no decision has yet been made to start the pilot plant phase. The reasons for this are paramount. The market prices for the metals derived from the manganese nodules are at a recession low. This coupled with the expectation that it would take at least ten years and in excess of one and a half billion U. S. dollars to establish a commercial operation has deferred industry from proceeding into phase two—the pilot plant. The pilot plant phase would require at least five years time and approximately three hundred million

U.S. dollars. These facts mean that even without any Law of the Sea problems, we would not mine at this time.

However, the resource is there and will be mined eventually. It is possible that some country will subsidize the development of a manganese nodule industry because of strategic reasons, not awaiting a recovery of the markets for these metals.

If in fact some country would subsidize this development, the metals from manganese nodules may be produced before the year 2000. Otherwise, it would require a significant increase in metal prices, at least a doubling of the mid-1980 prices, to attract the high-risk capital necessary for the commercial development of manganese nodule resources.

It must be remembered, however, that mines do not last forever. Regardless of any surplus, world production of metals continues at a high rate and with any demand growth at all, new mines will have to be brought into production. Economic studies indicate that deep ocean manganese nodule mining can compete very well with new land mines. Therefore when the markets require new production, the deep ocean mining of manganese nodules will begin. A review of the historical cycles of mineral production indicates that by the year 2010, there exists a good probability that manganese nodule mining should be well established.

Polymetallic Sulfides

In contrast to the manganese nodules, the polymetallic sulfides are three dimensional, apparently tens of meters high and wide, and up to a hundred meters or more long. Polymetallic sulfides rest in a water depth of approximately two and one half to three thousand meters depth or about half the five thousand meters water depth of the manganese nodules.

Polymetallic sulfides were not discovered until the latter part of the seventies when they were discovered as a result of scientific investigation of the fast spreading ridges where new ocean floor is being formed. Associated with these ridges are hydrothermal vents bringing up heated water from areas close to magma chambers. The vents contain highly mineralized water of high temperature. Apparently, salt water seeps down into the fractured ocean floor becoming heated because of the proximity of magma chambers and acidity due to the presence of sulfur. As a result metals such as copper, zinc, lead, nickel and others are leached out of the rock. The very high pressures keep the water from boiling so that it remains liquid at temperatures of three hundred degrees or more centigrade. Upon returning to the ocean floor from below, some of the metals in the supersaturated water precipitate out and form the deposits.

The marketable grades of the contained metals appear to be much higher than the manganese nodules. As an example, manganese nodules contain approximately one percent copper, while initial sampling of the polymetallic sulfides indicate ten percent. Some samples of polymetallic sulfides indicate grades of zinc up to fifty percent or more. The sulfides are crystalline in nature and therefore can be concentrated if desired. To

date, insufficient samples have been collected to more than speculate on the commercial possibilities. The fact that the polymetallic deposits are at half the depth of the manganese nodules and much closer to land may give them an economic advantage over the manganese nodules. On the other hand, the tools required for the efficient exploration of polymetallic sulfides do not exist and therefore the required exploration tools must be developed and extensively used before it is known that commercial deposits exist. This development and use would take about ten years—five years for development and five years for exploration. This time period could be shortened considerably if some samples, resulting from scientific investigations, indicated sufficient quantities of gold, platinum, silver, etc., to make an otherwise high-risk development worthwhile.

Some of the polymetallic sulfide deposits are within the exclusive economic zone; however, one would expect that the majority of the deposits will be found outside of the EEZ, because the majority of the ocean ridges lie outside of the EEZ.

Associated with the hydrothermal vents are new forms of biological life which depend upon the active vents for their existence. Apparently the vents have a life in the order of tens of years, perhaps not more than a few hundred. Once the vents cease to exist, the biological colonies die out. The environmental consideration to be given this factor is not yet known.

The active hydrothermal vents are known as smokers because they emit a dense particle laden water that has the appearance of a smoke stack on land emitting black or white smoke. Little analysis has been made of the contents of this "smoke." How much of the metal compounds of the hydrothermal vents are deposited in the so-called chimneys that form the vents and how much goes "up in smoke" is not known. Perhaps the smokers could be mined if they were rich enough and if safeguards could be provided for the environment.

Another factor involved here is the fracture rocks up to many hundreds of meters below the polymetallic deposits, the stockworks. They may contain sufficient quantities of minerals to make it practical to mine them.

The life of a deposit once formed is not known. Do they erode or chemically deteriorate with time, or do subsequent deposits of silt preserve them? If they do have a long life, it may be possible to find them at considerable distances from the ocean ridges, moving with the spreading ocean floor.

The foregoing statements are, of course, speculative. Only extensive scientific ocean floor exploration will provide the information necessary for the further commercial development of these deposits.

Phosphate Nodules

Phosphate nodules are found around the world at water depths usually less than five hundred meters. It is believed that the nodules are formed from the phosphate laden water by the upwelling of the nutrient water from greater depths. This occurs at many areas along the continental shelf.

It is expected that most phosphate nodules will be found in the EEZ.

One particular phosphate deposit that appears to have an early commercial development is the one on the Chatham Rise, an area a few hundred kilometers east of New Zealand. Phosphate rock is the principal ingredient of commercial fertilizer. It is a relatively low cost commodity and therefore shipping to great distances can add considerably to the cost. So far the deposits found on the ocean floor are not as rich as those on land. However, if the ocean deposits can be found close to the markets, they may compete with land deposits that have to be shipped great distances. Such a case may exist for New Zealand. Historically, New Zealand has depended upon relatively nearby island deposits for its phosphate. However, these deposits are being depleted and larger and larger quantities of phosphate rock are being obtained from the east coast of the United States. With the cost of energy and shipping increasing, a point may be reached before the year 2000 where the phosphate nodules of the Chatham Rise, which have a phosphate content of about 75% of the U.S. phosphate rock, may be competitive with the U.S. phosphate rock resources.

The deposits of the phosphate nodules have a much higher density than manganese nodules—up to 100 kilograms or more per square meter. This compares with approximately ten kilograms per square meter for manganese nodules. Furthermore, they exist in water depths of approximately 750 meters and close to shore.

These conditions place a much lesser demand upon the technical and engineering requirements of mining and shipping. All these factors give a reasonable probability that phosphate nodules will be one of the minerals to be mined from the ocean floor, if not before the year 2000, certainly soon thereafter.

Manganese Crusts

Manganese crusts are similar to manganese nodules; however, the crusts have a different percentage of metals, are at shallow depths, and are in a layer instead of individual nodules. The manganese crusts are found around sea mounts at approximately one thousand meters depths. The principal attraction is they contain approximately one percent cobalt as compared to about 25% for the manganese nodules. The crust contains less nickel and copper than the manganese nodules. The crusts are a few centimeters thick and being coated on top of a rock substrata may be difficult to mine.

Recent scientific explorations around the Hawaiian chain have discovered a number of deposits. A limited number of analyses of samples have been made. The samples,obtained by breaking off pieces of the crusts with a dredge bucket, are sparse and therefore one can only speculate on the extent of the deposits. It is too early to know if these deposits have any potential commercial value in the near future.

Technology for Deep Ocean Mining

Webster defines technology as (1) the science of the application of knowledge to practical purposes; (2) the totality of the means employed by

a people to provide itself with objects of material culture. The term is often misunderstood, mainly because the application of technology is a highly complicated business.

As a result, industries are very complex and should be thought of as large integrated systems depending upon, and made up of, many different technologies. Often an industry's development will stagnate awaiting breakthroughs in other technologies that will allow an efficient system to be designed. Another factor to be considered is the development stage of a particular technology. To the scientist, technology is available or useful when it comes out of the laboratory. To the engineer, technology is available at the completion of the pilot plant stage. To the industrialist, technology is available when the full commercial plant is on-stream and operating successfully. To the financier, the technology may not be available until a respectable return on investment is obtained.

Based upon the above criteria, one can say that technology development of deep ocean mining is out of the laboratory and is awaiting the pilot plant stage. The engineering and operating problems are known and believed to be solvable with the application of available technologies.

As an example, the deep ocean mining tests so far have demonstrated that large machinery in excess of a hundred tons can be lowered to the ocean floor approximately five thousand meters and operated successfully. The large machinery includes electrical, hydraulic and mechanical systems in the range of approximately one hundred to one thousand horsepower. The electrical system includes cables, transformers, switches, and electrical motors handling voltage ranging from one hundred to eight thousand volts. The sensors include television, sonar, pressure, temperature, electrical, and mechanical activity. The electronics include command and control, multiplexing, and data handling systems.

Based upon this technology it is believed that any ore body at or near the surface of the ocean floor with little or no overburden can be successfully mined from any location on the ocean floor to water depths of approximately six thousand meters. However, the development period for a full commercial plant is approximately eight to ten years. What is required is the discovery of an ore body rich enough to attract the risk capital necessary to finance the large front end development costs. In addition, the legal institution under which the miner must operate has to be designed for authorization and for reasonable taxation.

In summary, there is no known technology barrier preventing the development of a commercial deep ocean mining system.

Part XI of the Law of the Sea Treaty

Since the subject matter is the deep seabed and ocean mining, Part XI of the treaty is of primary concern.

Prior to and early in the activities of the Third United Nations Conference on the Law of the Sea it was hoped, especially by the United States mining industry, that whatever authority was established by the U.N. on

the deep seabed, it would be limited to a regulatory and license issuing activity. However, it soon became apparent that the Third World would not accept such a limited authority.

The mining industry of the United States and many other industrial countries were in favor of an international organization that was empowered to issue licenses and provide regulations on environmental and safety issues. Any further authority, especially that deviating from the free market, was strongly opposed. Therefore, initially the concerned industrial organizations looked upon the Third Conference with a positive approach to the development of ocean mineral resources.

It soon became evident that the Third World, *i.e.*, the developing countries, desired to establish an authoritative body over the deep seabed that would exercise complete control by a one nation, one vote rule, thereby granting the industrial developed countries little, if any, control over the deep seabed. Furthermore, the Third World's objective was a "state owned mining company" to the exclusion of a licensed private corporation to mine the deep sea floor minerals.

Later in the negotiations of the Third U. N. Conference on the Law of the Sea (UNCLOS), a compromise was achieved with the so-called parallel system. Under this arrangement a private corporation would be licensed to mine in parallel with the Seabed Authority. Because of the bias against the private corporation in the resulting compromise, the parallel system was considered also unsatisfactory by the United States mining industry.

It is believed there are several reasons why the Third World took such a strong stand on establishing supreme authority of the oceans with the Seabed Authority. First was the belief that the manganese nodules and yet-to-be discovered minerals of the deep seabed contained vast wealth that was easily translated into U. S. dollars. Second was the philosophy of the New International Economic Order, and third was the belief in the advantage of a central planned economy which, of course, is employed by most of the Third World.

The present known wealth of the ocean floor is almost exclusively confined to petroleum resources which occur on the continental shelves. In fact, approximately ninety-five percent or more of the known ocean resources occur within two hundred nautical miles of the coast lines of the world. The reason for this is that the thick sedimentary deposits, several kilometers, which are necessary to the confinement of petroleum resources exist on continental shelves and not on the deep ocean floor. The exceptions to this are such areas as the Gulf of Mexico. However, geologically the Gulf is not a true ocean floor, but a subsidence of a land mass. The true ocean floor contains a very thin sedimentary layer, usually less than one-quarter kilometer. In some areas there is no sedimentary cover, therefore the deep ocean floor is unable to confine a petroleum resource. The reason for this is that the deep ocean floor is very young geologically, due to the movement of the tectonic plates resulting from the creation of new ocean floor of the ridges and the destruction of the old ocean floor of the

conversion zones. As a result, there is not sufficient time to accumulate a thick sediment. It is ironic that the Third World was willing to exclude from the Seabed Authority the real richness of the ocean floor by the adoption of such a wide, two hundred nautical miles Exclusive Economic Zone. Under the terms of the treaty, the natural resources of the exclusive economic zone (EEZ) belong to the adjacent nation.

Other minerals will be found in the seabed and hopefully in large quantities, but if the resources of the continents are any indication, energy minerals, such as petroleum, will dominate by a wide margin the market value of the non-energy minerals.

The philosophy of the New International Economic Order and the Centralized Planning Authority are alien to the free market economy, which has a proven record for providing a good environment for economic growth and industrial development. The Third World therefore has erected high barriers to the accumulation of the capital, technology, and management necessary to the development of the ocean resources of the deep seabed.

There are many provisions of the Law of the Sea Treaty that make it exceedingly difficult, if not impossible, to raise the necessary risk capital in the free world to develop the deep seabed under the proposed Deep Seabed Authority. These provisions make freedom of access to markets practically impossible. Two provisions, among many, have been stated as unacceptable to the industry: the first is production controls and the second is technology transfer.

The production control formula is a mathematically devised formula based upon the past nickel world production. As discussed previously, there are great risks in attempting to predict future markets, so that one has to have maximum flexibility in investment and production to make any industrial activity a viable one.

The technology transfer provision is written in such a way that makes it practically impossible to transfer technology. One of the reasons for this is the third party provision. This provision requires that third party technology be transferred to the Seabed Authority for use in the mining system of the Authority. The development of any large complex system such as a deep seabed mining system requires the use of supplier technology. In fact, as much as two-thirds or more of the technology in any large system belongs to subcontractors or their subcontractors or other third parties. Furthermore, in many cases the prime contractor encourages the subcontractor to invest R&D dollars in their products to improve overall efficiency. Of course, the subcontractor depends upon the market for the improved product to recover his R&D investment. Mandatory transfer of the third party technology would have a devastating effect upon the development of a deep sea mining system. At the very least, the best technology would not be available and many standard products otherwise on the market would become unobtainable.

Several other parts of Part XI are also unacceptable:

1. Half of any exploration site must be ceded to the Enterprise, thus doubling the exploration expense.

2. The high degree of the discretionary powers of the Authority places many uncertainties in the processing procedures. The delays and expenses could cause great difficulty.

3. The Authority can become party to commodity agreements and thereby close access to markets to the applicant.

4. The requirement of one million U.S. dollars a year for a mining permit is considered to be excessive.

5. Obtaining a license in the first place can be extremely difficult and time consuming. Even though the work plan of the applicant is complete and meets known requirements, the council, by three-fourths majority, can reject the applicant.

6. Once approved by the Council of the Seabed Authority, the Council may reverse its decision by consensus. The only recourse then is a dispute settlement procedure.

7. In approximately fifteen to twenty years, the Law of the Sea Treaty may be changed in an unspecified manner by a three-fourths vote of the treaty members. It may not be possible for a corporation to recover its investment with a reasonable rate of return by this time. One possibility is the Authority taking control of the mining activities of the licensed corporation placing the corporation at great risk.

As a consequence of the language in the Part XI it is doubtful that there will be extensive development of deep seabed mining by the early part of the twenty-first century under the Authority. There are other more likely possibilities.

By the close of 1984, two years after the signing of the treaty by approximately one hundred and thirty nations, only fourteen have ratified the treaty. Practically all of the nations that have ratified are developing countries. The treaty is scheduled to come into force a year after it has been ratified by sixty nations. At the present time the pre-treaty functions are being administered by the Preparatory Commission which is empowered to receive applications for exploration licenses and to prepare the exploration and mining rules and regulations. As such, the Preparatory Commission is being financed by the general funds of the United Nations. Once the treaty comes into force, the Authority will be financed by the treaty members. The funding requirements could be quite large. This could delay, perhaps indefinitely, the ratification of the treaty by a sufficient number of industrial countries that would have to carry the financial burden.

Whether or not there is a long delay in the treaty ratification process, two other activities could encourage deep sea mining under favorable market conditions. One activity is already in process; it is the Reciprocal States Agreement with the United States, Great Britain, France, Germany, Japan, Italy, the Netherlands and Belgium, agreeing to recognize the claims of its citizens. Exploration licenses have been issued by the United States, Great Britain, France and Japan and others may follow.

There always exists the possibility of a fourth Law of the Sea Conference or a reconvening of the Third Conference to renegotiate the Part XI

provisions that are keeping many of the industrial countries from signing or ratifying the treaty. In this case it may be possible for the industrial countries, particularly the United States, to obtain the necessary revisions that would encourage signing and ratification by the United States and other industrial countries.

Summary

In summary, a good recovery of the world mineral markets is the necessary incentive to the development of ocean mining. Economic studies have shown that ocean mining of manganese nodules can compete successfully with new land nickel mines, but not with existing mines where the large capital investments have already been spent. Thus manganese nodules may not be the first mineral to be developed from the ocean floor. On the positive side, we know more about this mineral than any other non-fuel mineral on the ocean floor. However, the nodules are in deep water and because of the ore grade large-scale operations are necessary. This requires a large capital investment.

There is the special case of the phosphate nodules which are at much shallower depths and require a much smaller operation than the manganese nodules and therefore require much less capital costs than the manganese nodules. Again, markets are the dominant factor in the development of this mineral.

Some very rich mineral samples have been found by scientists among the polymetallic sulfides of the spreading ocean ridges. Improved sampling tools will aid in determining the nature and extent of these potentially promising deposits. Here again, improvements in the metal markets are necessary to encourage commercial exploration of these deposits. In the meantime, the scientific community, both with the government and private institutions, is learning more about the geology and morphology associated with the area surrounding these deposits. Some of the samples have shown traces of gold and platinum, besides high grades of zinc and copper. A combination of favorable factors deriving from the scientific work being done could stimulate early development.

A major factor in the early development of marine minerals is the development of efficient exploration tools. While some excellent progress has been made in such areas as sonar and navigation, there is a lag in the development of efficient sampling tools. Not only does it take too long to obtain a sample, the sample can be of questionable value. The market for these improved tools has not been sufficiently large to encourage equipment manufacturers to make the necessary expenditures.

These improved tools are necessary in the scientific community as well as in the commercial field. It would seem reasonable for the United States government to support the development of the basic ocean floor exploration tools just as they have supported the development of the base space exploration tools. The lack of efficient exploration will not prevent ocean floor development, but only slow it. Polymetallic sulfides were only

speculated to exist, and were not found until about 1980. Because of the vast size of the ocean floor, and increased scientific exploration, more mineral resources will be found.

Experimental mining tests at sea have shown that mining the deep ocean floor is technically feasible. Scientific and technical breakthroughs are not necessary. Large machinery containing an array of mechanical, electrical, hydraulic, and electronic components can be placed on the deep ocean floor and remotely operated with confidence. Successful operations of large complex machinery, both on the surface and subsurface, have been demonstrated by the offshore oil industry. The basic problem is one of engineering and design of an efficient system that can compete with equivalent land operations.

It is believed that the Law of the Sea Treaty will not deter the development of an attractive ore resource. Activities will either choose to operate outside the treaty or eventually changes will be made to make it attractive to operate inside it. The ratification progress has been slow; only one-fourth of the necessary countries have ratified it after two years. It is believed that Part XI, the deep seabed portion, will require a number of changes before it becomes a practical operating instrument.

Deep seabed mining development has been delayed principally because of the depressed minerals market, and secondly, because of the lack of exploration tools. The other factors—political, legal, technology, and environmental—are lesser factors. From a historical perspective we should see a reasonably good market improvement in minerals, as well as excellent development of explorations tools, in the next five years which will provide a good foundation for ocean floor development.

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