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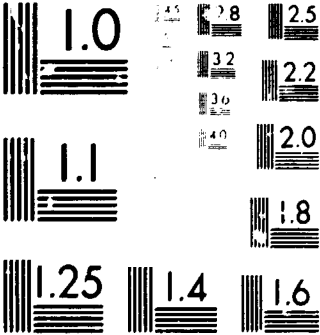

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TECHNOLOGIES FOR INVESTIGATION AND EXPLOITATION OF SEABED RESOURCES: THE POTENTIAL FOR DEVELOPING COUNTRIES*

by

David A. Ross
UNIDO Consultant

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CONTENTS

INTRODUCTION

With the world's population growing at a rate of close to 200,000 people a day, there are increasing demands being placed on the limited mineral resources of our planet. A particular need is for new sources of minerals, including hydrocarbons, that are necessary in our technologically complex world. The needs are especially important for developing countries that want to achieve economic development. Since mineral deposits are non-renewable, new sources implies either actually discovering new deposits or improving the "yield" from present mineral reserves. In either instance sophisticated technology is needed. The search for new mineral deposits eventually had to turn toward the ocean which, besides covering about 72% of the earth's surface, is an essentially unexplored and frontier region for minerals. Marine exploration and exploitation also will be accelerated by the proposed Convention of the United Nations Law of the Sea Conference which will give coastal States control of mineral resources out to at least 200 nautical miles off their coasts. The establishment of a mining regime for the deep sea bed, including the formation of a Deep Sea Authority, could lead to the mining of manganese nodules by the late 1980s.

As developing countries become more industrialized and improve their standards of living they will need additional mineral resources; this will reduce further the remaining supply. All these pressures should increase the value of many minerals found in the marine environment and may make exploitation economical for deposits in deeper water and farther offshore. Hydrocarbon exploitation has already shown this trend and exploitation from marine areas will continue to be critical until nuclear power, solar energy, conservation and other energy sources reduce the dependence on hydrocarbons; a prospect that does not seem imminent. The recent increase in costs for some minerals, such as nickel and sand and gravel, have brought prices to a level where some marine sources are economically compatible or even better than land-based sources.

In one sense, the probability of actually running out of most minerals is small since the amount of many minerals in the earth's crust is awesome. As an example, a cubic kilometer of average crustal rock contains about 106,000,000 tons of aluminum and 50,000,000 tons of iron. This does not mean that they can be economically recovered but rather that a physical exhaustion of most minerals (with the important exception of oil and gas) is technically impossible, if one is willing to pay the price. The price need not be expressed in units of money. For example, if more energy is required to recover oil than the oil contains, the recovery of that oil is not economical.

I. POTENTIAL SEABED RESOURCES OF THE CONTINENTAL MARGIN

The continental margin includes the coastal zone, continental shelf, continental slope and, if present, the continental rise or borderland (Figure 1). As such its area worldwide is equivalent to more than 50% of the total land area (see Table 1). The mineral resources of this region (Figure 2) can be divided into the following categories: elements in solution (including seawater); minerals recoverable from the underlying bedrock (such as coal, tin and iron); minerals on the seafloor (such as placers, sand, gravel and shells, phosphates and manganese nodules); and hydrocarbons or sulfur buried deep within sediments. This report will focus on the last three categories.

Minerals Recoverable from the Underlying Bedrock (Coal, Tin and Iron)

Minerals that are found and mined near the coast are usually recovered by just extending the mining operation out under the seafloor. For example, coal mining has been done in this manner off Japan, Scotland, Nova Scotia and the United Kingdom. Another example is a bauxite deposit discovered in the early 1950s near the Gulf of Carpentaria in Australia that has subsequently been extended seaward for several miles, and is now one of the world's largest bauxite mines. Mining operations for these types of deposits (see later sections of this paper) are similar to land operations.

In 1978 about 34 million metric tons of coal was mined from offshore sites, including areas off Australia, Canada, Chile, Japan, Turkey and the United Kingdom (Earney, 1980). One mine, off Nova Scotia, extends 8 km offshore, employs 4,000 workers and has been producing for over 100

Figure 1. General characteristics of the continental margin (adapted from McKelvey and others, 1969). Not drawn to scale.

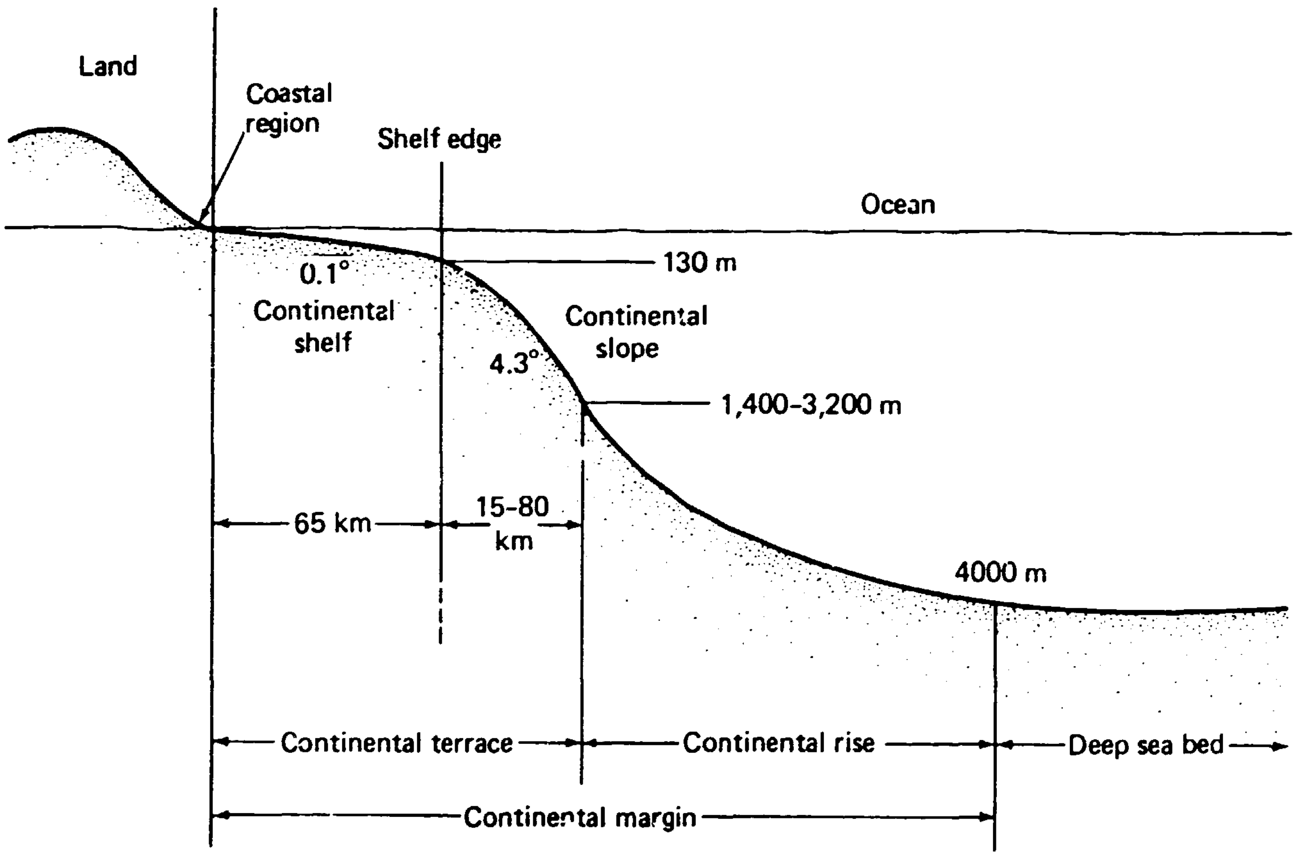


Table 1. Percentage of Major Topographic Features in the Main Oceans and Adjacent Seas[a]

Oceans and Adjacent Seas	Continental Margin[b]		Deep Sea			
	Continental Shelves and Slopes	Continental Rise and Partially Filled Sedimentary Basins	Abyssal Plains	Oceanic Ridges	Other Areas	Percent of Total Ocean
Pacific and adjacent seas	13.1	2.7	43.0	35.9	6.3	50.1
Atlantic and adjacent seas	17.7	8.0	39.3	32.3	2.7	26.0
Indian and adjacent seas	9.1	5.7	49.2	30.2	5.8	20.5
Arctic and adjacent seas	68.2	20.8	0	4.2	6.8	3.4
Percent of total ocean in each group	15.3	5.3	41.8	32.7	4.9	100.0

a/Data from Menard and Smith (1966).
b/The continental margin has an area of about 74.5 million square kilometers (28.8 million square miles).

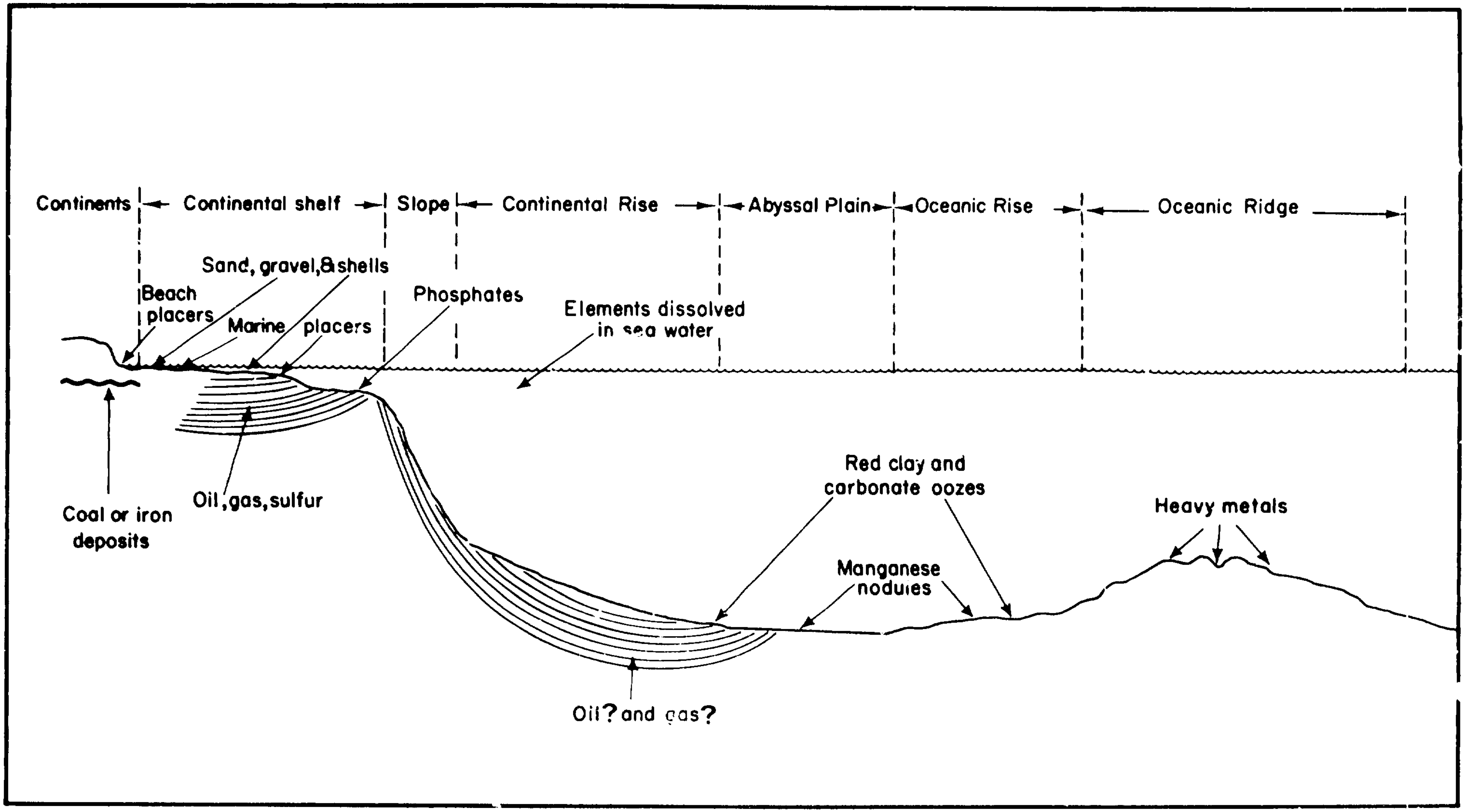


Figure 2. A generalized view of the major possible minerals available from the ocean. (From Ross, 1977)

years. About 40% of Japan's coal[1/] and 10% of coal from the United Kingdom is from offshore production (Holden, 1975). Other minerals recovered from below the seafloor have included tin from off Cornwall (United Kingdom), and iron off Finland, Australia, Newfoundland and the island of Elba. Salt deposits are mined from beneath the North Sea and Gulf of Mexico. Similar deposits exist under the Red Sea, Persian Gulf, and parts of the Mediterranean. Although most subsea operations are off developed countries, similar possibilities, once the discoveries on land are made, could be common elsewhere.

It should be stressed that subsurface marine mineral deposits (other than hydrocarbons) unrelated to land occurrences have yet to be mined or even seriously explored. In the deep sea (see Figure 1), little thought has been given as to whether buried deposits occur, although recent discoveries of metal sulfide minerals along present ocean ridges (Red Sea, East Pacific Rise, for example) suggest that similar, but ancient and buried, deposits may be found buried away from the ridges. On the continental margin, however, the similarity of rock types and geological history with those of the continent suggests that mineral deposits typical of land may be commonly buried below the sea floor. At present no satisfactory technology, other than drilling, exists to detect and evaluate such a marine deposit. In addition, there could be an extremely high cost involved to remove any overburden before such a deposit could be reached.

[1/] Some of the coal mining operations of Japan have recently been abandoned; so the actual percentage is less.

Minerals Recoverable from the Seafloor (Placers, Sand, Gravel and Shells)

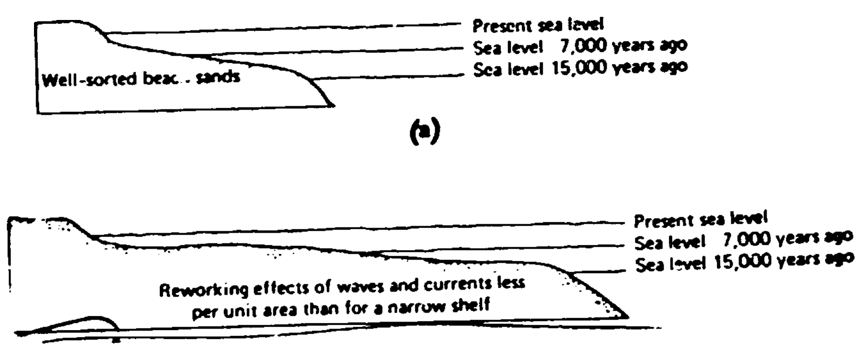
Mineral deposits on the seafloor (excluding, for the moment, phosphorite and manganese nodules) are generally due to three key factors: (1) the large amount of sediment present; (2) the reworking effects of waves and currents combined with recent changes in sea level; and (3) how an area has evolved and been affected by the processes of seafloor spreading and plate tectonics. (This latter subject in itself would take a major article to explain; those interested in further explanation should read Emery and Skinner, 1977 or Cronan, 1980.)

In general, most continental margins have several kilometers of sediment on their shelves, usually lesser thickness on their slopes (which are usually areas of faulting and slumping), and large thicknesses at the bases of the slope and seaward forming the continental rise. For example, up to 16 km (10 miles) of sediment lie along the continental margin of the eastern United States. Most of these sediments are derived from erosion of rocks on land and are carried to the ocean by various mechanisms including rivers, wind and coastal processes. The other major source of sediments is from biological and chemical reactions in the overlying water or on the seabed. On some continental margins, sediments have accumulated for hundreds of millions of years and reached thicknesses of ten kilometers or more. This aspect, combined with certain oceanographic conditions, could lead to conditions favourable for oil and gas accumulation. This is discussed in the next section.

The second key factor is the possible reworking of surface sediments by waves and currents combined with the rise and fall of sea level. These processes can directly account for the formation of certain mineral deposits. It is generally accepted that sea level has risen by as much as 130 meters in the past 15-20,000 years. But, this is only the most recent change and several other sea-level changes have occurred during the past million years. As a result of the most recent sea level rise, the shoreline, which was then near the edge of the present continental slope, moved landward over what was then exposed continental shelf. As the shoreline moved, the area of influence of coastal processes as well as the beach also moved. When shoreline movement was rapid (due to either a fast rise or fall of sea level or perhaps only a moderate change but occurring over a very gently sloping wide shelf), a beach could be stranded or left behind forming an ancient beach ridge. If biological processes were active, shell deposits could also be left behind.

On a narrow shelf, with a modest or steep slope, the shoreline movement would be relatively slow. Reworking of sediments by coastal processes, waves and currents can result in a selective sorting of the sediments by mechanical action, with finer-grained or lower density minerals being winnowed away leaving coarser-grained (gravel or large sand grains) and/or relatively higher density minerals (called heavy minerals) behind. On a slowly moving shoreline, reworking could be relatively intense, whereas, on a wide, gently sloping beach, the shoreline could move more rapidly with time, and reworking would not be as effective (Figure 3). If the rise or fall of sea level paused for a period of time, reworking would then focus on the corresponding shoreline-beach area.

Figure 3. The relative effects of rising sea level on (a) a narrow shelf and (b) a wide shelf.



(b)

One effect of reworking by waves and currents is that minerals that initially were widely dispersed on the sea floor can become relatively concentrated possibly forming a mineral deposit. Such processes are obviously more effective in shallow water (or where the water once was shallow) than in deep water where the reworking effects of waves and currents are minimal. Concentrations of such minerals or sediments often are referred to as placers. The term placer is generally applied to any unconsolidated accumulation of minerals or rocks near or on the seabed (Duane, 1976). Depending on the minerals involved, some deposits can be very valuable (Table 2). To a very large degree minerals in placers are a function of the adjacent geology since placer minerals are usually very heavy relative to quartz grains and are not carried very far from their source (usually igneous rocks). Placer minerals can include magnetite, rutile, ilmenite, zircon, platinum, diamonds and gold. These minerals, besides having a high specific gravity, are also very resistant to chemical and physical processes of destruction and thus can survive the erosional and mechanical effects of reworking. In many instances, the best placer deposits are found in or on the modern or present beach. Often there are aesthetic or environmental objections to their mining and it may be more desirable to mine offshore on ancient beaches or river channels. Some examples of placer deposits are gold and platinum found off Alaska; tin (cassiterite) and rutile off Australia and South-east Asia; zircon and rutile from the beaches of Sri Lanka; monazite and ilmenite from south India; and, in the past, diamonds off Africa.

Table 2. Mineral Deposits on the Sea Floor of the Continental Margin (From Ross, 1980)

Minerals	Use	Possible Mineable Marine Areas[a]	Value[b]
Marine placers			
Gold	Jewelry, electronics	Alaska, Oregon, California, Phillippines, Australia	$500 or more per ounce
Platinum	Jewelry, industry	Alaska	$700 or more per ounce
Magnetite	Iron ore	Black Sea, Russia, Japan, Phillippines	$6-11/ton
Ilmenite	Source of titanite	Baltic, Russia, Australia	$20-35/ton
Zircon	Source of zirconium	Black Sea, Baltic, Australia	$45/ton
Rutile	Source of titanite	Australia, Russia	$100/ton
Titanite	Source of titanite	Australia, Phillippines	
Cassiterite	Source of tin	Malaysia, Thailand, Indonesia, Australia, England, Russia	
Monazite	Source of rare earth elements	Australia, United States	$170/ton
Chromite	Source of chromium	Australia	$25/ton
Sand and gravel	Construction	Most continental shelves	
Calcium carbonate (aragonite)	Construction, cement, agriculture	Bahamas, Iceland, southeastern United States	
Barium sulfate	Drilling mud, glass and paint	Alaska	
Diamonds	Jewelry, industry	Southwest Africa	
Phosphorite	Fertilizer	United States, Japan, Australia, Spain, South America, South Africa, India, Mexico	$6-12/ton
Glauconite	Source of potassium for fertilizer		
Potash	Source of potassium	England, Alaska	

[a]Not necessarily including all areas, [illegible] in many localities exploration has been nil or minimal.
[b]Can vary depending upon degree of ref[illegible] data from various sources and may be in error because of changing economic conditions.

After hydrocarbons, sand, gravel and shells are the second most valuable marine minerals presently obtained from the ocean. On a weight basis, its consumption is one of the highest of all. As an example, almost a billion tons of sand and gravel are mined each year in the United States and this number could double by the year 2000. The construction of a basement for a 9 x 12 meter house, for example, uses as much as 80 tons of sand and gravel aggregate; one mile (1.6 km) of a four lane highway uses up to 100,000 tons of mineral aggregate. Other uses include beach replenishment, industrial abrasives and landfill. Although sand, gravel and shells are, on a weight basis, a relatively low-cost commodity their value should increase in the future, especially near areas of development as present sources on land are either used up or covered by development. However, because of the large volumes involved, transportation is generally the major of any operation. Thus only those marine sources close to areas of use can become economically feasible. In some countries large amounts of marine sand and gravel are already being mined; in the United Kingdom more than 75 dredges are operating. Other major producers are Japan, Denmark, the Netherlands, Sweden, Thailand, Hong Kong, France, and the United States.

Sand and gravel are common in many shelf areas, especially those that have been heavily reworked or glaciated; shell deposits are more typical in tropical or semi-tropical regions. As an example the upper 3 m of sediment off the north-eastern United States have been estimated to contain more than 400 billion tons of sand (Manheim, 1972). Similar deposits, although perhaps not as extensive, are common to many shelves of the world. An analagous resource is calcium carbonate, generally from oyster or clam shells. Calcium carbonate can be used in construction for roads as well as for a source of lime for agriculture or cement. Deposits are currently mined off the United States, Mexico, Scotland and Iceland.

Other, somewhat similar types of marine mineral resources include barite, coral, aragonite and, previously, diamonds. Barite, used in drilling muds, is presently mined off Alaska at a rate of over 1,000 tons a day. Coral can be obtained by diving or dredging from reef areas (generally in the tropics) and is mostly used in jewellry. Pink and black varieties, recovered off Hawaii, are especially prized. A small submersible has been used in a coral mining industry off the island of Taiwan (Baram, Rice and Lee, 1978) and Hawaii; coral is also mined off Sri Lanka as a source of lime. Aragonite, a relatively pure form of calcium carbonate, is mined as aragonite sand in the Bahamas. Close to a billion tons is present and over 1.5 million tons are mined each year. Diamonds were mined off the coast of south-west Africa although it is not known if the operation which ended in 1971, was profitable.

Phosphorites. Phosphorite and manganese nodules formed by chemical processes are two other important mineral deposits found on the seafloor. Phosphorite-rich rocks and sands (which may be concentrated by reworking) are common to many areas (Figure 4) of the seafloor and under the right circumstances could be mined and used for fertilizer. No deposits presently are being worked in spite of the fact that they usually assay between 20% and 30% P_2O_5, a value close to that needed in fertilizer manufacture. The water depth of most deposits and problems of recovery, transportation costs, government restrictions, and more

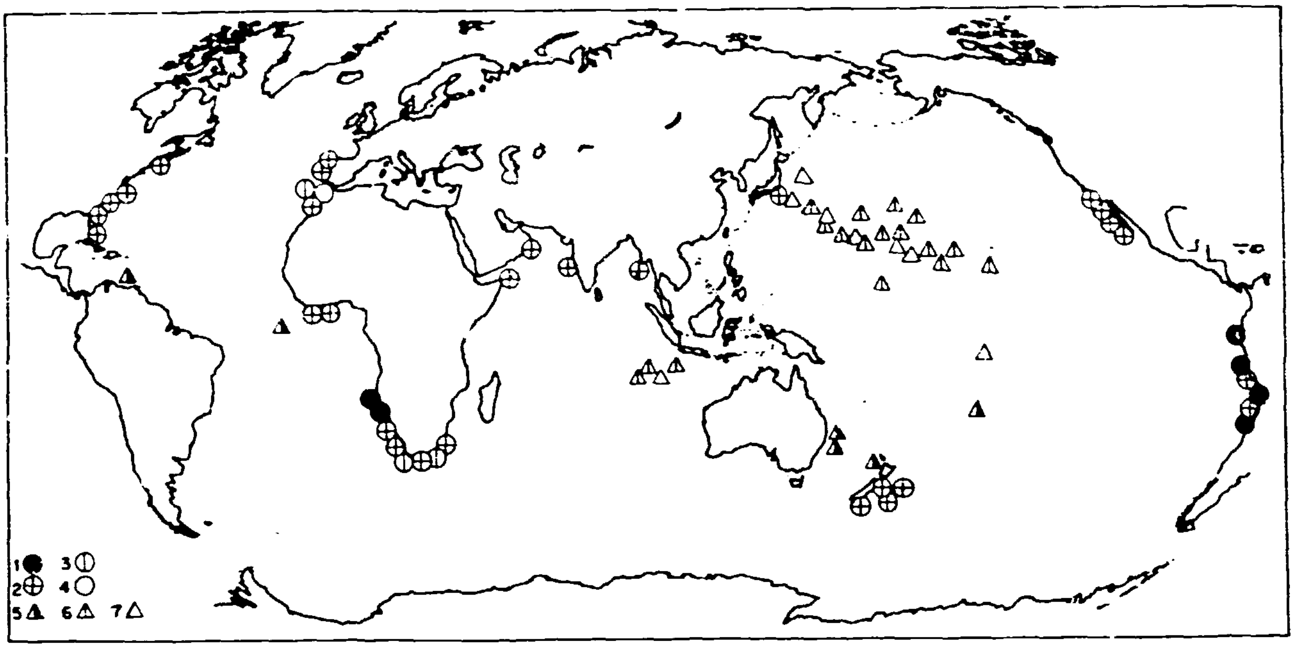


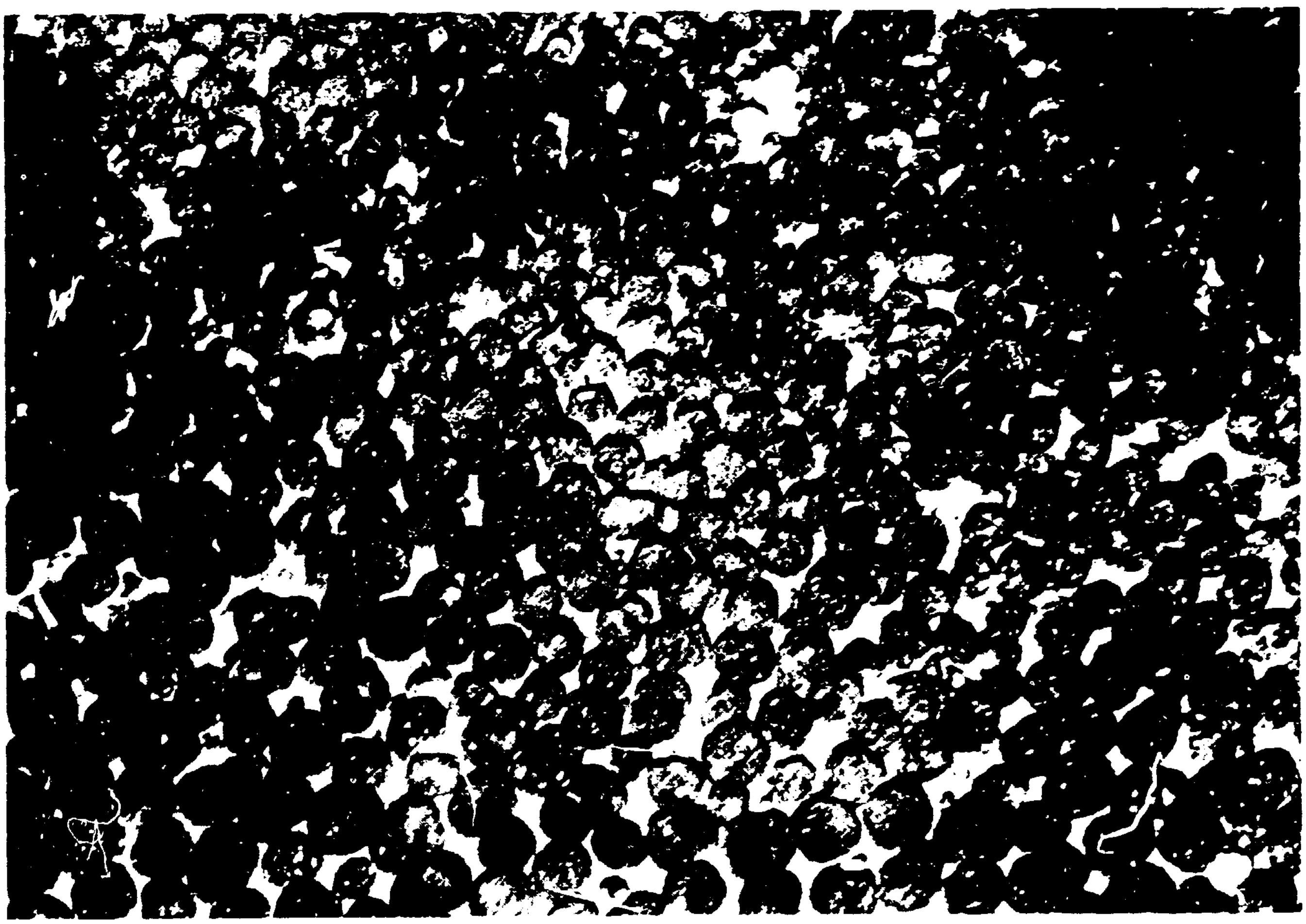
Figure 4. Location of marine phosphorites. Symbols 1-4 indicate deposits found on the continental margin, symbols 5-7 are those found on submerged mountains. The individual numbers refer to the age of the deposit and are not important to this discussion. Data from Bezrukov and Baturin, 1979.

competitive land sources generally have prevented most marine phosphorite deposits from being mined up to the present. However, some marine mining operations are seriously being considered off certain offshore localities near agricultural areas (India and New Zealand are examples), especially if the countries are phosphorite importers. It has been estimated that needs for P_2O_5 will increase in the near future by about 6%-10% per year. From 1965 to 1975 there was a 100% increase in demand that reached a total consumption of over 120 million metric tons of phosphate rock a year. Phosphate deposits off south-eastern United States alone cover an area of over 125,000 km^2 and contain several billions of tons of phosphate, although the grade of the P_2O_5 in these deposits is lower than that of most land reserves. Marine phosphorites often contain other minerals which may lower their phosphate content and make refining difficult. Pollution and other problems involving the land mining operations, on the other hand, may make marine sources of phosphate more attractive in the future.

The origin of phosphorite has become increasingly better understood in recent years (see review in Manheim and Gulbranden. 1979). It tends to occur in areas of upwelling, where cold nutrient-rich waters (phosphate is a nutrient) come to the surface but where sand and clay deposition is low. Marine phosphates can be found in waters as shallow as 20 m or deeper than 1,100 m off Africa (Mero, 1964). Exploitation, when it occurs, probably will be from relatively shallow and nearshore waters. Phosphatic sand and gravel, reworked and concentrated by marine processes, may be especially promising because its phosphate concentration may be higher than the primary phosphate-bearing sediments.

Manganese Nodules. Manganese nodules or, as they are sometimes called, iron-manganese or ferro-manganese deposits, are an especially interesting potential marine mineral resource. These deposits often occur as round spheres (nodules) on the sea floor having a diameter of 1-20 centimeters (Figure 5) or as coatings on rocks and other objects, sometimes forming pavements. In general, they occur beyond the continental rise or outside the continental margin. However, there are some regions of the world where they occur within areas under coastal State jurisdiction and, for that reason, are discussed here (Figure 6). The deposits mainly are composed of hydrated oxides of iron and manganese formed around some sort of nucleus such as a small shell, rock or shark's tooth. Although they are mainly found in the deep sea they also occur in lakes and other shallow water bodies. Nodules have been known for a century but have only recently provoked considerable interest due to their contents of copper, nickel, cobalt as well as manganese, combined with the apparent fact that they may easily be recovered from the seafloor. Although common to most oceans, their concentrations in numbers and chemical composition is variable (Table 3). The contents of some elements such as copper or nickel may be inversely proportional to the amount of nodules on the seafloor (Menard and Fraser, 1978). It is not yet completely understood why some areas have high metal contents while others have low but this is probably related into the origin of the nodules, which also is controversial. Nodules are especially abundant in areas with very low sedimentation rates such as abyssal plains. This is understandable since nodule accumulation rates may be of the order of a millimeter or so every million years, and they would be buried quickly in regions having even modest sedimentation rates. Even so, the lack of complete burial of nodules in prime Pacific areas is still a controversial and poorly understood problem.

Figure 5. Manganese nodules on the floor of the south-western Pacific Ocean. The average size of each nodule is about 10 cm, water depth is about 5,200m.



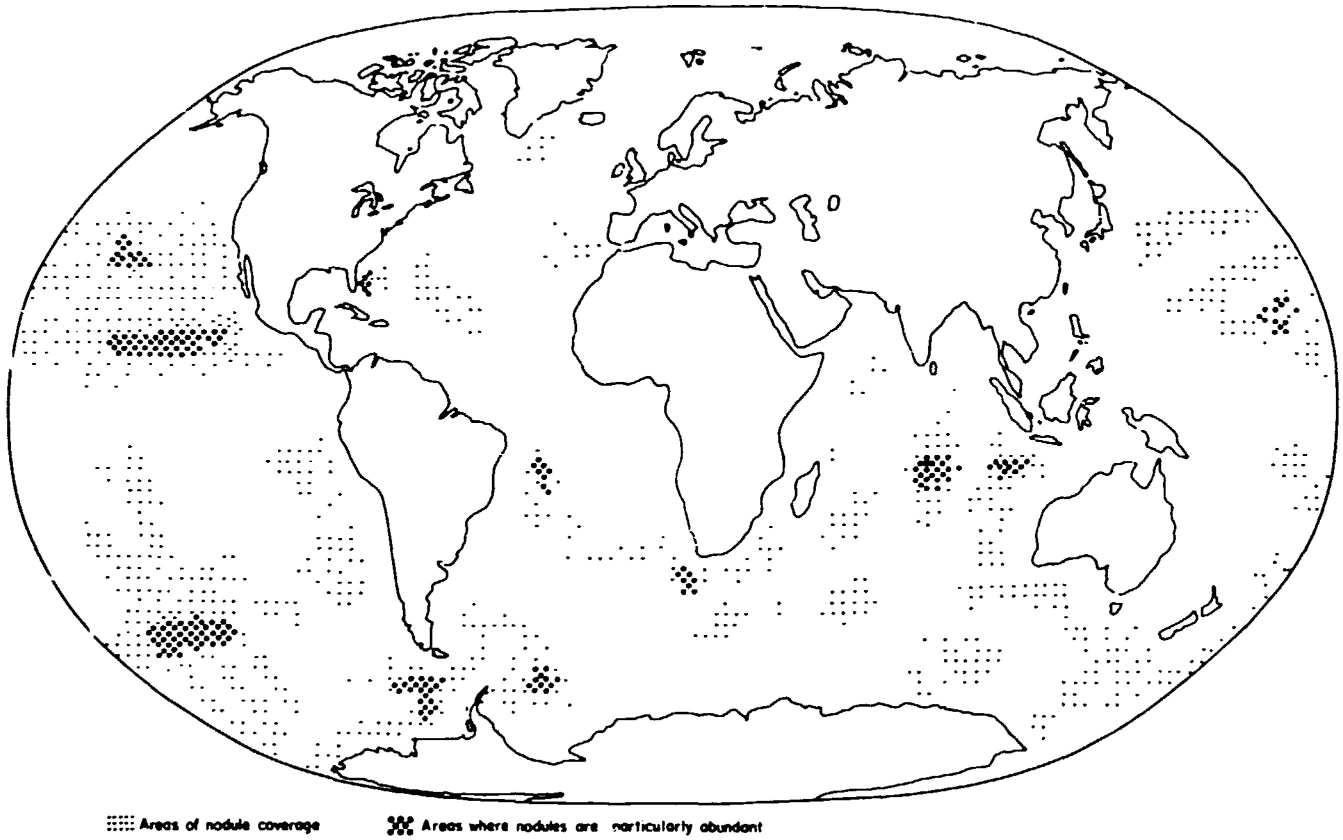


Figure 6. Distribution of manganese nodules in the ocean. (After Rawson and Ryan, 1978 and other sources from Cronan, 1980).

Table 3

Average Composition of Manganese Nodules from the Different Oceans

Minerals	South Pacific[a]	North Pacific[a]	West Indian[a]	East Indian[a]	Atlantic Blake Plateau[b]	Atlantic[c]
Manganese	16.61	12.29	13.56	15.83	15	16.18
Iron	13.92	12.00	15.75	11.31	11	21.92
Nickel	0.433	0.422	0.322	0.512	0.4	0.297
Cobalt	0.595	0.144	0.358	0.153	0.3	0.309
Copper	0.185	0.294	0.102	0.330	0.1	0.109
Lead	0.073	0.015	0.061	0.034	--	--
Molybdenum	0.035	0.018	0.029	0.031	0.03	--

a/Data from Cronan (1967) and Cronan and Tooms (1969) in weight percent, air-dried weight.
b/Data from Manheim (1972) in weight percent, air dried.
c/Data from Cronan (1972) in weight percent, air-dried.

Mineral Deposits Recoverable from below the Sea Floor

Oil, gas, gas hydrates and sulfur are presently the most valuable of the world's marine mineral resources -- a value that now exceeds $100 billion a year and is more than the sum total of all other marine resources. It seems reasonable to anticipate increasing exploitation of these resources. Gas hydrates, whose mineral implications are now under intensive study, can only be considered as a potential resource.

Petroleum is derived from the organic remains of organisms that previously lived in a marine or river environment and, after death, settled and accumulated on the seafloor. The actual chemical processes whereby the organic material is converted into petroleum is complex and far from understood. It is clear, however, that if the organic material is oxidized it will not form petroleum. To be preserved it should either settle into an oxygen-poor environment or into an area where the sedimentation rate is sufficiently high so as to bury the material before it is oxidized. Once the organic material reaches the bottom the conversion process starts, first by bacteria or other organisms that digest the material and redeposit it in modified form. As the material is covered by sediment, additional chemical changes occur, in large part influenced by the heating process associated with deep burial. The need for sufficient burial (on the order of at least a km or so) effectively excludes the deep sea (where sediments rarely exceed 300-600 m in thickness) as a source area of petroleum. In addition the sedimentation rate is so low in the deep sea (a centimeter or so per thousand years) that any organic material reaching the bottom usually remains unburied long enough to be oxidized. There is a possibility of hydrocarbons migrating to reservoir beds in the deep sea, but this is also improbable since most deep-sea sediments are too fine-grained to serve as good reservoir beds.

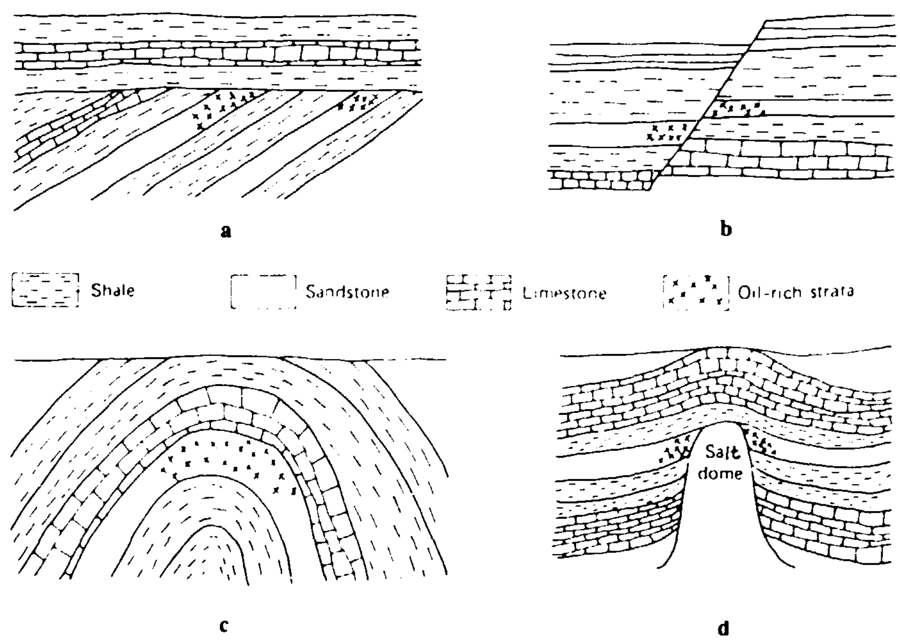
As the chemical process continues, it eventually will result in a hydrocarbon deposit. The amount of time needed is unknown but oil is rarely found in rocks younger than 2-3 million years although it can be found in rocks several hundreds of millions of years old. During the conversion of organic material, the first compounds formed are of relatively high molecular weights - the so-called viscous or heavy oils. With subsequent conversion at higher temperatures these larger molecules may be broken into smaller, lighter and more easily mobile molecules. In the initial stages the material formed is generally found with fine-grained sediments (clay or muds) that were deposited under the reducing conditions. These sediments eventually become rocks and are commonly called source rocks but they rarely can be exploited for petroleum. As petroleum is forming or soon after its formation it can move or migrate usually to coarser-grained rocks such as sandstones or reef deposits, which have large pore spaces through which oil can flow and accumulate (in other words, the rocks have high porosity and permeability). These are the so-called reservoir rocks, which are necessary for an exploitable deposit. The migration of petroleum from source rocks to reservoir rocks is slow and often results from the squeezing out of the interstitial water and petroleum from the fine-grained source sediment as it is compressed into rock. The water and oil move in the direction of least resistance and can travel vertically or laterally. However, if an impermeable layer intersects the migrating fluid, the oil or gas may be trapped and subsequently can be recovered (Figure 7). In sum, the key conditions for the formation of oil and gas deposits are:

1. Initial deposition and preservation of organic material, generally in a marine basin;
2. Burial by sediments and, under appropriate but not completely understood conditions, transformation of the organic material into petroleum;
3. Migration of the petroleum from fine-grained source beds to coarse-grained reservoir beds;
4. Geologic traps that restrict the movement of the oil or gas and concentrate it.

Petroleum actually is very common and occurs in most marine sediments. The problem is finding localities where it is concentrated in sufficient amounts to make it commercially exploitable.

Sulfur is a deposit that is occasionally found as part of a cap rock to a salt dome, often protruding into the sediments of the continental shelf or slope. Salt, formed under previous evaporitic conditions (evaporation of sea water) and buried, can flow upward forming a long, thin plug or dome; these features are especially common in the Gulf of Mexico and have formed traps for some of the oil recovered from that area. As the salt (and associated gypsum) nears the surface, some is dissolved by ground water and a residue or cap rock of relatively insoluble anhydrite may remain. Anhydrite ($CaSO_4$) can be acted upon by petroleum and bacteria, forming hydrogen sulfide gas, water, and the mineral calcite ($CaCO_3$). If oxygen then reacts with the hydrogen

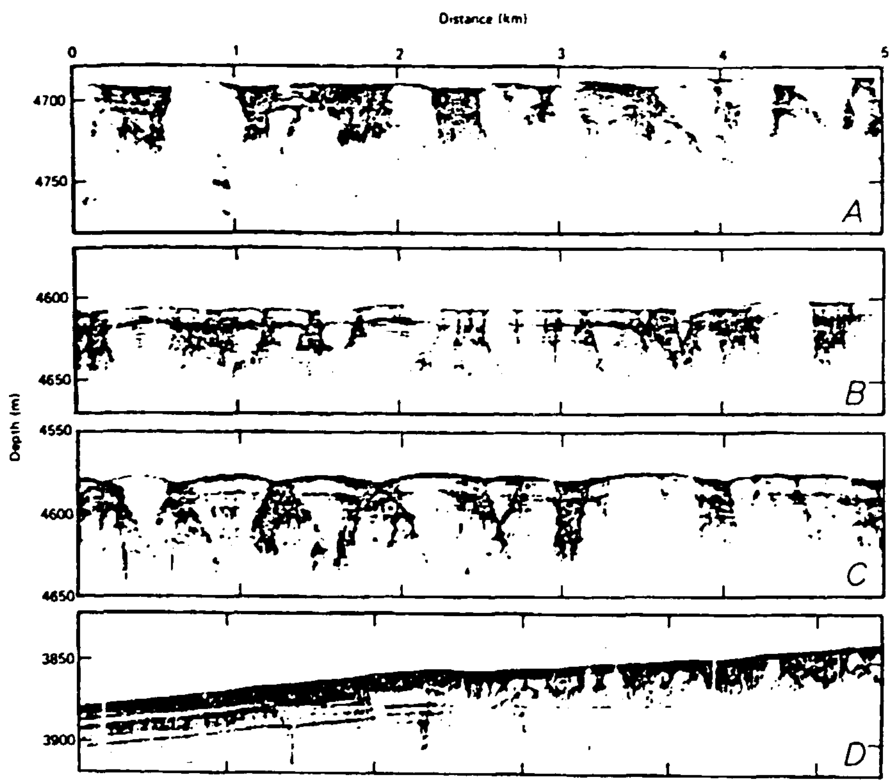
Figure 7, a-d. Different possible types of oil traps. For simplicity, the reservoir beds are always indicated as sands; a stratigraphic trap; b structural trap; c anticline; d salt dome or diapir.



sulfide, water and elemental sulfur can be produced and concentrated within the cap rock. The sulfur can be recovered fairly simply by the so-called Frasch process, by which steam and air are piped down the drill hole. This melts the sulfur and allows it and the water that condenses to be pumped to the surface. Salt domes off Louisiana have already yielded 200 million tons of sulfur. However, fewer than 10% of the drilled salt domes have commercial amounts of sulfur. The discovery by Glomar Challenger of sulfur-bearing domes in the deep parts of the Gulf of Mexico has encouraged an increased search for offshore sulfur deposits.

Recent seismic studies have detected buried features that may be gas hydrates or clathrates (Figure 8). A gas hydrate is a crystalline, ice-like solid consisting of a gas molecule within a framework of water molecules. The conditions necessary for these hydrates, low temperature and high pressure, are common to parts of the continental slope and rise. Hydrates usually are found in the upper parts of the sediment section since temperatures within the sediment increase with depth. The cement-like layers themselves might be a source of gas or may act as traps for other hydrocarbons (Tucholke et al, 1977; Dillon et al, 1980). The fact that hydrates and related gas deposits are restricted to the upper 500 m or so of the sediments might make for easy recovery. Samples of solid gas hydrates have been obtained by scientific drilling techniques. In theory, hydrates could occur in most areas of the slope and rise. Summary discussions of these features are given by Kaplan (1974) and Milton (1976).

Figure 8. Pagoda structures on abyssal plains and lower continental rises off western Africa. Whitish triangles (sections of cones) may be cemented by methane hydrates, or clathrates or they may be artifacts produced by refraction of sound from the irregular topography. Seismic reflection profiles show basement-sediment interfaces at roughly 4700 m (A), 4600 m (B) and (C), and 3850 m (D). (From Emery 1974)



II. PRELIMINARY INVESTIGATION AND DETECTION OF RESOURCES

Technologies Needed to Detect Marine Mineral Resources

Exploration for marine minerals on or under the continental margin generally uses many of the same techniques that are already commonly used in modern marine geological and geophysical research (see, for example, Table 4; Mineral Resources of the Sea 1970 (United Nations publication, Sales No. E.70.II.B.4); Sea-bed Mineral Resources: Recent Developments (1973) (United Nations document A/AC.138/90); and Rona, 1972 for a general discussion of some techniques).

Basically, three key aspects are involved in the exploration for marine resources. First there should be an assessment of any previous research in the area, including land geology (especially useful in location of nearshore placers); offshore bathymetry; and regional environmental conditions. The other two key aspects are a field mapping and surveying program (first in general, later in detail), and a detailed sampling and analysis programme, which are necessary actually to define and evaluate a deposit.

Exploration for placers or sand and gravel deposits can often be done from small boats of limited range. However, larger, more sophisticated ships are needed for oil and gas, offshore phosphorite or manganese nodule exploration. Subsurface deposits, with the exception of hydrocarbons or magnetic ore bodies, are essentially impossible to detect with present technology.

One of the best ways to locate candidate areas for placer deposits is by studying the rocks of the adjacent land area, since these are generally the source of the minerals in the placers. If valuable placer-type minerals are known on land, especially near rivers, it should increase the probability of offshore deposits. When a potential deposit

Table 4. Some Specifics of Marine Mineral Exploration Devices (Adapted from Rona, 1972)

	BATHYMETRY	BOTTOM PHOTOGRAPHY	BOTTOM SAMPLING	SEISMIC REFLECTION	SEISMIC REFRACTION	MAGNETIC
INSTRUMENTS	Vertical echo-sounder Horizontal echo-sounder	Underwater Camera	Core, grab dredge, drill	Hydrophone, amplifier, recorder	Hydrophone, amplifier, recorder	Magnetometer
MOVING OR STATIONARY	Moving	Stationary	Stationary	Moving	Moving	Moving
RECONNAISSANCE OR DETAIL	Either	Detail	Detail	Either	Either	Reconnaissance
QUANTITY DIRECTLY MEASURED	Travel time of reflected sound wave between ocean surface and bottom	Picture of small area (tens of square meters) of ocean bottom	Sample of bottom material	Travel time of reflected sound wave between ocean surface and sub-bottom reflecting interfaces	Travel time of refracted sound between ocean surface and sub-bottom refracting layers	Variations in intensity of magnetic field
QUANTITY INDIRECTLY DETERMINED FROM MEASUREMENTS	Depth and shape of ocean bottom	Shape and texture of ocean bottom	Detailed composition and engineering	Dip of beds Depth to distinct reflecting interfaces	Depth to refracting horizons, horizontal speeds of seismic waves	Depth or susceptibility of rocks with magnetic properties or magnetic ore bodies
TYPES OF STRUCTURES MOST OFTEN LOCATED	Submerged features such as beaches, channels, and exposures of bedrock	Small-scale features such as ripple marks, shells, nodules, and exposures of bedrock	Chemical, placer, massive vein, and tabular deposits	Faults, anticlines, monoclines unconformities ore deposits buried in sediments	Faults, salt domes, basement configuration, anticlines	Igneous intrusive rocks, iron bearing deposits

Table 4. Some Specifics of Marine Mineral Exploration Devices (Adapted from Rona, 1972) (contd.)

	GRAVITY	RADIOACTIVE	CHEMICAL ANALYSIS
INSTRUMENTS	Gravimeter	Geiger counter Scintillation counter	Emission and flame spectrometer, X-ray spectrometer, radiometer, wet laboratory
MOVING OR STATIONARY	Moving and stationary	Moving	Moving and stationary
RECONNAISSANCE OR DETAIL	Reconnaissance	Either	Either
QUANTITY DIRECTLY MEASURED	Variations in force of gravity	Natural and artificially induced gamma radiation	Composition of rock and water samples, identity and amounts of elements present
QUANTITY INDIRECTLY DETERMINED FROM MEASUREMENTS	Density of rocks and depths to anomalous rock bodies	Presence of radioactive elements	Proximity to mineral concentrations
TYPES OF STRUCTURES MOST OFTEN LOCATED	Buried mountains, salt domes, faults	The presence of radioactive minerals and certain rock types	Chemical hydrocarbon, placer, massive, vein or tabular ore deposits

is found, a surveying programme including samplings, measurement of overburden and mineralogical analyses of the sampled material will be necessary. If the focus of the exploration is for placers, emphasis should be on finding and defining trends of old beaches or river channels. If sand or gravel is the objective, discovery and assessment of topographic ridges or hills having relief of at least 5-10 meters and some lateral extent should be the objective.

Among the general characteristics and data that could be measured or obtained in a field marine exploration program are water depth, acoustic characteristics of the bottom, subsurface structure (from seismic studies), magnetic field, gravity, and possibly some geochemical aspects of the bottom sediments. Generally a first step is to make a bathymetric chart of the region. This will show the general aspects of sea floor topography and can be used as a base upon which to plot or note subsequent observations and data. Conventional echo-sounding equipment, available from many sources, can be used to obtain the data. The technique is simple; sound is transmitted from a surface transponder to the sea floor from which it is reflected back, and recorded. The information is usually displayed as water depth plotted against time (or essentially distance traveled over the bottom). The plot will give a two dimensional view (sometimes distorted) of the sea floor. Depending on the sound frequency used, it is sometimes possible to get acoustic returns from subsurface layers that will show the shallow or upper structure of the sea floor (Figure 9). With some devices (for example, those using colour to indicate signal strength) it is possible to make a preliminary assessment about the nature of the surface sediments from the character of the returning echo, since sand, gravel and mud will often have different acoustic properties.

Figure 9. A 3.5 kHz echo-sounding record taken in the Persian Gulf. Note the three different interfaces (labelled on figure). Each may be a different type of sediment.

To use the echo-sounding data to produce a chart requires good navigational control. This often involves modern electronic systems, sometimes with land-based stations. Simpler devices such as sextant sightings on land features, conventional radar or even dead reckoning can be used, if the initial chart is not intended to be very accurate. Offshore operations out of sight of land definitely require radar or electronic systems such as Loran or satellite navigation. Prior to exploitation a very accurate chart is needed.

A magnetometer often is used in conjunction with echo-sounding surveys to measure variations in the magnetic field of the ocean bottom. These variations are caused by changes in the magnetization intensity of bottom sediments and rocks. Rocks or sediments containing magnetic minerals or other iron-rich (such as magnetite) or titanium-rich minerals will give a magnetic signal, whereas manganese nodules, phosphorites, sand and gravel have no distinctive magnetic characteristics. Magnetometer surveys are especially useful for locating placer mineral deposits, many of which contain magnetic minerals.

Another useful surveying device is a marine gravimeter which can provide information on a more regional scale. This is a fairly sophisticated piece of gear requiring a large vessel and very accurate navigation. It has little use in surveys for sand and gravel, placers, nodules, or phosphorite and is mainly for oil and gas exploration.

Sophisticated exploration surveys might also use side-scan sonar which can delineate bottom features to either side of a vessel's track; they are especially sensitive to the roughness or reflectivity from the seafloor. Information from this device can be used to evaluate the texture of the surface sediment as well as the bedforms.

If direct observations of the bottom are needed, divers using scuba can visit a site. They can be especially useful in exploration for placers, sand, gravel or shell deposits; most other types of deposits are in water too deep for such exploration. Other techniques for visual exploration include underwater television and photographic cameras. There are cameras that can take an almost continuous series of pictures as they are towed over the seafloor. Freefall cameras (which may also take a grab sample) have been used for manganese nodule exploration in deep water. One difficulty with any camera work is that there is an information delay until the pictures are developed. Another problem is knowing exactly where the picture was taken. Underwater television avoids much of this, and has the advantage that its image can be videotaped. Submersibles, either manned or unmanned, can also be used for exploration and sampling, but their costs are usually very high. Some very sophisticated, unmanned submersibles have been designed for manganese nodule studies.

One of the more important surveying techniques, especially for oil and gas exploration, are the various forms of continuous seismic reflection profiling (Figure 10). These devices use acoustic energy, similar to echo-sounding but with lower frequency and higher energy. Echoes are reflected from the seafloor as well as from deeper interfaces. If refraction techniques are used, it is possible to determine the velocity of sound within the different layers and thus learn something about their composition. Seismic profiling systems are also useful in determining the overburden (amount of sediment) above a particular layer, buried channel or ridge. Extremely sophisticated techniques are used in the oil industry. Some can penetrate to ten

Figure 10(b)

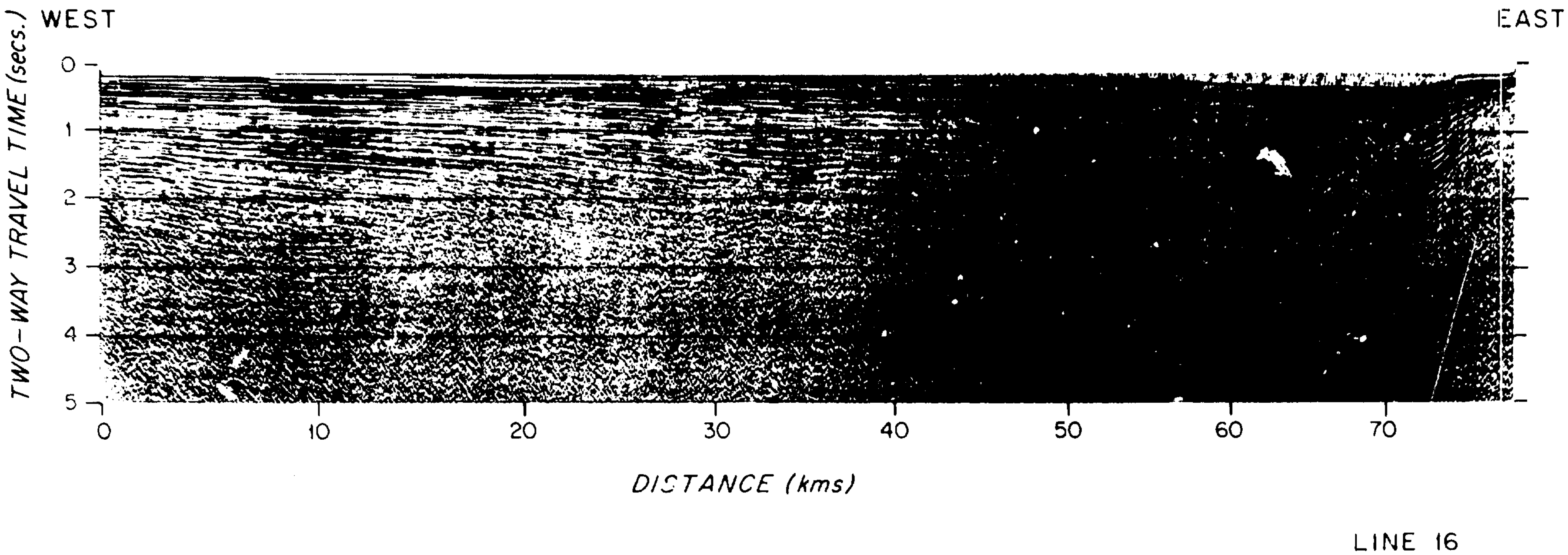

WEST
EAST
TWO-WAY TRAVEL TIME (secs.)
0
1
2
3
4
5
0
10
20
30
40
50
60
70
DISTANCE (kms)
LINE 16

Figure 10. (a) Basic technique of seismic profiling

(b) Example of a seismic profile.

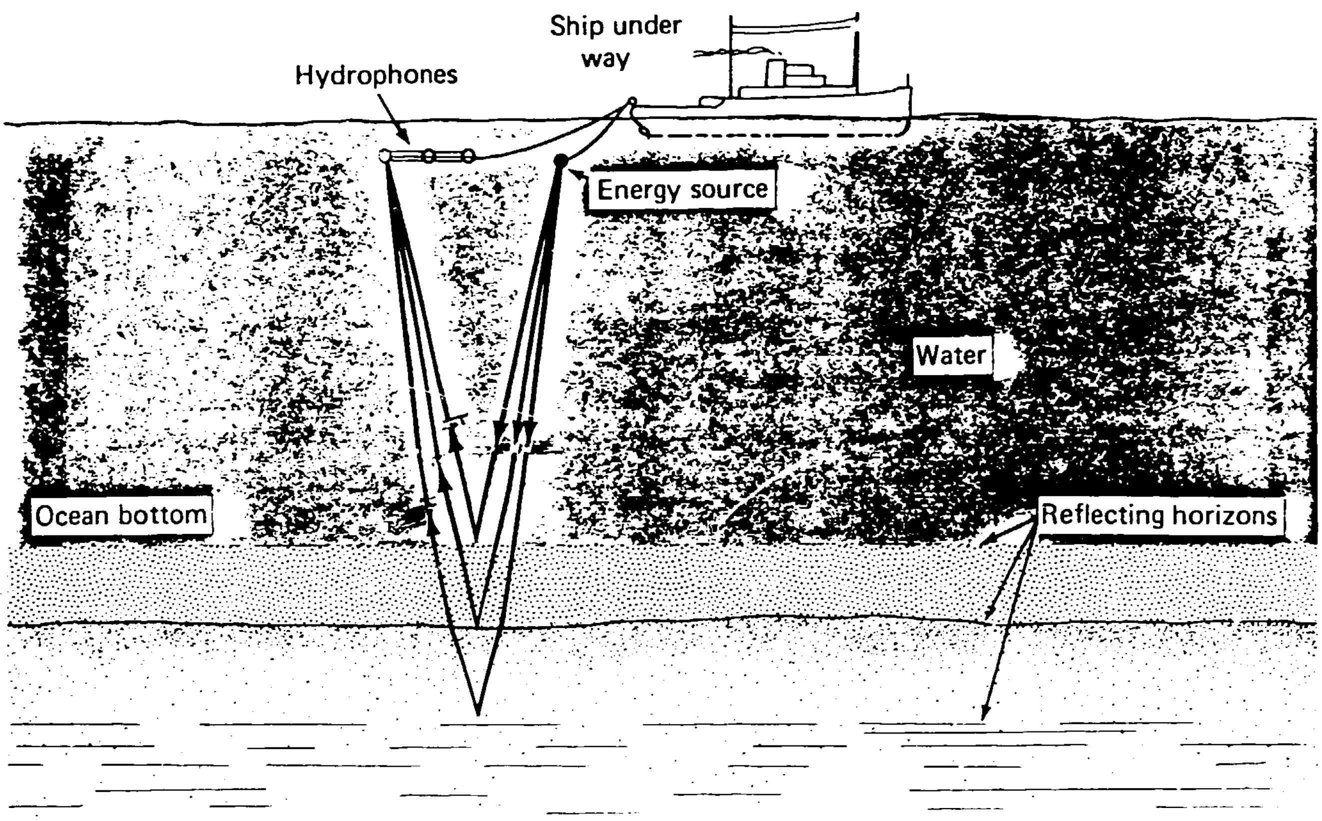


Figure 10(a)

kilometers or more and provide accurate data on structure and general sedimentary and rock characteristics. These instruments are important tools for determining if an area has oil and gas potential. The profiles obtained from such techniques often are used to pick the actual drilling location. It should be stressed that only by drilling can an oil deposit actually be confirmed.

The third important aspect of exploration involves sampling the potential resources or surrounding deposits. There are numerous devices including surface grab samplers, corers, dredges, and various drilling or drilling like techniques. Each device is especially suited to a specific environment; grabs are good for sands; corers, mainly for soft sediments; and dredges for rocks, phosphorites, nodules, etc. The grabs and small corers can be used from a small vessel, but dredges, larger corers and drilling devices usually require a relatively large ship, a powerful winch, and strong wire for lowering and recovery. Each technique requires some modest skill and experience, but these often can be quickly learned by field experience. Sophisticated sampling equipment include rock drills (power usually supplied from the surface vessel), free-fall corers (return to the surface where they can be retrieved) and even submersibles for sampling. Vibratory-corers are the best device to take long samples of sandy material. These can have vibrating heads (driven either by electricity, pneumatically or hydraulically), and receive power from the surface ship (Ling, 1972). It should be stressed that it is usually more difficult to accurately sample coarse-grained sediments, such as sand or gravel, than finer materials.

Geochemical techniques are sometimes employed in a mineral exploration program, and can be used for in situ measurements or as an analytical method on collected material. Field analyses have to consider the dispersal aspects of waves, currents or other marine processes on many marine mineral deposits. In other words, there will be a pattern or halo of varying mineral quantities around the actual deposit. Detailed sampling and analysis can often lead back to the source. These techniques can work well with phosphorites and placers which are moved around by currents but would not be applicable for deposits like nodules which are relatively stationary. In situ analyses may utilize the fact that certain minerals are radioactive or contain radioactive decay products (phosphorites, zircon and monazite, for example) or perhaps that seeps of hydrocarbon are sometimes detectable. Some sophisticated gamma-ray detectors have been towed in shallow waters to look for heavy mineral sands.

Ownership Source of Technologies and Equipment Used in Exploration of Marine Minerals

Most of the equipment needed in an exploitation program for nearshore mineral deposits (placers, sand, gravel and shells) are readily available from numerous reputable sources. Equipment such as echo-sounders and sampling devices can be bought almost anywhere in the world. Sources of such equipment are listed in trade journals such as Oceanology International, Ocean Industry or Sea Technology. Many instrument companies maintain offices around the world and have engineers that can aid in the installation of the gear as well as in its maintenance. Navigation, echo-sounding, seismic, gravity and magnetic equipment can be expensive and some components may not be compatible with each other. If a systems approach is desired, it may be prudent to hire a consultant (preferably one unconnected with a company). Often countries have purchased exotic equipment that far exceeds their needs for an adequate exploration programme.

A major piece of equipment will be the vessel. For nearshore work the conversion of an existing ship is possible. The key considerations are electrical power, winch capabilities, and sea-keeping ability. The electrical supply must be sufficiently powerful, stable and appropriate for whatever instrument systems are desired. Winches are needed for manipulatory equipment; sea-keeping is obvious. Work further offshore has the same needs but conversions are more complex and expensive. Several companies have vessels and surveying systems available for hire.

More sophisticated equipment such as gravimeters and seismic gear, besides needing highly-trained technicians, also requires special facilities aboard the vessel such as air conditioning and stable platforms. Such equipment also needs trained scientists aboard to evaluate the data as it is being received and later for interpretation. The complexities increase even more when seismic systems for shallow water work a e involved. Often a special ship, many technicians, several computers and cientists are necessary. Much of the shallow water exploration is done by the oil industry or occasionally by research institutions who generally are not looking for resources, but are doing reconnaissance or specially focused research.

The technology for oil and gas exploration (i.e. especially seismics and gravity) comes mainly from developed countries. Exploration, however, has occurred off at least 80 countries during the last few years. Extremely important discoveries have been made off developing countries such as Egypt, Indonesia and Mexico.

An initial step in any exploration plan is to assess existing data. For a developing country this in itself can be a formidable task. However, there are several international data banks that can provide a first step towards supplying whatever data exists. In addition organizations like the Intergovernmental Oceanographic Commission may be able to assist by providing scientific advice. One relatively simple and inexpensive way for a country to obtain baseline data off its coast is through the development of co-operative marine research programmes with scientific laboratories from other countries. This technique has proven very successful in the study of marine biological resources but has rarely been used for mineral resources. In developing such an effort the country should realize that publication of the data may be a necessary consequence of such cooperation. Another possibility is hiring or contracting with a professional surveying company. This may provide confidentiality, but will be expensive whereas the co-operative programme may have been relatively free, as well as being useful for the training of scientists and technicians.

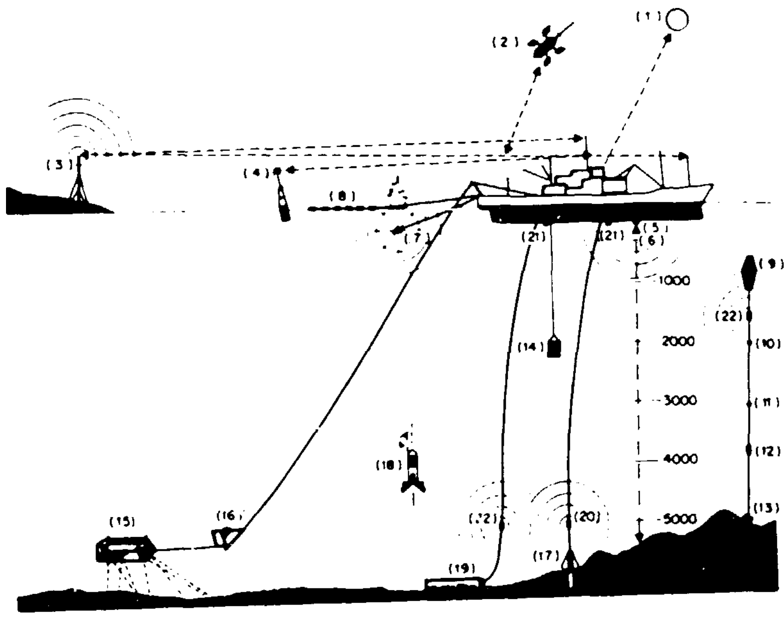
Future Technologies, Changes Relative to Investigation and Detection of Resources

Future advances in exploration techniques probably will mainly be in the area of data interpretation and evaluation. Self-contained navigation and echo-sounding systems that automatically produce charts are some other possible examples. In seismic profiling, new computer techniques and theories will continue to be developed and will improve resolution. The capability to drill exploration wells for hydrocarbons in almost all parts of the ocean essentially already exists.

The concept of having vessels especially designed for multi-purpose mineral exploration is obvious and some have already been built. Besides being very versatile, they can stay at sea for long periods of time. An example is VALDIVIA, a German vessel, that has explored in the Red Sea and the Pacific (for nodules) and HOLLIS HEDBERG, a seismic vessel built for Gulf Oil Company. Many oil companies or surveying companies have ships specialized for seismic, gravity or other work. A possible type of vessel is shown in Figure 11. (Note that all exploration techniques shown in the figure are not performed at the same time.)

There will probably be increased exploration, especially for placers, phosphorites and hydrocarbons, in future years. The detection and location of sand, gravel and shells is fairly simple and many sites are already known. Likewise, much general information is apparently already known about manganese nodule distribution, although little is known about the causes of variation in grade. Further exploration activities involving nodules should focus on finding areas having higher grades of certain minerals and regions where recovery is relatively easy (smoother terrain, for example).

Figure 11. All purpose mineral exploration vessel. Navigation: (1) stars; (2) satellites; (3) radar navigation; (4) navigation buoy (transponder/radar). Bathymetry: (5) narrow beam sounder and sediment echograph; (6) various depth records. Reflection seismic: (7) airgun; (8) streamer with hydrophones, analogue and digital registration. Oceanographic survey: (9) underwater measuring chain with localizable buoy: (10) current meter; (11) thermometer; (12) water pressure gauge; (13) cut-off anchor; (14) bathysonde (continuous measurement of temperature, salinity, sound velocity, pressure). Survey of ore deposits: (15) deep diving probe with TV camera with camera and lights; (16) depressor platform; (17) corer for sampling sediment with nodules (18) free fall sampler; (19) bulk sampling of nodules for metallurgical tests. Location of launched survey gauges: (20) pinger; (21) hydrophone; (22) transponder (from *Mining Engineering*, April 1975).



III. EXPLOITATION OF THE RESOURCE

Technologies Needed to Exploit the Resources

Exploitation of mineral deposits that were first discovered on land and later were found to extend out under the ocean has been going on for several decades; in general using the same land-developed technology. Examples include numerous coal, iron and tin deposits and some offshore oil and gas accumulations. Exploitation of marine placers and other uniquely marine deposits, however, is a relatively modern activity. Because of the environmental complexities of working in the marine environment, exploitation has focused on unconsolidated surface material and hydrocarbons. Subsurface exploitation (and even exploration) of veins or buried mineral deposits not associated with land deposits (with the exception of oil, gas and sulfur) remains a future activity that will require advanced forms of technology.

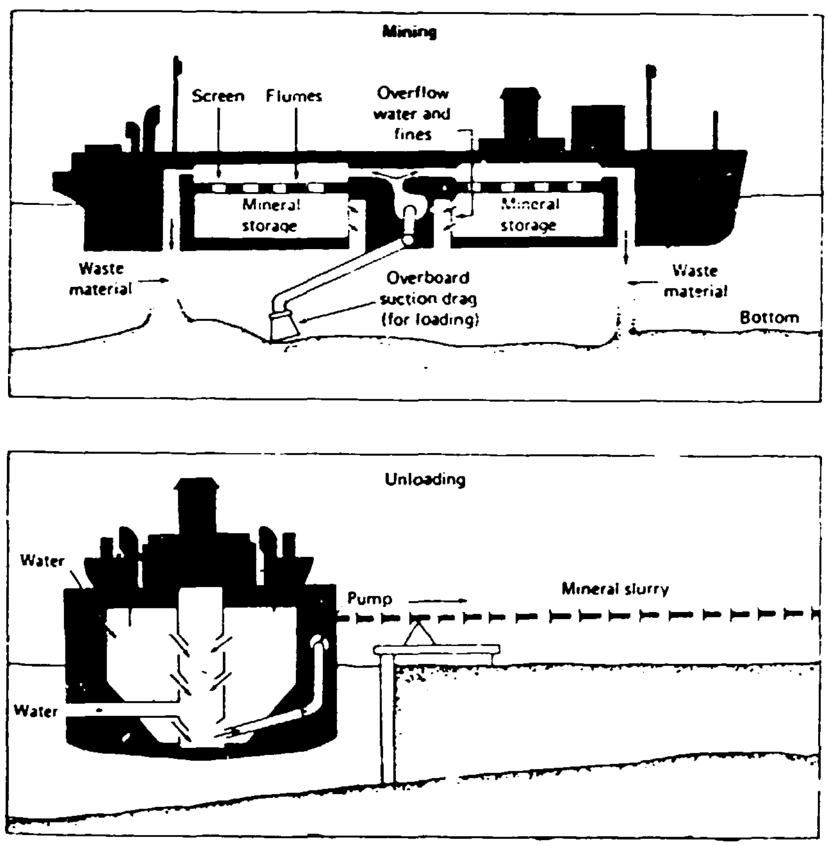
By the mid-1970s there were over 100 subsea mines that ranged in depth from 30 m to over 2000 m and were as much as 8 km from shore (Albers, 1978). These types of operations can present considerable challenges to the engineer and often lead to dangerous working conditions. Among the important problems are finding and sealing faults, joints or cracks that can carry water into a mine. Subsea tunneling and extraction add to mining costs, making competition with onland producers difficult.

Sand, Gravel, Shells and Placers

Sand, gravel, shells and placers are generally mined by dredging, which is a relatively easy technique. Although most dredges (Figures 12 & 13) can work under variable conditions many are limited by water depth, storms or waves. Basically there are two fundamental types of dredges - mechanical and hydraulic - but there are many variations (Figure 13). The general characteristics of dredges are summarized in Tables 5 and 6. Some are more adapted to quiet, protected water, others to deeper waters or for placers rather than shells. Vessels or plants that operate below or on the seafloor may avoid most of the wave, wind and current forces that limit surface vessels (Duane, 1976). Submerged systems thus can sometimes have greater flexibility in their operations than surface systems. In general each area may require a different type of dredge. Hopper dredges are usually well-suited for open-water work. Some hydraulic dredges are capable of working to depths of 70 m; in principle, mechanical dredges work to virtually unlimited depths.

Water or air jet systems have been designed for work in waters as deep as 600 m (Herbick, 1971) and even for deep manganese nodule operations (see later sections). In most nearshore operations there is a potential for environmental damage from dredging but, in some instances, it may be less than that from land operations near residential areas. Offshore problems could involve erosion of beaches since the offshore sediments may be involved in the seasonal beach cycle, and the destruction of or interference with bottom biological systems, including fisheries. Large, deep excavations can change the bottom depth contours and approaching wave patterns, which, in turn, can affect the sediment

Figure 12. Cross sections of a dredge used for mining sand and gravel. (Courtesy of Construction Aggregates Corporation, Chicago, Illinois)



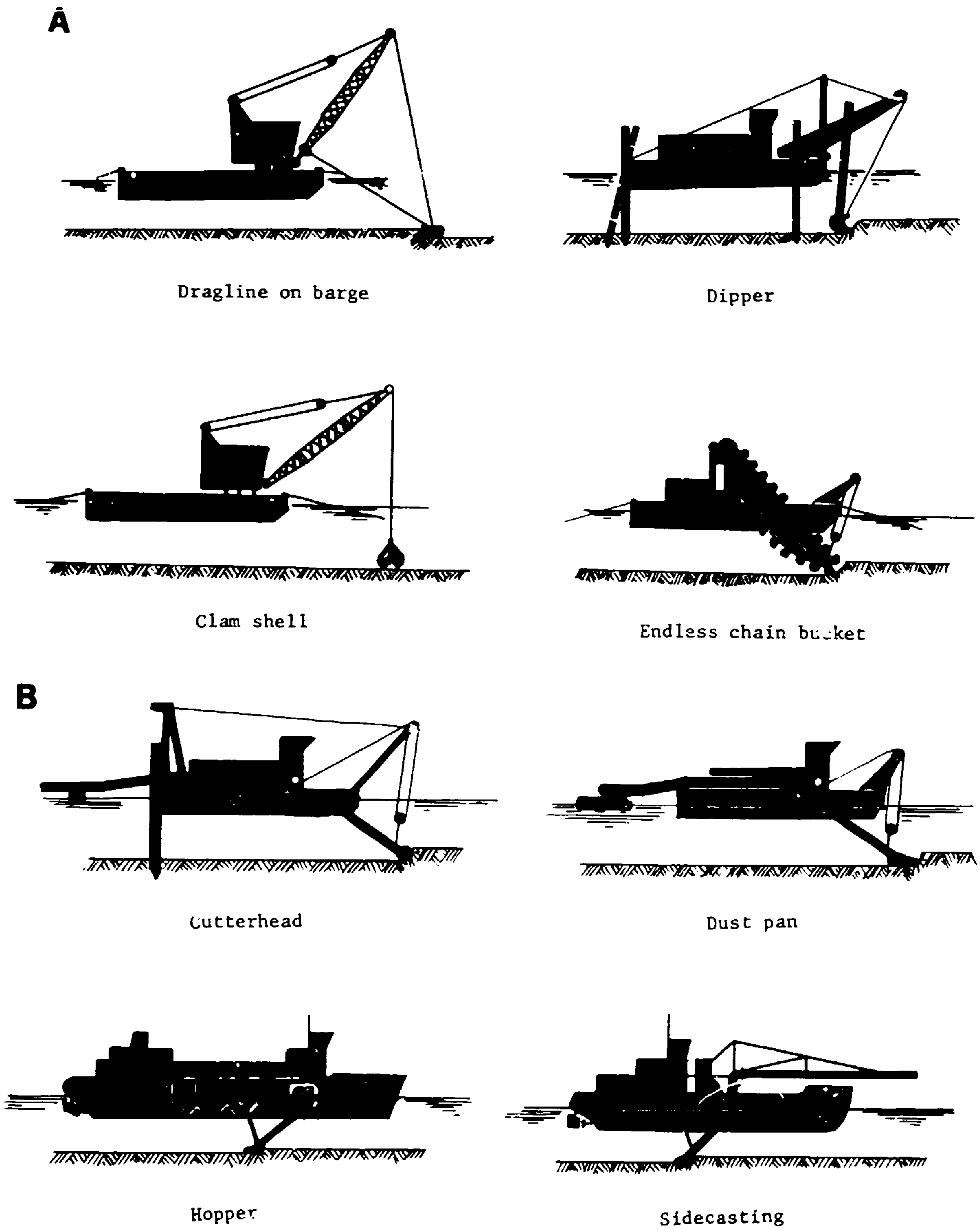


Figure 13. Silhouettes of dredges in common use throughout the world (a) mechanical dredges; (b) hydraulic dredges. Adapted from Duane, 1976.

Table 5

Characteristics and Types of Mechanical Dredges

	Dredge Type			
	Dragline on Barge	Dipper Dredge	Clam Shell or Orange Peel Bucket Dredge	Endless Chain Bucket Dredge
Dredging principle	Scrapes off material by pulling single bucket over it toward stationary crane. Lifts bucket and deposits dredged material in a conveyance or on a bank	Breaks off material by forcing cutting edge of single shovel into it while dredging is stationary. Lifts shovel and deposits dredged material in a conveyance or on a bank.	Removes material by forcing opposing bucket edges into it while dredge is stationary. Lifts bucket and deposits dredged material in a conveyance or on a bank	Removes material by forcing single cutting edge of successive buckets into material while dredge is slowly moved between anchors. Lifts buckets and deposits dredged material in a barge or on a hopper
Horizontal working force on dredge	Medium intermittent force toward bucket	High very intermittent force away from bucket	No forces	Medium constant force away from bucket
Anchoring while working	Dragline crane can be on shore or on barge. If on barge, latter can be secured with spuds or anchors	Several heavy spuds	Several spuds or anchors	Several anchors
Effects of swells and waves	Can work up to moderate swells and waves	Very sensitive to swells and waves	Can work up to moderate swells and	Very sensitive to swells and waves
Material transport	Transport occurs in barges, trucks, or cars. Crane does not transport material. Material disposal occurs in many ways	Transport occurs in barges, trucks, or cars; dredge does not transport material. Material disposal occurs in many ways	Transport occurs in barges, trucks, or cars; dredge does not transport material. Material disposal occurs in many ways	Transport normally occurs in barges. Dredges equipped with hoppers are limited to material disposal by bottom dumping
Dredged material density	Approaches in-place density in mud and silt. Ap- Approaches dry density in coarser material	Approaches in-place density in mud and silt. Approaches dry density in coarser material	Approaches in-plan density in mud and silt. Approaches dry density in coarser material	Approaches in-place density in mud and silt. Approaches dry density in coarser material
Comments	The term "dredge" is questionable for this machine, since it is not exclusively built for underwater excavation and is frequently used for material removal above water. It is suitable for all but the hardest material and has a low production for its size	Special hard material dredge of simple principle. Rudimentary machine can be assembled for temporary service for placing power shovel on spud barge. Low production for size of plant and investment	This machine is simple in principle. It can be assembled in rudimentary form for temporary service by placing a crane on a barge. It is suitable for all but the hardest materials and has a low production for its size	Highly developed machine. Not used in United States (other than as part of mining plant), but used extensively in other countries. It is suitable for all but the hardest materials and has a high production for its size

Source: From Mohr (1974).

Table 6

Characteristics and Types of Hydraulic Dredges

	Dredge Type			
	Cutterhead Dredge	Dustpan Dredge	Hopper Dredge	Sidecasting Dredge
Dredging principle	Material is removed with a rotary cutter (or plain suction inlet in light material) picked up with dilution water by the suction pipe, and transported through the pump and the discharge line. While working, dredge swings around spud toward an	Material is removed with water jets, picked up by a wide but shallow suction opening, and transported through the pump and the discharge line. While While working, dredge is slowly pulled toward two anchored spuds or anchors	Material is removed and picked up together with dilution water by draghead sliding over bottom (or stationary) and flows through suction piping, pump, and discharge piping into hoppers of vessel	Material is removed and picked up together with dilution water by draghead sliding over bottom and flows through suction piping, pump, and discharge arm over side of vessel back into the water
Horizontal working force	Medium intermittent force opposing swing to side	Medium constant force opposing forward movement ment	Slight constant force opposing forward movement	Slight constant force opposing forward movement
Anchoring while working	Two spuds and two swing anchors (one working spud and one walking spud)	Two spuds or anchors secured upstream while working	Dredge moves under own power to dig a channel or is anchored to dig a hole	Dredge moves under own power to dig a channel
Effect of swells and waves	Very sensitive to swells and waves	Very sensitive to swells and waves	Little affected by swells and waves	Little affected by swells and waves
Material transport	Transport occurs in pipeline. Length of discharge line depends on available power, but can be extended with booster pump units to a total length of several miles	Transport occurs in pontoon-supported pipeline to side of dredge. Spoil discharges into water. Booster pump units are not used with this plant	After material is in hoppers, transport is over any suitable waterway. Material can be bottom dumped or pumped out (if so equipped). Pump-out is similar to pipeline dredge operation	Transport occurs in pipeline on discharge boom over side of dredge. Material discharges into adjacent water
Dredged material density	Diluted to an average of 1200 g/l	Diluted to an average of 1200 g/l	Diluted to an average of 1200 g/l	Diluted to an average of 1200 g/l
Comments	Highly developed machine with intricate horizontal moving procedure used throughout the world. Suitable for all but very hard materials. High production for size of plant	Special sand dredge used only in United States in Mississippi River. Floating line is positioned with rudder in discharge stream. High production for size of plant	Highly developed machine used throughout the world. Suitable for all but very hard materials. Production depends on traveling time to dump and mode of discharge	Special sand dredge. Sand transport is limited to length of discharge boom. Used in coastal inlets or where material discharge into water is not objectionable. High production for size of plant

Source: From Mohr (1974)

budgets of beaches, cause erosion or deposition, both offshore (for example, changing navigational channels) or onshore (affecting beaches). Change in bottom characteristics may also affect larval settlement and filter feeders (oysters for example). Dredging may also influence the biological and chemical regime; for example, by destroying benthic communities by the actual dredging operation or by settling out of material. It can also release pollutants or nutrients that were buried in the sediments. Large increases in nutrients can lead to oxygen depletion if there is rapid plant growth in an area having restricted circulation. Alternatively, there could be some benefits in increasing the nutrient supply and thus also the biological productivity in more open areas. Dredging operations will resuspend sediments into the water increasing turbidity and causing a downdrift plume, that can affect photosynthesis and bury organisms. Reef areas are especially sensitive to turbidity.

Phosphorites

At present there are no marine phosphorites that are being exploited from the sea floor, although numerous deposits are known. Mero, in 1964, estimated that there were 30 billion tons of recoverable phosphorite on the sea floor -- about 1000 years' supply at present rates of consumption. In spite of the lack of successful exploitation, some deposits are potentially valuable for agricultural regions that do not have adequate sources of phosphorus as well as for developing countries that must import phosphorite.

When exploitation occurs it will probably come from shallow water close to shore with the phosphorite being raised by conventional dredging techniques. Most offshore phosphorite nodule deposits do not contain as much P_2O_5 (phosphorus pentoxide) as land deposits and usually need enrichment, adding to the cost of exploiting a marine deposit (Earney, 1980). Phosphate muds and sands (accumulated by similar mechanisms as placer deposits) may be more valuable since they can be used directly. Garrand in 1978 estimated that a marine phosphate nodule plant would need a capacity of at least 1 million tons to be economical, but it would also require special conditions (nearby market, etc.). Garrand thinks that offshore Baja, California has potential, as does India which imports large quantities of phosphates.

Manganese Nodules

Nodules, in one of the more favourable Pacific sites, contain about 25% manganese, 1.4% copper, 1.6% nickel and 0.3% cobalt (see Table 3). In spite of the enthusiasm concerning nodules there are some who doubt the economic value of these deposits. In any case, there have been numerous international consortia and companies formed to prepare to mine manganese nodules. Nodule exploitation-oriented research is presently going on in Belgium, Canada, the Federal Republic of Germany, France, Japan, the United Kingdom, the United States and the USSR. Appendix II contains a recent listing of the various consortia and their activities.

Exploration and exploitation activities concerning nodules are generally not common knowledge. Local variability of nodule quantity can be considerable, and abundance may vary with small-scale changes in topography such as small hills, sedimentation rates or type of bottom sediment (in part, both are also controlled by topography). The so-called "ore zone" of the North Pacific extends about $6^{o}N$ to $20^{o}N$

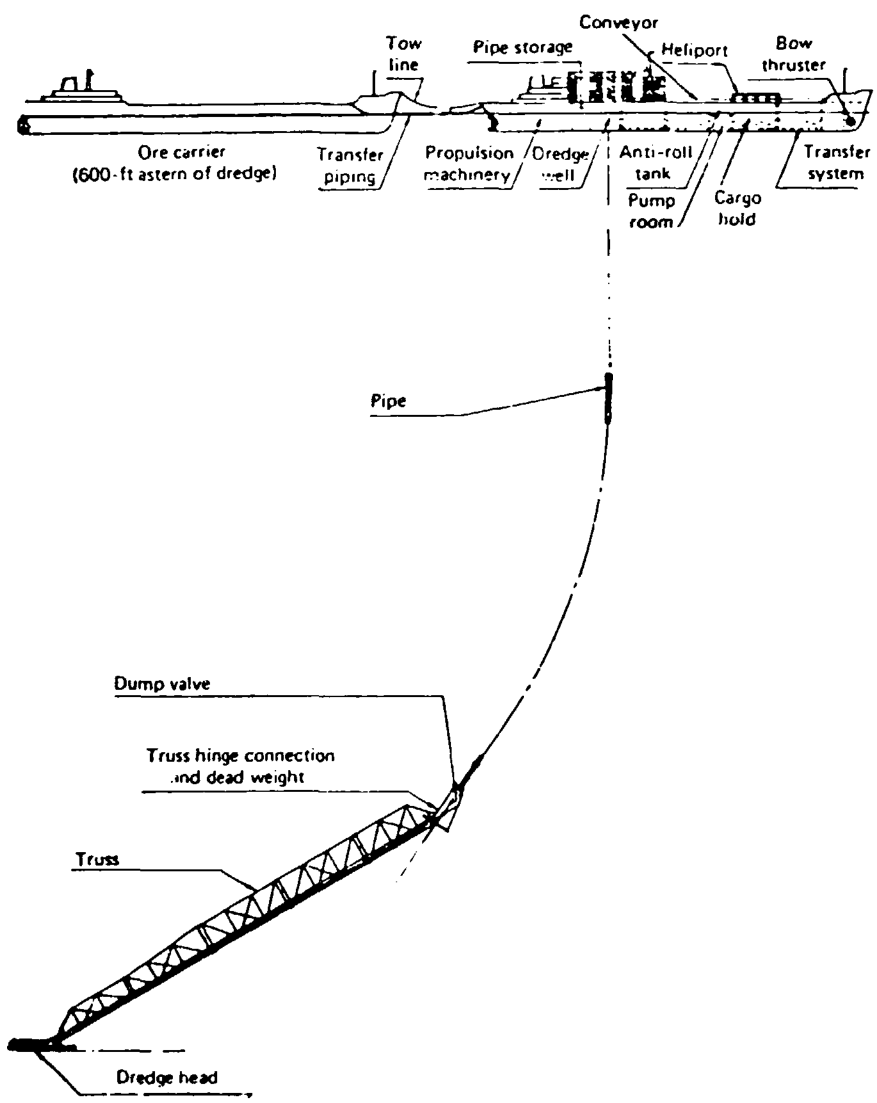
and from 120°W to 160°E, and its limits apparently are controlled by sedimentation rates. In the Indian Ocean most good nodule regions are south of the equator. Limited distribution occurs in the Atlantic, perhaps because of the higher sedimentation rate in this ocean. Many areas of the sea floor in all oceans have hardly been sampled or surveyed.

Deepsea Ventures, a United States company, was probably the first to develop an operational prototype hydraulic dredge system for the recovery of nodules. In 1970, their device was successfully tested in a water depth of about 800 m. A specially designed ship (R/V Deepsea Miner), using a 9-5/8 in. (24.4-cm) pipe and an air-lift hydraulic suction dredge, was able to lift large amounts of manganese nodules off the sea floor. The success of the prototype system (Figure 14) indicated to the company that recovery from 7000 m is possible. A large ore carrier has been converted (Deepsea Miner II) and became operational in 1977. Deepsea Ventures and its consortia members have had extensive plans to build recovery systems, carriers, and chemical processing plants, but have been equalled or exceeded in activity by other consortia.

Important aspects concerning exploitation of manganese nodules are: exploration and evaluation of deposit; recovery and; extraction of different elements. Some comments concerning their economics and legal problems are given in the next section.

Exploration and Evaluation of Deposits In the past the occurrence of nodules was determined by photography of the ocean bottom, or by obtaining samples via dredging or coring. Modern methods include using

Figure 14. The ocean mining system that Deepsea Ventures plans to use to mine manganese nodules from the ocean floor. The nodules are pumped to the surface. (Courtesy of Deepsea Ventures, Inc.)



deep-sea television cameras and free-falling sampling devices to ascertain the extent and concentration of a particular deposit. The data from these techniques, combined with chemical analyses, have shown at least one very promising area in the North Pacific. This area is considered, by many, large and promising enough for exploitation. Exploration certainly will find other promising areas (some are probably already known). Other sites may have different ratios of the important elements, indeed compositional variability could actually be an advantage because, with changing market conditions, the mining operation could be changed to the more profitable nodules.

Recovery At present, there appear to be two main methods of recovering manganese nodules from the deep sea: continuous line bucket systems or hydraulic systems using either air or water. The continuous line bucket system was developed by the Japanese and is a purely mechanical system. It consists of a long line or cable that has numerous buckets attached to it (Figure 15). The line is continuous, reaching from the surface ship to the bottom and back to the ship, and as buckets are lowered on one side they are brought up on the other side. A considerable length of the cable is dragged across the sea floor, hopefully filling the attached buckets with nodules. As this is being done the surface ship moves perpendicularly and slightly forward relative to the cable and buckets on the sea floor. In this manner a new portion of the bottom is exposed to the dredging action of the buckets. In 1970 this system was used successfully in a water depth of over 1000 m with 240 buckets each having a capacity of about 50 kg of nodules. Later,

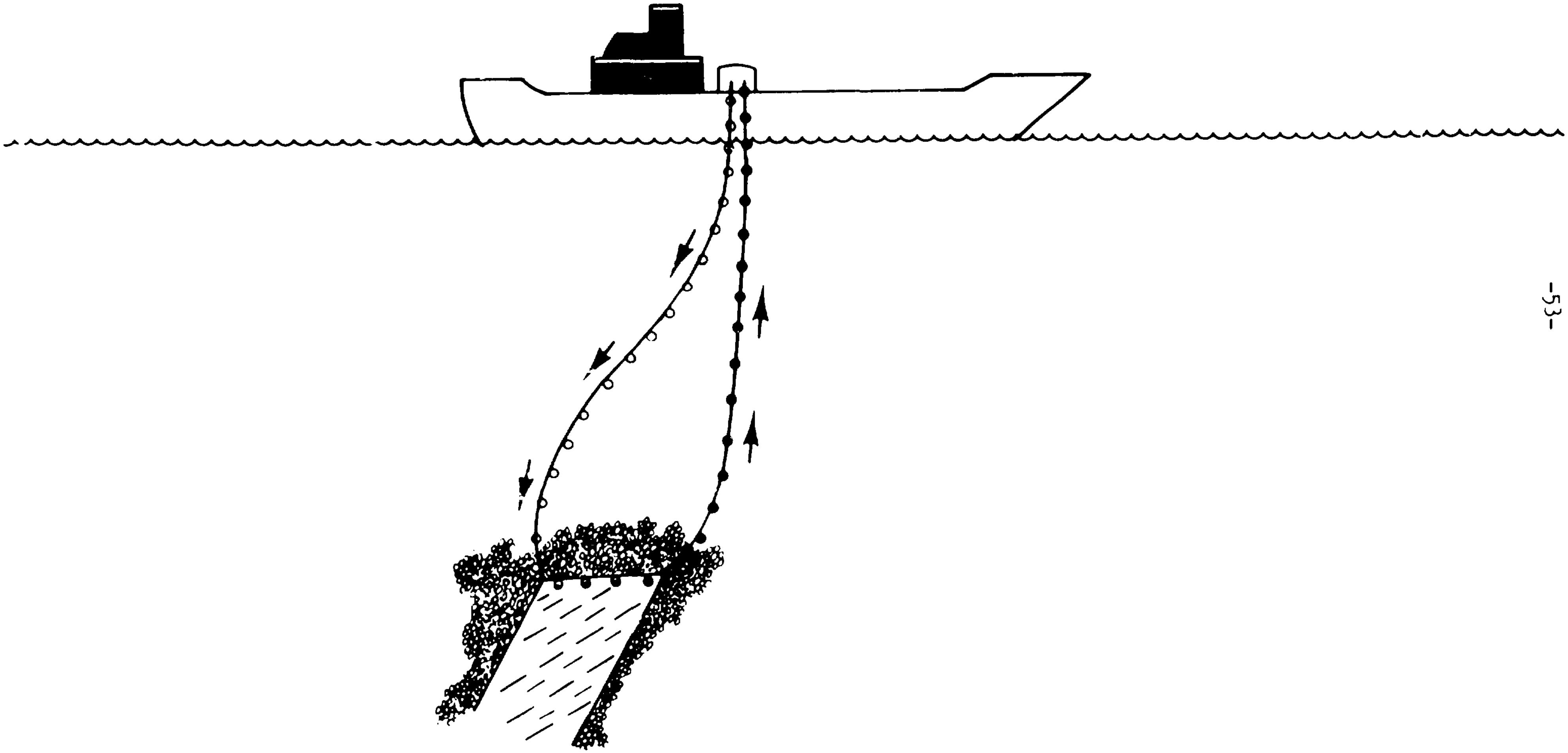


Figure 15. The continuous bucket system of mining manganese nodules from the sea floor. See text for explanation.

apparently successful tests were made in over 4000 m of water. Nevertheless, it seems that hydraulic systems have the most promise for actual use.

Hydraulic mining systems, of which there are numerous variations, essentially consist of either a conventional centrifugal pump or a compressed air system and a long pipe reaching to the bottom (see Figure 14). Air or water is injected into a dredge on the sea floor, causing a flow of water, sediment, and nodules up the pipe to the surface vessel. Nodules larger than a certain size have to be screened out to prevent clogging of the pipe. In some systems the nodules are crushed before being brought to the surface. Variations of this system are being considered by most of the active consortia (Appendix I). Table 7 shows a schematic overview of a first generation mining operation.

One potential problem with the hydraulic and, to a lesser degree, the cable systems method of mining nodules is that of possible environmental damage. Most economical nodules come from 3000- to 6000-m depth, and the water that comes to the surface with the nodules is generally colder and of a different salinity than the surface waters. In addition, it contains relatively large amounts of suspended material and probably a higher nutrient content than the surface waters. In general, it appears that although mining of nodules has its environmental risks these are less severe than similar mining operations on land.

The United States National Oceanic and Atmospheric Administration (NOAA) ran a major environmental study on the effects of nodule mining (called DOMES for Deep Ocean Mining Environmental Study). A partial summary of effects and possible mitigation strategies is shown in Table 8.

Table 7

Schematic Overview of First Generation Mining Operations. Where listed, numbers in parentheses denote amount of vessels involved per mining operation.

AT SEA

Continuous Line Bucket (CLB) → **Support Activities** ← **Hydraulic Pump System (towed or self-propelled)**

Support Activities

1. Nodule transport vessels (2 to 8)
2. Supply vessels (1)
3. Exploration/mapping vessel (1)
4. Operate about 300 days per year

↓

ON SHORE

↓

Port Facilities

(including 12 m or 40 ft minimum mooring site)

1. Slurry terminal
   - (a) 180 to 270 m (600 to 900 ft) waterfront
   - (b) 4 to 10 ha (10 to 25 acres) land
   - (c) Total of about 10 to 50 ha (25 to 125 acres)
   - (d) Storage
2. Dry nodule terminal
   - (a) 4 ha (10 acres) minimum land
   - (b) transport system for nodule handling

↓

Port-to-Plant Transportation

1. Slurry pipeline
   - (a) 1.5 ha (3.8 acres) of land per 1 km (0.6 smi) traversed
   - (b) pumping station at port
2. Conveyer
   - (a) land needs similar to slurry pipeline
   - (b) feasible up to about 32 km (20.5 mi)
3. Railroad
   - (a) use existing lines
4. Trucks

↓

Nodule Processing Plants and Operations

1. Operate 24 hrs. a day year round
2. Two types of plants
   - (a) Three-metal
     - (1) Copper-nickel-cobalt
     - (2) Process 2.3 to 3.6 million tonnes (2.5 to 4.0 million tons) dry weight per year.
   - (b) Four-metal
     - (1) Copper-nickel-cobalt-manganese
     - (2) Process 0.6 to 1.4 million tonnes (0.7 to 1.5 million tons) dry weight per year.

↓

Waste Disposal Facilities

1. Containment structures (tailings ponds)
   - (a) Three-metal plant -- 40 ha (100 acres) at 13 m (40 ft depth per year
   - (b) Four-metal plant -- 8 ha (20 acres) at same depth per year
2. Landfill
   - (a) Three-metal plant -- half of tailing pond size and depth each year
   - (b) Four-metal plant -- half of tailing pond size and depth each year
3. Ocean dumping
   - (a) two barges of solid wastes per week or use outbound nodule transport ships
   - (b) waste slurry to port for holding could require at least an additional 4 to 6 ha (10 to 15 acres) of holding ponds

Source: National Oceanic and Atmospheric Administration, 1981.

Table 8

Potential Biological Impacts and Supporting Research to Evaluate Possible Mitigation Strategies

Potential Biological Impacts	Potential Significance[a]	Examples of Possible Mitigation Strategies	Supporting Research
Trace Metal Uptake by zooplankton	UNCERTAIN (Very low probability of occurrence)	Retain fine materials on board vessel	Determine probability of trace metal uptake Evaluate effectiveness of fines retention on board ship
Fish Larvae Feeding Behavior Modification	UNCERTAIN (Very low probability of occurrence)	Premature	Determine occurrence Determine potential year class effect
Destruction of Benthic Biota In Collector Track	UNAVOIDABLE	Premature	Evaluate effect on benthic community
Smothering and Starvation of Benthos	UNKNOWN	Varying mining pattern	Monitor recolonization following disturbance
		Restrict rain of fines to mine site	Identify factors important in recolonization Evaluate effectiveness of various mining strategies in minimizing impact Develop capability for long-term monitoring of suspended particulate matter concentrations at mine site boundaries

a/Uncertain is used when prediction is based on some knowledge, although insufficient. Unknown is used when prediction is primarily conjecture, being based on very minimal knowledge. (National Oceanic and Atmospheric Administration, 1981)

Extraction of Different Elements Preliminary work suggests that physical or smelting methods of mineral separation are not the best and that chemical techniques hold the most promise. In the chemical method the nodules are either partly or completely dissolved and individual elements are removed. The method is especially useful for removing copper and nickel, which are easily taken into solution. The actual choice of a production process will be influenced both by technical and economic factors but also by what metals are to be produced.

The specifics of most techniques of refining are kept confidential. But in general the operation first involves crushing the nodules, followed by leaching with suitable reagents such as hydrogen sulfide or hydrogen chloride. In the latter case the important elements become water-soluble chlorides. Individual elements may then be separated by ion-exchange processes and collected on electrolyte cells. The cost of a processing plant may be twice that of the actual mining operation. A detailed discussion of some of the proposed extraction methods is given by Agarwal et al (1979) and references therein.

There have been numerous estimates of the cost of recovering and refining manganese nodules. It is difficult to argue, using incomplete data, whether the mining of manganese nodules would produce a profit to those companies engaged in the operation, but it is also difficult to imagine them engaging in such a venture if the possibilities of profit were not high.

Hydrocarbons

Exploration for hydrocarbons occurs off almost all countries that have a coastline and exploitation is common to many (Table 9). The rate of exploration and development is increasing, and frontier areas are now being considered that were not economic a few years ago. One estimate is that the world has 925 billion barrels of undiscovered oil of which 41 per cent, or 382 billion barrels is in offshore regions (see Uses of the Sea United Nations Economic and Social Council, E/1980/68). Currently exploration is occurring off over 80 countries.

Potential for offshore oil and gas may be better in the Atlantic than the Pacific for several reasons. First, its margins generally have a much thicker accumulation of sediments than the Pacific because the amount of land that is drained into the Atlantic is 4 times that of the Pacific. This has led to broader shelves and rises with thicker sediment accumulations in the Atlantic than the Pacific. In addition, much of the margin of the Pacific are subduction zones (trenches) where sediments are being thrust under the outer shelf and slope regions. However, landward of these subduction zones are regions like the Yellow and China Seas, which may have considerable hydrocarbon potential. The potential for the Indian Ocean may be high especially within the large sediment masses that make up the Indus and Ganges Cones (on either side of India). The so-called marginal seas, or small ocean basins like the Mediterranean Sea, Persian Gulf, Gulf of Mexico, North Sea, Yellow and China Seas are generally promising, if not already producing, areas for hydrocarbons.

Marine exploration and exploitation are more complex and expensive than land operations and items like maintenance and supply require sophisticated and expensive technologies. There has already been considerable investment in offshore technology; between 1975 and 1980 about $37 billion was forecast for exploration and $69 billion for development of offshore oil and gas deposits around the world (Flood, 1975). Part of the willingness to make such investments has been the high rates of success in finding hydrocarbons in the marine environment. The 1980s will surely see expanded exploration and exploitation on the continental shelf, as well as in deeper waters over the continental slope. The potential for offshore petroleum can only be guessed, but it should be realized that only a small portion of the world's continental shelves have been adequately explored.

After a potential site is determined, in large part by the geophysical techniques mentioned in previous pages, and leasing and other contractual and regulatory arrangements are completed, drilling can begin. There is no technique available for the direct detection of subsurface hydrocarbons. Regardless of the attractiveness of an area as a prospect, drilling must occur before it can be determined if oil or gas is present. Offshore rigs are of two principal types, those used primarily for drilling and those used primarily for production once a field has been found. The drilling rigs can be either towed to the site or be self-propelled; they can be jack-ups that are attached to the seafloor; semi-submersibles; or drilling ships. The basic

Table 9

Daily Worldwide Offshore
Oil Field Production for 1980

Region and country or area	Number of fields	Estimated production (thousand bbl/d))
Middle East	42	5,825
Saudi Arabia	7	2,958
Abu Dhabi	7	1,322
Qatar	3	247
Egypt	8	390
Dubai	4	345
Iran	10	150
Sharjah	1	10
Divided Zone	2	403
North America	33	1,538
United States	27	1,038
Mexico	6	500
Canada	n.a.	n.a.
East and South-east Asia	46	1,339
Indonesia	17	533
Australia	6	323
Malaysia	14	280
Brunei	5	192
Philippines	1	4
Japan	1	2
Viet Nam	n.a.	n.a.
People's Rep. of China	2	2
New Zealand	2	3
South America	26	1,364
Venezuela	4	1,095
Trinidad and Tobago	6	166
Peru	4	30
Brazil	12	73
Europe	29	2,523
United Kingdom	14	1,650
Norway	8	629
USSR	n.a.	200
Spain	4	31
Italy	2	6
Denmark	1	7
Africa	64	1,009
Nigeria	26	579
Gabon	18	178
Angola (Cabinda)	9	97
Tunisia	1	43
Congo	1	27
Zaire	3	21
United Republic of Cameroon	4	56
Ivory Coast	n.a.	6
Ghana	n.a.	2
Indian Ocean	1	142
India	1	142
World Total	---	13,740

Source: Offshore, Vol. 41, no. 7, June 20, 1981, p.64, 75-80.

Notes: n.a. = not available.

equipment of any drilling rig - derricks, hoist, rotary table, pumps, etc. - are essentially the same. The jack-up variety, which is actually self-elevating, is the more commonly used device, especially in shallow waters. It is relatively inexpensive, but can only work in depths of less than 450-500 feet. It has an array of legs that rest on the seafloor with the actual working platform jacked up to a specific position above the sea surface. These devices are generally very stable.

Drilling ships and semi-submersibles can work in deeper waters but are more expensive. These types of rigs are more vulnerable to movement of the sea than jack-ups and are usually held at the site by anchors or cables. Drilling ships and submersibles theoretically can drill in any water depth.

Once a field has been adequately surveyed, drilled, and found to be exploitable, production platforms are normally installed. These devices usually either rest on or are attached to the sea floor; they have already been used in water depths of about 1,300 feet. Through directional drilling, on a production platform, as many as 60 wells can be drilled. Production platforms are very common; by 1979 over 1,000 were in place in the Gulf of Mexico. Some production platforms are submersible in part, having a large hollow base that rests on the bottom and is used for storage of crude oil. One of the first of these is used in the Ekofisk Field (North Sea) and can hold about a million barrels of crude oil. A new type of production platform device is the so-called guyed towers which are tall, thin structures, somewhat like modern T.V. transmitting towers, that touch the seafloor and are mainly attached by a series of cables, radiating outward. They can move slightly up and down in strong seas. Presently it is water depth and weather that limits areas where production platforms can be used and thus where oil and gas can be produced.

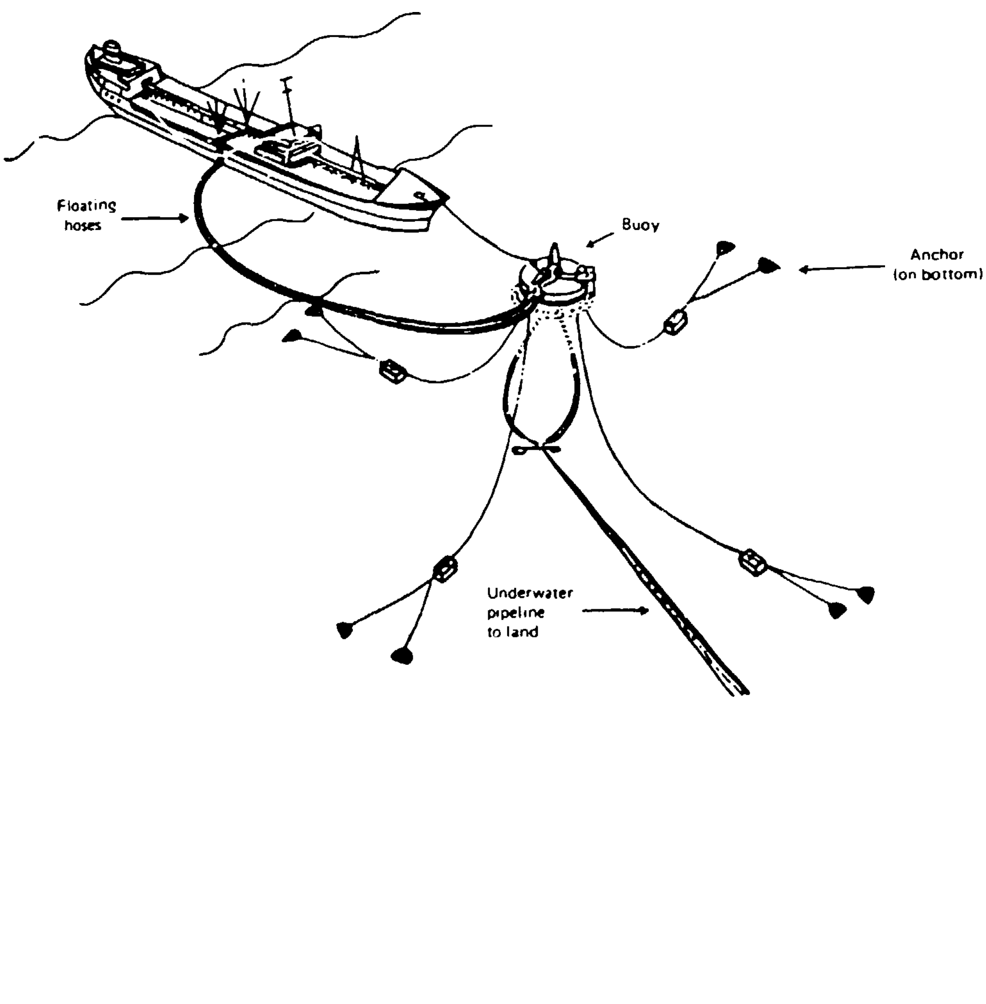
The next important component in an offshore petroleum system is the completion or wellhead unit. These devices sit on the seafloor over the well and control the flow of oil as well as capping the well. Deployment of these devices, in many instances, requires divers or submersible operations. Some wellhead units have the capability for men to work within them; such completion systems are especially important in deep water work where it is difficult, if not impossible, for divers to reach them from outside. The installation of these devices is another depth-limited factor in exploitation.

As an oil field is being developed adequate transport, storage and movement facilities also must be developed. Usually a field has a series of pipelines along the bottom that will collect the oil and transfer it to a central platform or loading area where it can then be picked up by tankers. Alternatively, if land is nearby and there are refinery or storage capabilities, a pipeline to land may be installed. Pipelines are initially expensive to build but are generally cheaper to operate than tankers, once in place. Pipelines may be buried in the seabed to prevent damage by ships or fishermen. A good knowledge of the sedimentary and environmental characteristics of the region is necessary for the safe installation of pipelines. One shortcoming of pipelines is the difficulty and expense in laying them in deep water.

Transfer of oil to tankers is usually done from some type of mooring buoy that takes the oil from a production platform or special tanks. In many instances, the ship being loaded has a deep draft and thus loading has to be done offshore. In some areas deep water mooring facilities are used to transport oil from tankers to land facilities (Figure 16). They are very effective since the tanker is moored to the buoy at one point and can freely rotate with the winds or currents. Large storage tanks can also be used and are fairly common in the Persian Gulf and North Sea. Some production platforms have storage capacities of over half a million barrels of oil. New, innovative storage systems include large bladders made of synthetic material that can be towed as well as being used for storage.

Numerous environmental concerns are associated with offshore oil development including: waste disposal problems; effects of natural or man-made hazards; and ecological damage. Drilling muds in sufficient quantities can smother organisms, they are also dangerous in that they generally contain some toxic materials. The latter effect is not well understood. The petroleum deposits, themselves, are under considerable pressure, which is maintained during drilling by using heavy drilling mud in the drill pipe. If there is a failure in this system, the oil or gas can escape or blow-out. During drilling operations and later in production, a device called a blow-out preventer is usually placed on top of the seafloor above the well to prevent the accidental release of the oil and gas. Nevertheless, blow outs do occur from human or mechanical error and though they often reseal themselves, they may have to be

Figure 16. A typical configuration of an offshore, single-point mooring system. (Adapted from Draft Environmental Impact Statement, Maritime Administration Tanker Construction Program, Vol. I, NTIS Report No. EIS-730-392D).



relieved by drilling side wells to reduce the pressure or stop the fire. During blow-outs large amounts of oil and gas can escape. Two of the most spectacular blow-outs were the Ekofisk in the North Sea in April 1977 and the IXTOC one in the Gulf of Mexico.

A major problem in any marine operation is storms and high waves. Winds of 180 m/h or more can occur during hurricanes and waves can exceed 20 m. Such conditions can subject any offshore operations to critical stresses. Most platforms are designed to survive such conditions, but conscientious operators will remove personnel and shut down operations when and if a storm is even near their region. An accurate satellite weather system is especially valuable for offshore operations, including mining.

Other problems associated with platforms are scour of sediment around the legs of jack-ups or production platforms and therefore their possible collapse, and the growth of algae on their legs which can increase drag. In cold areas, metal fatigue and ice can cause hazardous conditions for drilling platforms. One method used to drill in areas of extreme cold is to build an artificial island and then drill from the island itself, using it as a platform. Such an operation was successfully used in the Beaufort Sea by Union Oil.

A common difficulty in the assessment of pollution and environmental impact is the general lack of knowledge concerning the previous environmental conditions of a region. In some countries, such as the United States, monitoring for a year or two is necessary before permits are granted.

Ownership or Source of such Technologies

Dredges are fairly common vessels and may be purchased, chartered or leased from many sources. Many countries, including developing ones, already have dredging capabilities that are used to maintain navigational channels. These ships might easily be used for some types of marine mining operation, but the correct choice of a dredge (Tables 5 & 6) is often a critical aspect in developing a mine site. Submersible tractor-type dredges, are available from Japan, the United States, and other countries. Dredging skills and technology are common in many European countries, particularly the Netherlands and the United Kingdom. Both countries have large commercial operations, and have advised others.

Much of the technology for manganese nodule operation is known in principle but details are proprietary or in a developmental stage, other than what has been discussed on previous pages. The actual raising of the nodules will probably involve some form of hydraulic dredging; refining techniques are confidential. Most aspects of nodule exploitation may be developed by just a few countries - mainly Belgium, the Federal Republic of Germany, France, Japan, the Netherlands, the United Kingdom and the United States (see Appendix I).

Tecnnologies for the development of offshore petroleum range from geophysical surveying to drilling, production, storage and transport. In all aspects it is an extremely expensive operation. Surveying can cost \$600 per km and the expenses of a semi-submersible drilling rig can reach \$100,000 or more a day. Offshore oil fields are much more expensive to develop and maintain than land deposits. The technologies - drilling ships, production platforms and the rest - are available for rent or hire from many international companies. However, in many instances, there is a considerable wait for the availability of such equipment, especially drilling rigs. A yearly listing of new drilling rigs is given by Ocean

Industry magazine. Again, most of this technology comes from developed countries or from transnational companies.

Future Technologies, Changes Relative to Exploitation of the Resource

It is evident that marine resource development will increase in the coming years. However, to do so will require intensive marine exploration and new techniques for mining, extraction and transportation. These techniques will often be innovative and perhaps specific for each area. They will have to consider the unique conditions that the marine environment imposes, as well as the regional environmental situation. Increased use of the offshore regions must also consider land facilities such as ports, conflicting uses of the coastal region, marketing and transportation. Some resources like sand, gravel, shells and phosphorite will probably have to be used locally whereas hydrocarbons, manganese nodules and some placer deposits can be exported. The fact that a deposit may be technologically exploitable does not necessarily imply that it is economically exploitable. There are numerous examples where apparently rich deposits may never be profitable (see, for example, Wilcox and Mead, 1972).

Estimates of future mineral resources generally have been either overly optimistic, such as the trillions of dollars often mentioned for the manganese nodules, or too conservative, such as earlier projections for offshore oil and gas. The total value for marine resources is not really the question. The point is the value after extraction, processing, and marketing for a local deposit. These numbers are hard to determine especially if new technology must be developed or if crude assumptions must be made about the impact of the marine environment on the operation.

The continued use of land-derived minerals will certainly lead to more offshore mining. Local needs for sand, gravel and shells (and also coral and aragonite for cement in many instances) will certainly increase. Locally, near agricultural areas, mining for phosphorite could develop. One need is already obvious, that of additional sources of energy; this should ensure continued seabed mining of coal deposits as well as expanded exploration and exploitation for hydrocarbons. Deeper water activities, for manganese nodules in particular, depend on development of an international legal regime and on improved technology.

The increased need to extract coal from mines that extend out under the seafloor may lead to in situ techniques such as gasification and other methods of extraction that can be used to reach deposits beyond the present limits of seabed mining (Wang and McKelvey, 1976). Such techniques for coal as well as for other minerals, may include building land-based tunnels or artificial islands to reach the underwater mineral deposit.

It seems evident that the future will also require increased development of facilities such as harbours, deep-water ports, and perhaps offshore nuclear power plants. In addition, the coastal regions of the ocean will be increasingly used as sites for waste treatment facilities and desalinization plants. Some of these facilities can be placed on the shallow parts of the continental shelf. When such structures are eventually built, they will require large amounts of sand and gravel, both for foundation material as well as for breakwaters surrounding the facility. There are other types of offshore facilities such as the islands previously mentioned for mining or oil drilling that likewise would need vast amounts of sand, gravel or shells.

Van den Kroonenberg (1978)feels that rather than continually modifying existing dredging equipment for continental shelf mining that new breakthroughs are necessary, and he suggests a fundamental and systematic design approach. Through a series of cartoons he shows some of the possible new methods and techniques that can be used, for loosening, recovery, transport, and discharge of marine minerals (Figure 17).

The Dutch, probably because of their extensive experience in dredging are especially innovative in conceptualizing equipment and techniques for marine mineral mining (see, for example, Donkers, 1980; Van den Kroonenberg, 1979). Donkers (1980) has described a system designed to mine tin off Indonesia in waters as deep as 45 m. In actuality futuristic concepts have not been developed by the shallow-water mining industry (sand and gravel or placers) whereas the deep-water miners (manganese nodules) are the ones who have proposed innovative ideas, although little full-scale development has occurred.

Most techniques proposed for mining manganese nodules use some variation of airlift methods to raise the nodules. Two especially innovative ideas are those of Donkers (1980)and van den Kroonenberg (1979). Donkers' concept is based on a low density slurry mixture (similar

Figure 17. Possible methods of (a) loosening overburden or sediment; (b) recovery; (c) transport and discharge of bottom or subbottom material. Adapted from von der Kroonenberg (1976).

phys pr	method	execution	presentation	soil
mech. force	cutting shearing scraping	cutter bucket (wheel) grab shovel		hard sand gravel sandy-clay pebbles
erosion	hydraulic	jet drag-head		sand silt gravel
impact	rock-breaking	hammer		hard rock
sound-waves	vibration	vibratory drilling vibratory cutting		hard rock
buoyancy	upward force	heavy-med freezing		loose sand pebbles
gravity	undercut natural slope	caving in hole		clay hard sand sandy-clay loose-sand
chemical	explosion	blasting		rock

(a) loosening

phys pr	method	execution	presentation	soil
mech force	filling	bucket shovel grab scraper screw feeder		all materials
erosion	hydraulic	water-stream		loose sand+pebbles
gravity	filling	bin		loose material
centrif force	sling	rotary feeder		loose material

(b) recovery

phys pr	method	execution	presentation	soil
mechanical	bearing	bucket grab shovel belt elevator redler screw		all materials loose material loose material
hydraulic	suspension	slurry capsules		loosesand gravel all mat
buoancy	upward force	heavy-med freezing		loosesand pebbles

(c) transport

phys pr	method	execution	presentation	soil
gravity	downw force	buckcet grab shovel		all materials
centrif. force	top tumbler	elevator		loose material
mechan force	sliding	screw		loose material
mechan. force	soil pressure	redler		loose material
hydraulic	settling jetting	tank pipeline		loose material
kinetic energy	velocity	belt		all material

(c) discharge

to air-lift systems) but uses non-expanding light particles instead of air (Figure 18), and may have considerable energy savings. Van den Kroonenberg's 1979 system uses a vertical capsule transport method (Figure 19). In this method the nodules are moved up a pipe in capsules with the driving force coming from a pressure differential over the two legs of the transport pipe.

The future for phosphorite mining requires the finding of high grade deposits close to shore. Locally they can be important if a source of phosphate is needed or if a country requires either to save their land deposits or to help their balance of payments.

One future technology that can be used for oil and gas development as well as for subsurface mining is the use of offshore tunneling. Tunnels could be driven from land at the end of which directional drilling could be done using land-based technology.

An important necessary future technology for hydrocarbons will be the development of techniques that permit exploitation from the deeper continental slope and rise; two areas felt to have considerable potential for petroleum. First, however, deep-water production platforms (now limited to about 1,300 m) will be needed as well as remotely controlled or manned submersibles. The latter are necessary for well completion.

Exploitation of gas hydrate sealed oil and gas deposits might be a viable option in future years. However, new technology will be necessary to provide a seal around the casing of the drill pipe so that the drilling operation does not melt the hydrate. Special coring devices will be needed to maintain pressure and test if a hydrate exists. One

Figure 18. Light particle nodule lifting system to raise manganese nodules (from Donkers, 1980).

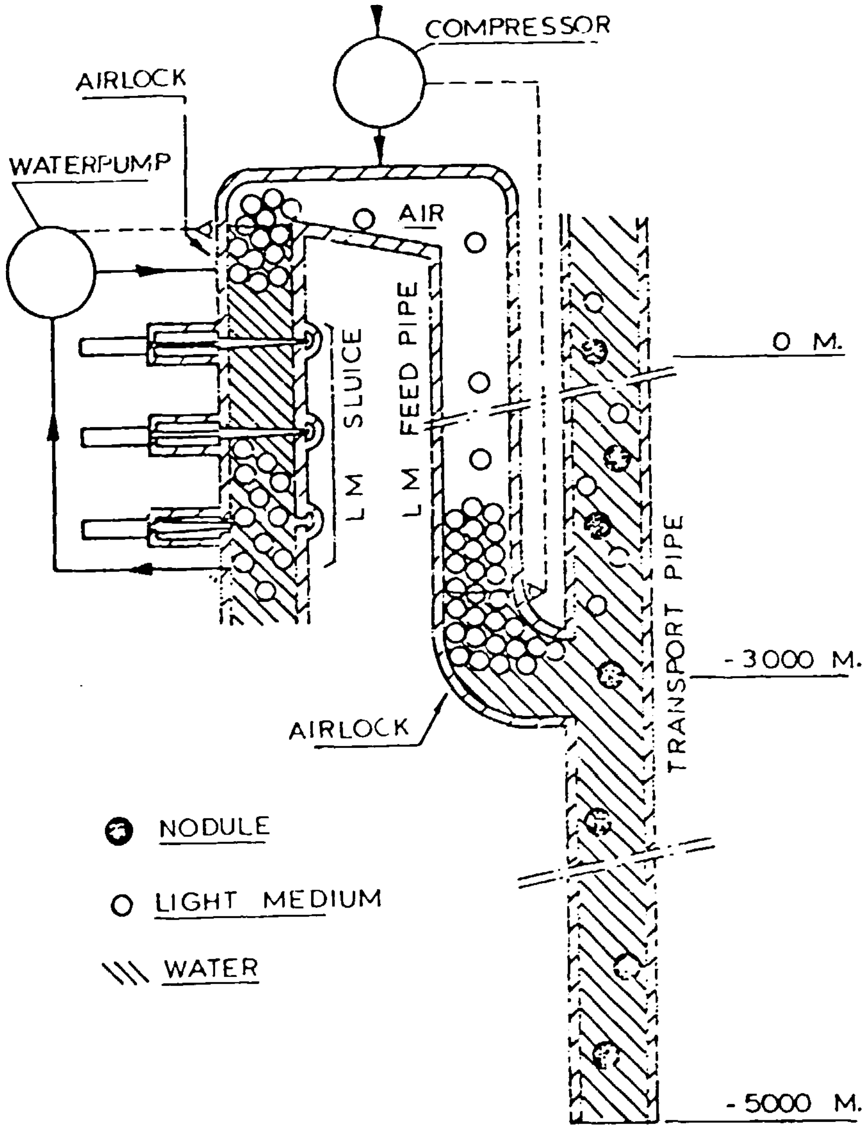
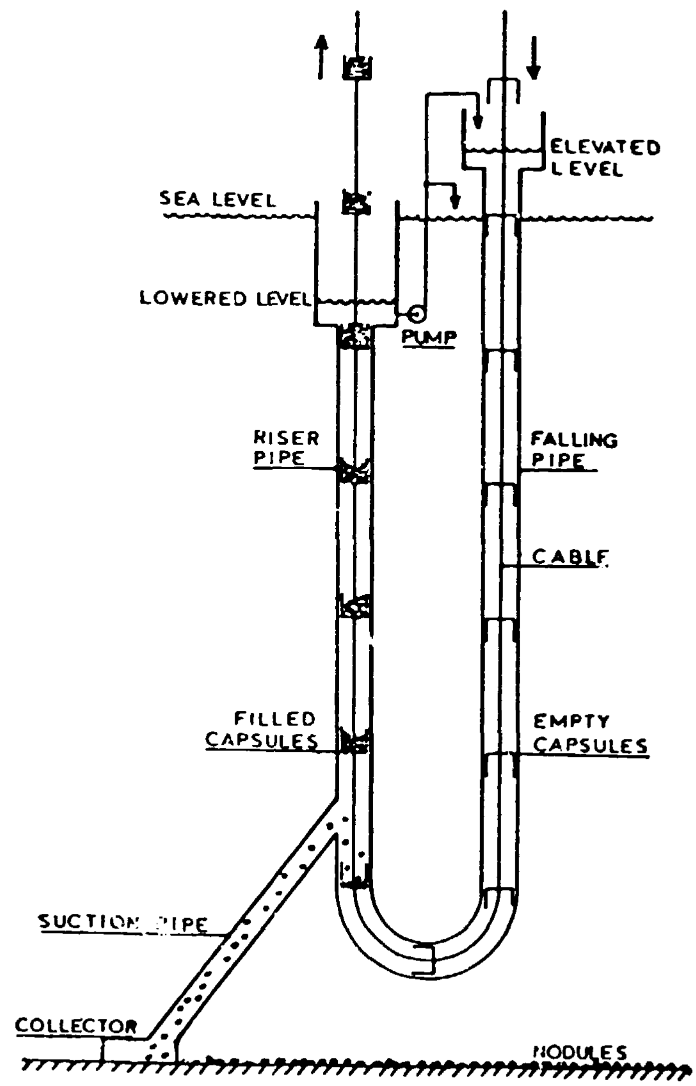


Figure 19. Manganese nodule capsule lifting system designed Ly Van den Kroonenberg, 1979.



sampled by the DSDP Glomar Challenger has yielded as much as 5 times the amount of gas that could have been present at saturation values (Dillon et al, 1980).

Remote sensing techniques, which many think offer considerable potential for detection of land deposits, probably never will be significant in marine exploration. Basically this is due to the masking effect of the water. On land, satellites are most useful in detecting structural relationships that can have mineral implications. But even if remote sensing could penetrate the water column the sediment cover would often obscure the underlying structure.

IV. VALUE AND POTENTIAL FOR DEVELOPING COUNTRIES

Past evaluations of marine resources often have been either amazingly optimistic or less frequently, pessimistic. Part of the reason for such optimistic appraisals is the common confusion between whether a deposit qualifies as a resource (i.e., it is economically workable under present technology and conditions) or really is just a reserve (deposits, which because of their grade, distance from shore or water depth may be workable in the future). Using this consideration many marine deposits readily fall into the reserve category. It is also felt by some that the "technology for deep-sea mining (i.e., nodules) is ill-proven and the economics precarious" ... and even if marine mining happens that it "will not make a large difference to world mineral resources" (The Economist, Feb. 14, 1981). There are equally strong voices supporting the contention that marine minerals hold great promise for the future (see, for example, Levy, 1979).

There are several regions of the world that have especially promising marine seabed resource potential. One such region is the northern Indian Ocean where thick sedimentary sequences extend on either side of the Indian subcontinent. In addition numerous placers and phosphorite deposits are known and in some instances are being mined off Burma, southern India, Indonesia, Pakistan and Sri Lanka. Further offshore are manganese nodule deposits, but they do not appear to be as economic as those of the Pacific. Offshore petroleum production is especially active in the Persian (Arabian) Gulf but limited exploration has occurred elsewhere.

The Caribbean has varied marine resources, including numerous fisheries, hydrocarbon deposits and major areas of marine tourism. Other seabed resources are relatively unstudied. In general much of the region has thick sediment sequences, thus oil and gas potential may exist; significant finds have already been made in the Gulf of Mexico, most recently off Mexico. Several offshore salt domes have sulfur deposits. Sands, especially shells and occasional placers and phosphorites (especially off Venezuela) are known although exploration has not been very thorough. Iron and titanium are known off Colombia and Costa Rica and chromite, titanium and gold may be present off Cuba and Haiti but none of these are presently being recovered. Some nodules are known further offshore. Similar types of deposits are common along the east coast of Latin America.

Seabed mineral resources of regions like the Mediterranean, Red Sea and Southeast Asia are known in various degrees, such as cassiterite and hydrocarbon deposits off Indonesia, heavy metals in the central Red Sea and oil and gas off Italy, Libya, Spain and Tunisia. Continued exploration should find additional deposits.

Technological Capabilities Needed in Developing Countries for Exploration and Exploitation of Marine Mineral Resources

Previous chapters discussed the technologies needed for the exploration and exploitation of marine mineral resources. With the important exception of hydrocarbons and manganese nodules, the technology for most marine resource exploitation is essentially already developed and easily obtainable. In some instances advanced or improved technologies could make the difference between a marginal or profitable operation. For hydrocarbons very sophisticated techniques, ships and platforms are needed. These are generally owned by developed countries or the petroleum industry; advanced technology will be needed for exploitation from the deeper continental slope and rise. Several developing countries, Mexico in particular, along with the development of their offshore hydrocarbon deposits, also have built up exploration and exploitation capabilities. In the case of manganese nodules much of the technology is either in the proprietary or development stage by international consortia (see Appendix I).

As a country starts to develop its offshore mineral resources it will have to evaluate how much of the technology it should develop itself. It has been stressed in this paper that most of the technology for basic exploration and exploitation already exists and thus in many instances it would be an unnecessary duplication of effort to develop the same technology. This point is especially pertinent to some high technology instruments such as side-scan sonar, chemical apparatus or navigation systems. Alternatively, larger systems such as ships, dredges and even drilling platforms could be built in the country, especially if some ship or construction capabilities already exist.

Underlying most of the technology needs is the often more important necessity of having trained scientists and technicians within or available for work in a developing country. Lack of these personnel often may make a country hesitant to proceed with development since it cannot accurately or confidently estimate its own resource potential, and is not willing to put its trust in a foreign company. The importance of the lack of trained personnel was noted by the United Nations Economic and Social Council which observed that "further progress in the development and utilization of marine resources (would) depend greatly on more specific knowledge being gained on the various characteristics of marine environmental conditions" (Resolution 1380(XLV)), and further that "one of the main obstacles to the development of marine science and technology (was) the shortage of experts and qualified personnel, particularly in the developing countries" (resolution 1382 (XLV)). Lack of experience and qualified personnel can also be a factor impeding loans or other financial guarantees for start-up capital.

Developing countries, including those with limited skills and capabilities in marine science, may be anxious to explore for and exploit their offshore seabed resources. A realistic programme should consider a three-part approach:

(1) Develop an in-country capability in marine geology, marine geophysics, offshore technology, and other aspects (a "core group" - see later pages);

(2) Develop an advisory group (probably utilizing foreign experts) that can assist in more immediate decisions;

(3) Develop marine policy capabilities to allow initial planning and development.

Although these three approaches should proceed simultaneously, the latter two will initially be more important. The training of marine scientists and technicians may take many years and will probably have to be done in developed countries. In addition there are problems with foreign training of scientists including overspecialization and some not returning to their home country. Encouraging students to work on these topics that are of immediate concern to their country and assuring that a job is available upon return can reduce these risks. Contacts made with developed countries in this process should be strongly maintained to insure continued access to new technology and techniques. Another approach could be to re-train established scientists, such as turning a geologist into a marine geologist, etc. In any case, it could take a period of time (5-10 years) before the country is self-sufficient in marine skills for well-planned exploration and exploitation to proceed.

Initial planning and perhaps help with the development of training programme may be achieved with the assistance of a competent advisory group, probably utilizing foreign experts. These individuals should be chosen carefully and be willing to seriously involve themselves in the seabed activities of the country. Likewise, the country should be willing to cooperate with these individuals. One consideration may be to develop a cooperative agreement with a foreign marine research institution or university. One advantage of such an agreement is that skills covering the full range of marine activities may be available as well as mechanisms for training. The foreign institution will probably be interested in research opportunities.

A third point is the need for a marine policy capability. Early in a country's marine resource development it will have to make choices as to what are the primary uses of its marine environment and to establish rules for pollution control on one hand and resource development on the other hand. These decisions will involve the skills of lawyers, economists, and many varieties of social scientists in a field field that may be broadly called "Marine Policy". These skills can often be easily transferred to social scientists in the developing country. This is a relatively new approach and one that should be explored by developing countries, as it will greatly help them to proceed with early rational planning for seabed resource development.

Although there are not adequate data it appears that many countries are favouring the first approach without considering the second and third. This, however, may actually delay any offshore activities until a country feels that it has an adequate core group to proceed with seabed resource development. Such a core group may include foreign experts in the initial stages. For seabed resources it should include but not necessarily be limited to the following:

Field	Specialty
Geologist	Sedimentology
Geologist	Coastal zone processes
Geologist/Geophysicist	Structure, bathymetry
Geophysicist	Seismic, gravity, magnetics
Engineer	Coastal zone processes
Engineer	Structures
Physical and/or Biological Oceanographer	Environmental concerns and monitoring problems

Economist	Marine minerals
2-3 Marine Policy Experts	Various, depending on area of development

A co-ordinator may be necessary as well as research assistants and technicians. In the early stages library research may be especially important.

Even if technology and trained people are available it may not simply follow that a marine mining operation should proceed when a deposit is located. A detailed examination of cost-benefit must be made. The exploitation of marine minerals involves a more complex series of decisions than for land minerals. For example, regardless of the degree of exploration, the extent and composition of a marine deposit will rarely be as well known as a land deposit. In addition the unpredictability of the marine environment with the possibility of catastrophic storms or accidents (ship collisions, for example) clearly impose economic restraints not typical of land. An evaluation of a marine deposit must include several key factors such as: the distance that the deposit is from a market or processing facility; ease of recovery from the seafloor or below; processing aspects; environmental aspects (on land a mining company may simply own the entire mining area and surrounding regions and not have to worry about conflicting uses) and; ownership of the deposit. The latter is especially relevant to manganese nodule deposits (discussed later), but because of the distinct possibility of a world-wide 200 nautical mile economic zone is probably not a factor for most other marine resources, which will generally fall within some countries' Exclusive Economic Zone (EEZ). As of February

1981, 88 coastal States out of 135 have established some form of 200 nautical mile economic zone. Indeed the extension of coastal State control to those areas on the legal continental shelf beyond 200 nautical miles will cover almost all areas having hydrocarbon potential.

A simple example of the above is a study of a possible offshore sand, gravel and placer mining operation in Santa Monica Bay, California that showed that mining could be as much as 70% more costly to start than an onshore plant (Mokhtari, Saghafi and Osborne, 1980). This was mainly due to the high cost of equipment needed to dredge and transport material from the mining site to the processing plant. In addition, labour, insurance, fuel and social costs are generally more expensive at sea than on land, and finally, average operating costs are almost 20% higher offshore than onshore.

Negotiating Arrangements for Exploration and Exploitation by External Agencies

There are several techniques that a country can use to increase its knowledge of its offshore mineral resources. First and easiest is to ascertain what information has already been collected and is available in the scientific literature and/or in the various oceanographic data banks. Various services exist for computer searches to scan the scientific literature for specific subject or area studies. These services can be contracted or consultants can be used, or both. The Ocean Economics and Technology Office of the United Nations has several programmes and publications on marine resources, some in cooperation with the Intergovernmental Oceanographic Commission (see, for example, IOC/INF-413). In addition several workshops have been held on marine resources of certain areas. An example of one is a workshop held at Bangkok in 1973 on Metallogenesis. Hydrocarbons and Tectonic Patterns in Eastern Asia organized by the Committee for Co-ordination of Joint Prospecting for Minerals s part of its work for the International Decade of Ocean Exploration. There also are several arrangements within the United Nations that distribute information on marine technology (Appendix II).

In 1967 the United Nations Industrial Development Organization (UNIDO) was established and it has supported several marine mineral-related projects. The future role of UNIDO (as stated in United Nations Document E/1980/68) should make it extremely important in marine mineral development. This role is "to promote and implement a consistent programme of technical co-operation, at the national, subregional, regional and interregional levels, drawing upon the technical machinery, expertise and facilities already available in the industrialized and the development countries. These activities will be based on a strategy comprising the following factors: (i) assessment of the state-of-art, conditions and perspectives of the actual industrial exploitation of vegetable, animal and mineral resources of the seas, and of the foreseeable impact on the socio-economic patterns of the developing countries, in the medium and long terms; (ii) co-ordination and monitoring of relevant initiatives at the national, regional, subregional and interregional levels, to foster the creation and expansion of marine-based enterprises, infrastructures and research facilities, including the transfer and development of appropriate marine technology (iii) collection and dissemination of relevant industrial information to interested governments, institutions or enterprises, concerning techniques, achievements and experiences relating to marine industry affairs; (iv) assistance to develop research and training facilities and skills, so as to enhance the interest and the ability of the developing countries in the area of marine-based industry and marine technology; and (v) promotion of co-operation and of exchange of experiences between developed and developing countries, as well as among the developing countries themselves, on relevant technical, economic, scientific, administrative and managerial aspects concerning the industrial exploitation of marine resources."

A point worth noting about the detection of marine mineral resources is that many such deposits have been found in the course of basic oceanographic research. Among some important examples are the finding of manganese nodules in the deep sea by the Challenger Expedition in the 1970s, the Red Sea brine deposits in the 1950s and the metalliferous deposits along the Galapagos spreading region in the 1970s to 1980s.

Countries generally have followed one of two main procedures in leasing areas for mineral exploration. The first is large-scale leasing (hundreds of square miles), generally with prior bidding. The successful bidder must usually promise to spend a certain amount of money and development effort over a particular period. Royalties or shared interests are usually negotiated prior to development. This procedure generally is more common in frontier or unexplored regions. The second procedure, generally more common to areas that are already undergoing exploration or exploitation, is small-scale leasing. Generally no promise of development expenditures are necessary but the lease may be lost if exploration or exploitation activity does not proceed in a given period of time. Some countries, like Egypt, have leased essentially all parts of their country for hydrocarbon exploration. The political climate, especially the risk of a take-over or major change in government, has often limited exploration and exploitation of certain regions.

In developing arrangements with external agencies several important issues must be considered and these can vary depending on the resource(s) involved. For example, should development be made totally by the external agency, should it be a joint venture, or should the development be totally by the country with aid and consultation with the external agency? Other issues include financial arrangements, for example, should a royalty or license fee system be used? Other important points following development include processing, refining, packaging and marketing. Likewise there may be important questions concerning possible environmental issues and other uses and rights of the developed area. A developing country should pay due attention to these aspects in negotiating with other organizations.

Policy Implications

In any marine mining operation a series of political, economic, social and technological considerations must be evaluated. Obviously, in some instances the liabilities may outweigh the advantages. Among the positive points of a marine operation are: 1) the resources of the ocean are, in many instances, immense and easily obtainable (see earlier sections); 2) the technology to explore and exploit many resources are either available or may soon be available; 3) the ocean itself provides a relatively cheap method of transportation; 4) pollution problems, with some marine resources, especially the further offshore ones, are considerably less than that needed to obtain the similar minerals from a land-based site; 5) in many instances infrastructural facilities like harbours and storage facilities may already exist (Bunick, 1975); 6) many regions of the ocean, for which mining is contemplated may have little or no other economic value; 7) mining in areas outside of coastal state control can have their products transferred to almost any available region; 8) a stable and internationally acceptable legal regime is developing for the exclusive economic zone and the continental shelf. Disadvantages of a marine mining operation may include: 1) many potential marine resources are far from their region of use; 2) some marine resources, although immense in size (sand and gravel, and phosphorites, for example) are not yet financially competitive with land-based sources; 3) the mining of some nearshore mineral resources (placers, sand and gravel) may create real environmental problems which may be more difficult to contain than on land; 4) offshore mining or hydrocarbon exploration may stress or compete with limited land-based facilities; 5) the ocean itself is subject to severe and often (in spite of the best engineering considerations) unpredictable storms and stresses; 6) marine activities are usually more expensive than land operations - thus more capital may be needed for start-up costs. an especially important point for developing countries; 7) an unclear and potentially unstable legal regime exists for the areas outside of the coastal state control; 8) there will be an effect of some marine mineral exploitation, especially nodules, on the price of similar land-originated resources (much of which comes from developing countries).

There is a concern on the part of the developing countries of the world that the ocean could be a vital mechanism for reaching their economic maturity. In spite of the general enthusiasm that exists for marine minerals, several, such as manganese nodules, phosphorites, and hydrates are really only in the exploration stage. Other deposits such as sand and gravel, offshore coal, and shells are well known but their exploitation is strongly influenced by local needs and infrastructures.

With future advances in technology (both in detecting and refining deposits) and inflation, marginal or currently uneconomic reserves may eventually become valuable. In addition, new deposits will continue to be found. For some minerals demand will continue to exceed supply, leading to increased exploration for specific minerals (Table 10). These trends will require that countries make specific decisions about their offshore resources, in some instances mining them for their own need, in other instances as a source of foreign currency. Developed countries are usually the net consumers of many minerals; the United States for example, imports a major portion of its strategic minerals. Thus, for some developed countries mining the marine environment presents an opportunity to reduce their dependency on foreign countries for minerals such as chromite, nickel, platinum, cobalt, oil and manganese.

Table 10

Possible Supply Requirements for Various Minerals

World Supply Problems May Appear During the Remainder of This Century	World Supply Problems Are Likely to Appear Early Next Century	World Resources Are Vast and No Early Supply Problems Are Envisaged
Base metals (tin, copper, lead, zinc)	Nickel	Iron ore
Silver	Titanium (ilmenite and rutile)	Bauxite and other aluminum source
Cadmium	Zircon	Manganese ore
Tungsten		Chromite
Gold		Phosphate
Fluorspar		
Uranium		

Source: From Dunn (1964).

In almost every instance coastal countries will view offshore oil and gas as having highest potential for marine resource development; it will often dominate any national plan or effort. A secondary resource, for planning, could be any of the others previously mentioned. The choice of a secondary resource will be strongly influenced by local geological, environmental and economic factors.

There are many variables that are critical to industry's approach to marine petroleum exploration and development decisions. These can include:

(a) The size of the resource and its geological setting;

(b) Offshore oceanographic conditions and potential environmental impact and rules that may be imposed;

(c) Political climate including regulations concerning leasing, royalties, production and ownership;

(d) Relationship or nearness of the resource to markets, refineries and competition;

(e) Capital costs and availability of funds.

Governments, on the other hand, are concerned with the above as well as with:

(a) Their present and future energy needs;

(b) Costs of developing, refining and transporting the hydrocarbons and how much foreign currency is needed;

(c) Extent of national participation, including "downstream" operations;

(d) Social and economic impacts, and conflicts;

(e) Effects on their foreign relationships.

In the case of marine phosphates, the world's land reserves are adequate to meet future demands. Nevertheless, land mining covers large areas and creates major environmental problems. For example, phosphate mining in parts of the south-eastern United States have been stopped because of environmental damage to the ground water. In some situations transportation costs may exceed mining costs. These factors, and a shortage of phosphate in certain agricultural areas, may lead to eventual exploitation from the marine environment.

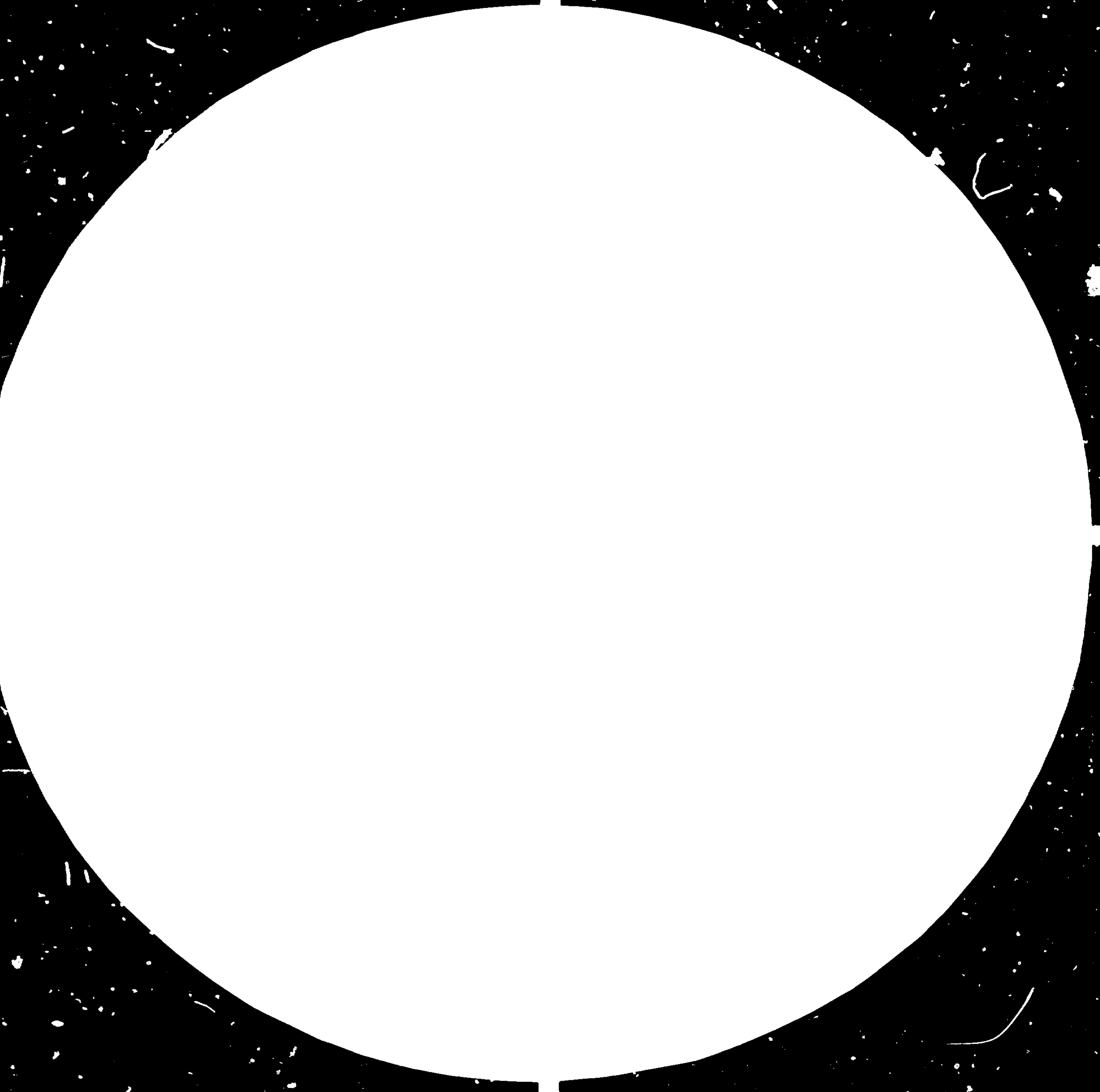
Prior to the present Third United Nations Conference on the Law of the Sea (UNCLOS-III) and the Draft Treaty there were no acceptable jurisdictional limits to the mining of offshore mineral resources. The 1958 Convention on the Territorial Sea and The Contiguous Zone did not adequately define the width of the territorial sea and subsequent claims up to 200 nautical miles had been made. Coastal States without UNCLOS-III, can follow the so-called "exploitability clause" to guide them. This clause, from the 1958 Covention on the Continental Shelf, defines the shelf as "the seabed and subsoil of the submarine areas adjacent to the coast but outside the territorial sea to a depth of 200 meters or beyond that limit to where the depth of superadjacent waters admits of the exploitation of the natural resources of the said areas".[2/] In effect, therefore, coastal countries have control over their "shelves" (and beyond) for as far seaward as they can exploit its resources. Technology has now advanced to the state where exploitation could shortly occur in all parts of the ocean.

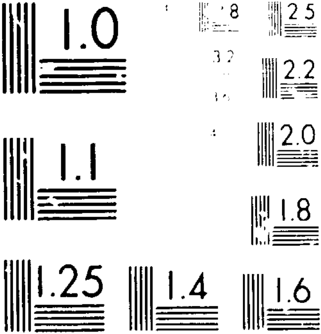
[2/] 1958 Convention on the Continental Shelf - Convention on the Law of the Sea Adopted by the United Nations Conference at Geneva, 1958 (U.N. Doc. A/Conf. 13/55).

UNCLOS-III is trying to establish international and legal guidelines for the resources of the high seas, but there are many complex issues involved that are beyond the scope of this paper. Certainly one of the major problems concerns manganese nodule mining. The mining industry (see Appendix I) is obviously hesitant to risk funds on an actual marine mining operation until there is a guarantee that they could actually mine. Nodule mining and processing is, as previously stated, extremely sophisticated requiring very high start-up costs and technology. Mining consortia have already spent about $300 million exploring for nodules. Unfortunately each group has developed a different type of recovery technology making larger consortia improbable.

The negotiations at UNCLOS-III concerning nodule mining are somewhat unique since it is perhaps for the first time that rules are being written for a non-existent industry. A key point is that deep-sea mining ventures be taxed or licensed and such income be divided among the world's countries as part of their common heritage from the ocean. The actual yield from such a system, however, requires examination.

In 1980, the total world-wide use of the major metals present in




1.0
2.5
2.2
2.0
1.1
1.8
1.25
1.4
1.6

manganese nodules (i.e., manganese, cobalt, nickel, and copper) was of the order of $10 billion. Making an optimistic assumption that 10% of these metals could come from nodules and that a 10% tax or license was appropriate, about $100 million would be available for distribution *per annum*.

La Que, in a 1980 article discussed the potential contribution of income from deep sea mining to the economic potential of developing countries in the near future. His calculations differed from the comments of Ambassador Pardo, who in his famous 1967 speech at the United Nations, suggested that the revenues from deep ocean minerals could be important in reducing the economic differences between developed and developing countries.

In summary, the mining of manganese nodules from the deep sea floor should be technologically feasible in the 1980s. Likewise, sufficient commercial interest (see Appendix I) exists to imply that a mining operation will occur, although several questions concerning legal aspects and economics still exist.

The international regime for deep sea mining that would be created via an UNCLOS-III Treaty may have more wide-ranging effects than just a mining authority. It could lead to a spirit of international cooperation that could extend beyond mineral exploration.

Conflicts/Co-operation

There are many social and economic impacts associated with marine mining that can lead to conflicts especially in coastal regions of developing countries where there might be limited facilities, such as housing, hotels, airports, freezing and dockage capacity. These areas could come under intense pressure from offshore development including an increase in population and business that could squeeze out "less profitable" enterprises like fishing. Aberdeen, Scotland, for example, quickly changed from a quiet fishing town to a major oil industry centre with 26,000 new jobs in 400 companies related to oil, including the servicing of 21 rigs. The general nature of the community was drastically changed.

A development programme should, if possible, be part of an integrated concept obtaining information that can be used for a wide variety of efforts. For example, a carefully designed baseline environmental programme will be useful not only for sand and gravel, placer or hydrocarbon operations but also for fisheries development and assessment, harbour design, tourism, etc. Likewise, technology should be chosen that affords the widest variety of uses, but specific need should not be sacrificed just to obtain variety.

Coastal areas themselves are an especially valuable marine resource that need preservation and proper management. In most countries it is just this region that is critical for all marine activities. Coastal regions are often the most populated and developed areas of a country and resources like sand and gravel are often in short supply. Continued land development may cover remaining sources of these minerals making a marine source even more appealing. Travel costs are often a major factor in sand and gravel mining making shallow nearshore sites cheaper to mine and use than more distant land sources.

Environmental problems and conflicts are almost guaranteed to develop between fishermen, shellfishermen, conservationists and dredgers or even the oil industry. Temporary business landfalls for pipelines and tanker terminals and facilities development will stress other uses of the coastal region, but on the other hand may help lagging industries such as shipbuilding and construction. In the North Sea several conflicts have been identified from drilling including: industrial space usage versus ecological variability and aesthetics; having either a stable community life versus a rapid social change; having locally based and financed economies dependent on indigenous labour versus having international consortia with foreign capital, markets and labour (Earney, 1980).

A major concern in marine mining may result from the mining of manganese nodules not producing the financial rewards many have anticipated. Manganese has the highest metal value in the ore but is not really competitive with land ores (Table 11). Its main use is in the steel industry, but ores having a grade of 50 per cent manganese are generally used whereas 25-30 per cent is the common manganese range for the nodules. A marine mining operation heavily based on manganese exploitation, at least in the short term, may be risky. Nickel is generally felt to be the prime metal to be recovered from nodules (see

Table [illegible]1

Metal Values Per Dry Short Ton of Ore[a]

	Grade (%)	Amount (lb)	Price/lb	Value ($)
Manganese	30.0	600	$0.175[b]	105
Nickel	1.3	26	2.10	55
Copper	1.1	22	0.80	17
Cobalt	0.2	4	3.00	12
				$189

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a/From Agarwal, 1979. Note that their selection of prices may vary from actual values.

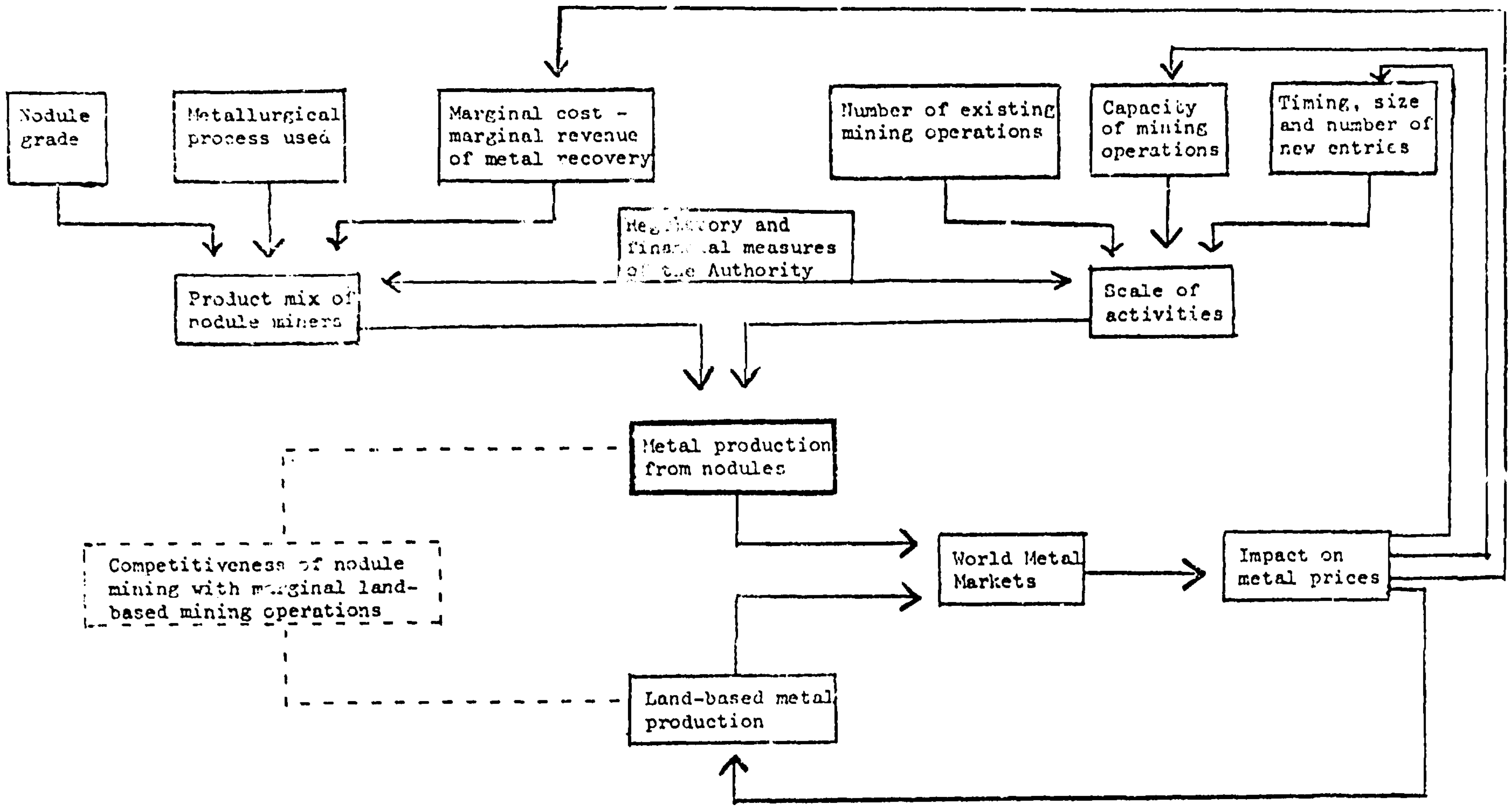
b/Price in ferromanganese.

Agarwal, 1979, for example). The consumption rate of this metal is increasing at 6-8% per year and land-based ores are relatively expensive to mine. Similar potential exists for copper and cobalt.

An important question about the mining of the nodules concerns which elements are extracted and how they are likely to affect some of the countries, both developing and developed, that are dependent on the exports of these elements as a large source of their foreign currency. Countries that can be affected include: Australia, Canada, Chile, Gabon, Ghana, Peru, Philippines, South Africa, Uganda, Zaire and Zambia (Levy, 1979). It is, however, difficult to accurately estimate the magnitude of the impact of deep-sea mining on the other markets of metals, because of the uncertainties like the size and number of each marine operation, the starting year of operations and the growth rates of the total demand for the metals (U.N. publication ST/ESN 107). The increase in supply from marine mining for specific minerals in the nodules should reduce the total value of the mineral from marine and land operations. A simplified model of some interactions is shown in Figure 20. This figure shows an interdependent model whereby a change in one major variable will affect the price of metals that will, in turn, affect the other variables. To reduce the impact of nodule mining on land-based producers, production quotas are being considered in the present UNCLOS-III negotiations. It is beyond the scope of this paper to discuss their actual implications, but the previously mentioned two references do discuss these aspects.

Another problem associated with mining manganese nodules is that the ratio of metals in the nodules is not in balance with the consumption of these metals by the world's market. This point was made by La Que (1971)

Figure 20. Simplified diagram of the impact of metal production from nodules on metal markets



Source: Economic Implications of Sea-bed Mining in the International Area: Report of the Secretary-General: United Nations Third Conference on the Law of the Sea (A/Conf.62/37, 1975).

for the 1967 world production of these metals and it also holds true for present conditions. It can be seen from Table 12 that if nodules were mined at a rate to produce 100% of the world's copper consumption, a considerable excess of cobalt, manganese, and nickel would result. If mining were aimed at just 10% of the cobalt market, only a modest amount of nodules could be mined (about 900,000 tons), with a limited amount of other elements produced. It is possible that increased availability of certain elements from nodules could produce new uses for the metals, but probably not enough to balance the inequalities in the ratios in the nodule. It should be noted that the United States, the major participant in the mining of manganese nodules from the deep sea, imports about 15% of its copper, 71% of its nickel, 98% of its manganese, and 98% of its cobalt for an annual trade deficit of about $1 billion.

The United States, for the above and other reasons, enacted in 1980, the Deep Seabed Hard Mineral Resources Act (Appendix III). Similar legislation has been passed in the Federal Republic of Germany and is being considered in other developed countries. The Act allows the issuing of licenses for exploration of nodules after 1 July 1981, and permits which will authorize commercial recovery, but not until 1988. These mining activities would come under the international regime, as established in UNCLOS-III, if such a regime enters into force and the United States supports it. One can only speculate on the issues that might arise if the developed countries proceed with mining without an international regime coming into force.

Table 12

Possible Production of the Different Metals Contained in Manganese Nodules Assuming 100% of the World Production for Each of the Main Metals (from Ross, 1980)

Metal	World Production[a/] (metric tons)[b/]	Pounds of Element Contained in 1 Ton of Nodules	Percentage of Recent World Production of Elements in Nodules that Could Be Obtained from Nodules Assuming 100% World Production of each of One Element			
			Copper	Nickel	Manganese	Cobalt
Copper	5,822,456	22.5	100	7.2	16	1.5
Nickel	475,988	25.6	1391	100	224	22
Manganese	20,573,518	493	620	44	100	9.8
Cobalt	22,606	5.5	6296	452	1015	100

a/Data from U.S. Geological Survey (Albers 1973) and latest data available.
b/2,205 pounds = 1 metric ton
c/Using data from siliceous ooze area in North Pacific.

In conclusion, the ocean has considerable mineral resource potential. Most immediate is oil and gas from the continental shelf and subsequently continental slope and rise. The value of the oil and gas recovered from the marine environment should exceed the sum of all the other mineral resources at least until the end of this century, if not longer. Sand, gravel, shells, placer minerals and phosphate are or can be mined in many regions. Their exploitation is a function of local needs, infrastructure, and competition with land-based resources. Manganese nodules, have great promise but several questions concerning legal aspects and economies still exist. Several highly industrialized countries are strongly dependent on foreign sources for many of the minerals that can be obtained from the ocean - thus they especially look to the sea and its marine resources. Technology for the exploitation of marine resources is often really just a question of economics. Production platforms, dredging devices, etc. capable of working in relatively deep water will probably be developed when they are needed.

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APPENDIX I

UNITED NATIONS
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FACTS

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DEEPSEA MINING CONSORTIA

Who's Who in the Nodule Business

Manganese nodules, potato-shaped objects which pave sections of the sea floor beneath 3,000-6,000 metres of water, have long been the subject of scientific interest. Recently, a number of companies have become interested in mining nodules as a business; nodules, after all, constitute an ore, basically of manganese, but with commercially interesting proportions of nickel, copper, cobalt and various trace metals.1/

The main actors on the commercial stage are eight consortia, six of which are actively engaged in operations. Bringing these resources into full commercial production will require considerable research and development work, capital, skilled labour and sophisticated hardware, all of which are beyond the ability of one company to put its resources to risk. So, consortia perform a division of labour and a sharing of risk. The information given below on the composition and activities of the consortia has been gathered from published sources and from consultations with industry insiders and analysts. Its purpose is to identify the actors and their work to date, and it is not, by any means, an analysis of the industry.

1. KENNECOTT EXPLORATION CORPORATION

Commonly known as: Kennecott Group. Established: January 1974.
Equity capital: $50 m.
Composition:

Kennecott Copper Corp. - USA		50%
Rio Tinto Zinc (RTZ) Ltd. - UK	Subs: RTZ Deepsea Enterprises Ltd.	10%
Consolidated Goldfields Ltd. - UK		10%
British Petroleum (BP) Co. - UK	Subs: BP Minerals Ltd.	10%
Noranda Mines Ltd. - Canada		10%
Mitsubishi Corp. - Japan		10%

Exploration activities: Extensive exploration in the Clarion-Clipperton Zone; last cruise in 1977; no longer actively exploring.

Test mining activities: Collector test, at one-fifth scale, in 1975. Pipe system tested at sea.

Test processing activities: Finished construction of a pilot processing plant in 1976; capacity is about one-half ton per day. Essentially inactive since 1976.
Plans: To test mining system of one-fifth scale including collector as well as ore-lifting method.

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1/ For an up-to-date evaluation of the scientific, technical and economic aspects of the nodule industry, see Manganese Nodules: Dimensions and Perspectives, Proceedings of a U.N. Expert Group Meeting on Sea-Bed Mineral Resource Assessment (D. Reidel Publishing Co., Netherlands, in press).

2. OCEAN MINING ASSOCIATES (Acronym: OMA)

Commonly known as: US Steel Group or Deepsea Ventures Group.
Established: 1974. Equity capital: $50 m.
Composition:

United States Steel (USS) Corp. - USA	Subs: Essex Minerals Co.	33-1/3%
Union Minière S.A. - Belgium	Subs: Union Seas Inc.	33-1/3%
Sun Co. Inc. - USA	Subs: Sun Ocean Ventures	33-1/3%

This consortium evolved out of Deepsea Ventures Inc. (DVI), which started as a wholly-owned subsidiary of Tenneco - USA and was joined by Japanese Manganese Nodule Development Co. (JAMCO), a Japanese group consisting of C. Itoh, Nichimen and Kanematsu-Gosho. Later, US Steel and Union Minière joined the venture, but Tenneco and JAMCO withdrew. With Sun as a recent partner, OMA was formed.

Exploration activities: Extensive exploration in Clarion-Clipperton Zone by exploration ship Prospector; 1974 - claims announced for a 60,000 sq. km. minesite in the Zone, between latitudes $14^{\circ}16'$ N and $15^{\circ}44'$ N, and between longitudes $124^{\circ}20'$ W and $127^{\circ}46'$ W.

Test mining activities: 1970 - DVI demonstrated airlift system offshore Florida at depth of 800 m; late 1978 - completed prototype testing with Deepsea Miner II, recovering 500 tons of material.

Test processing activities: Finished construction of pilot processing plant.
Plans: Plans to convert ore carrier Weser Ore as test mining ship.

3. OCEAN MANAGEMENT INCORPORATED (Acronym: OMI, OMINC)

Commonly known as: INCO group. Established: February 1975.
Head Office: New York, New York. Equity capital: $45 m.
Composition:

International Nickel Co. (INCO) Ltd. - Canada		25%
Sedco Inc. - USA		25%
Metallgesellschaft AG - FRG)	Cons: Arbeitsgemeinschaft	
Preussag AG - FRG)	Meerestechnischgewinbare	25%
Salzgitter AG - FRG)	Rohstoffe (AMR)	
23 companies - Japan	Cons: Deep Ocean Mining Co. (DOMCO) Ltd.	25%

The Japanese companies include nine from Sumitomo group, Bank of Tokyo, Dowa Mining, Idemitsu, Industrial Bank of Japan, Komatsu, Kyokuyo, Marubeni, Mitsui OSK Lines, Nippon Mining, Nissho-Iwai, Shinko Electric, Tokyo Rope Manufacturing and Toyo Menka. 1977 - Rheinische Braunkohlenwerke - FRG, which was the fourth partner in AMR, withdrew.

Exploration activities: Extensive exploration in Clarion-Clipperton Zone by exploration ships Valdivia and Sonne.

Test mining activities: Mid-1978 - three successful test runs by Sedco 445, a drillship converted to a test mining ship; sea trials established technical feasibility of lifting capability, pumping system and air lift method.

Test processing activities: A pilot processing plant for testing purposes has been developed.
Plans: In the process of evaluating the data gathered during test mining in order to use them in the design of commercial mining system; nodule bulk sample mined during test operations will be used in the pilot processing plant. German partners are continuing exploration work.

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4. OCEAN MINERALS COMPANY (Acronym: OMC, OMCO)

Commonly known as: Lockheed Group. Established: November 1977.
Head Office: Mt. View, California, USA. Equity capital: $50 m.
<u>Composition</u>:

Lockheed Missiles and Space Co. - USA	53.3%)		
Billiton BV - Netherlands	33.3%)	Cons: Ocean	
Bos Kalis Westminister (BKW) Ocean Minerals BV	13.3%)	Minerals Inc.	75%
Standard Oil of Indiana - USA		Subs: Amoco Ocean	
		Minerals Co.	25%

<u>Exploration activities</u>: Exploration in Clarion-Clipperton Zone by exploration ship <u>Governor Ray</u>; mid-1978 - recovered 450 samples (several thousands lbs.) of nodules by free-fall grab samplers; planned programme of six cruises began.

<u>Test mining activities</u>: Successfully completed one-fourth scale collector test in mud pit. Late 1978 - <u>Glomar Explorer</u>, on lease to the consortium, completed shallow water test at depth of 1,500 m; November 1978 - deepsea testing at depth of 5,000 m cancelled due to rough seas and mechanical problems with doors at the bottom of <u>Glomar Explorer</u>.

<u>Test processing activities</u>: Ground broken for test plant in Hawaii; operation scheduled by mid-1979, at 50 mt/day for 3-5 years.
<u>Plans</u>: Test mine at depth of 5,000 m; operate pilot processing plant.

5. ASSOCIATION FRANCAISE POUR L'ETUDE ET LA RECHERCHE DES NODULES (AFERNOD)

Commonly known as: French Group. Head Office: Paris, France.
<u>Composition</u>: Several French Government agencies, including Centre National pour l'Exploitation des Océans (CNEXO), Comissariat à l'Energie Atomique (CEA) and Bureau des Recherches Géologiques et Minières (BRGM) and a few private companies including Société Le Nickel (SLN) and Chantiers de France-Dunkerque, a member of the Empain Schneider Group.

<u>Exploration activities</u>: Perhaps the most systematic exploration of Clarion-Clipperton area, using optimised grid patterns.
<u>Plans</u>: Focus on detailed exploration and equipment development.

6. CONTINUOUS LINE BUCKET (CLB) SYNDICATE

Commonly known as: CLB Group.
<u>Composition</u>: About 20 companies from 6 countries - USA, FRG, F. [illegible] Canada, Japan and Australia. These include US Steel - USA, AMR - FRG, CNEXO and SLN from France, INCO and Noranda Mines from Canada, DOMCO, Sumitomo Heavy Industries and Furukawa from Japan and Broken Hill Proprietory (BHP) from Australia. Composition of CLB Group varies by test.

<u>Test mining activities</u>: Tested one ship system in 1970-1972.

7. DEEP OCEAN MINERALS ASSOCIATION (DOMA)

Commonly known as: Japanese Group. Head Office: Tokyo, Japan.
<u>Composition</u>: An association between Japanese industry and government. Thirty-five Japanese companies including three from Mitsubishi group, four from Mitsui group, six from Nippon group, four from Sumitomo group and C. Itoh, Dowa Mining, Furukawa, Kanematsu-Gosho, Kyokuyo, Marubeni, Nichimen, Nissho-Iwai and Toyo Menka.

Exploration activities: Carried out by Metal Mining Agency, a semi-commercial entity, linked to MITI of Japanese Government; co-operative arrangement with Geological Survey to use vessel Hakurei-Maru; survey on southern Hawaiian seas.
Plans: Extensive exploration by new ship scheduled to be launched in 1980.

8. EUROCEAN

Established: 1970
Composition: Twenty-four European companies; France - 2, Belgium - 3, Netherlands - 4 including Bos Kalis, UK - 1, Italy - 3, Sweden - 8 including Boldien, Graenges and Kockums, Norway - 1, Spain - 1, and Switzerland - 1.

Activities: Of non-commercial nature, directed to scientific research and survey.

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Extract from Uses of the Sea: Report of the Secretary-General (E/1980/68, 23 May 1980)

E. Assistance from United Nations organizations: An overview

1. The United Nations: Ocean Economics and Technology Branch

51. Broadly speaking, the over-all goal of the Ocean Economics and Technology Programme, which is implemented by the Ocean Economics and Technology Branch of the Department of International Economic and Social Affairs, is to provide assistance at the international level to introduce the marine dimension in development planning. In reference to the major developmental and international co-operative frameworks being elaborated within the United Nations - namely, the New International Development Strategy, the New International Economic Order and the Charter of Economic Rights and Duties of States - measures are being taken to ensure that both the concept of ocean policy and management in the widest sense as well as marine sectoral considerations, particularly in the case of marine minerals, are properly reflected.

52. At a more specific level, a number of research activities are being implemented under subprogrammes on uses of the sea, including ocean energy, and on minerals, integrated coastal area development and marine and coastal technology. Substantive support is also provided for a limited number of technical co-operation activities in the area of coastal area management and development. The brief section below describes certain new directions for activities for which early preparations are already under way.

(a) Ocean management: new directions

53. In view of the growing importance of ocean resources and uses for the economic development of States, particularly in light of the extension of national marine

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resource jurisdictions, a number of new directions are being envisaged under the Ocean Economics and Technology Programme. As a starting point, the Ocean Economics and Technology Branch in co-operation with other United Nations organizations is exploring the feasibility of developing a questionnaire to be sent to coastal States under cover of a note verbale. The questionnaire would attempt to ascertain the present and potential role of marine resources and uses in the development process of coastal States; the ways and means in which coastal States are endeavouring to take account of marine resources and uses in their development planning, both sectorally and comprehensively; and the types of problems and needs that are being encountered from one coastal context to another. With the assistance from the United Nations Statistical Office, the questionnaire would also be designed to determine the availability within coastal States of statistical data on marine resources and uses.

54. Taking into account government responses to the questionnaire, a number of activities might be considered:

55. (1) Several carefully selected national case studies could be prepared for the purpose of illustrating how coastal States, both in similar and in contrasting developmental, geographical and physical contexts, are dealing with the marine areas - resources and space - under their jurisdictions. While the dissemination of information on national experiences in this regard could itself be instructive, it would be useful to carry the analysis a step further and induce from the national case studies a number of sets of guidelines. Each set of guidelines could specify approaches to developing and implementing a policy and development plan for marine resources and uses in terms of particular sets of geographical, physical and developmental traits and/or national marine sectoral priorities. Concurrently with this activity, an evaluation would be carried out of the concepts, techniques and guidelines set out in two manuals on Coastal Area Management and Development already prepared by the Branch 14/ in order to ascertain what modifications might be required, if any, for their application in the wider context of extended marine resource jurisdictions.

56. (2) In co-operation with the United Nations Statistical Office and under the aegis of the Administrative Committee on Co-ordination (ACC) Sub-Committee on Statistics, careful consideration would also be given to the feasibility of preparing on a periodic basis an international marine affairs statistical bulletin. The scope and format of such a bulletin would have to be carefully defined, and there undoubtedly would be sectoral and geographical gaps in its coverage initially. However, in addition to highlighting the role of marine resources and uses on a world-wide scale, the purpose of such a bulletin would be to stimulate efforts nationally and internationally to initiate or improve procedures and

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14/ The first manual relates the economic issues of coastal management to the general development planning process and provides planners and decision makers with detailed guidelines for establishing a national programme for coastal management. The second study deals with the legislative and institutional aspects of coastal area management. It sets out the results of a survey of coast-related legislation in 40 nations, identifies a number of specific needs in light of the survey and summarizes critical issues in different countries. Both manuals will be published in 1980.

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measures for collecting data in areas presently not covered or inadequately covered. Over a period of time, the scope of a marine affairs statistical bulletin could be expanded and the quality and usefulness of its data enhanced.

57. (3) Still another area in which effort is warranted and planned pertains to the development of methods for measuring in monetary terms the contribution of marine resources and uses to national development and for devising "marine" income accounts which can be introduced into national income accounting systems.

58. (4) Work is also required in the field of coastal and marine mapping, which has received inadequate attention thus far. A survey could be carried out of techniques presently in use, followed by an assessment of their applicability and possible adaptation in developing coastal States, taking account of the requirements of managing extended marine resource jurisdictions.

2. The United Nations Industrial Development Organization

(Prepared by UNIDO)

59. The industrial exploitation of marine resources is a factor of vital importance for the acceleration of the industrial growth of the developing countries and is destined to develop considerably over the long term taking into account the increased requirements, throughout the world, for food and industrial products.

60. The sea represents an untapped reservoir of industrial marine resources (mineral, vegetal, biological and thermal) which are particularly abundant in developing countries. Consequently, the accelerated development of marine-based industries would contribute considerably towards the achievement of the target set by the Second General Conference of UNIDO at Lima in March 1975 that the share of the developing countries in the world industrial production should reach 25 per cent by the year 2000.

61. Since its establishment in 1967, UNIDO has carried out some 50 projects related to marine-based industries, particularly in areas such as solar salt production, non-metallic mineral extraction, fish processing, algae production and ship-building, ship repair and marine engineering.

62. The future role of UNIDO in this field will be to promote and implement a consistent programme of technical co-operation, at the national, subregional, regional and interregional levels, drawing upon the technical machinery, expertise and facilities already available in the industrialized and the developing countries. These activities will be based on a strategy comprising the following factors: (i) assessment of the state-of-art, conditions and perspectives of the actual industrial exploitation of vegetable, animal and mineral resources of the seas, and of the foreseeable impact on the socio-economic patterns of the developing countries, in the medium and long terms; (ii) co-ordination and monitoring of relevant initiatives at the national, regional, subregional and interregional levels, to foster the creation and expansion of marine-based enterprises, infrastructures and research facilities, including the transfer and

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development of appropriate marine technology; (iii) collection and dissemination of relevant industrial information to interested governments, institutions or enterprises, concerning techniques, achievements and experiences relating to marine industry affairs; (iv) assistance to develop research and training facilities and skills, so as to enhance the interest and the ability of the developing countries in the area of marine-based industry and marine technology and (v) promotion of co-operation and of exchange of experiences between developed and developing countries, as well as among the developing countries themselves, on relevant technical, economic, scientific, administrative and managerial aspects concerning the industrial exploitation of marine resources.

3. Food and Agriculture Organization of the United Nations

(Prepared by FAO)

63. The new legal régime of the ocean is having a profound effect upon world fisheries. Some 90 countries have now declared jurisdiction over zones commonly extending 200 miles from their shores. However, few developing coastal countries are presently able to take full advantage of the new situation. They need to set new priorities for fisheries and to acquire the capacity to assess, allocate, exploit and manage the resources now falling under their control. At the request of its Governing Bodies, the FAO has therefore established a special programme of assistance designed to help developing coastal States to take advantage of the new opportunities and to fulfil their responsibilities in the optimum use of the resources over which they now have jurisdiction.

64. Detailed proposals for a comprehensive FAO programme of assistance in the development and management of fisheries in economic zones were unanimously approved by the FAO Conference at its twentieth session at Rome, November 1979. The Programme has two main objectives: (i) to promote rational management and full use of fishery resources in the economic zones of developing countries; and (ii) to enable these countries, as part of efforts to establish the New International Economic Order, to secure a greater share of living marine resources. It has been designed to respond to urgent requests for help in the medium term and to analyse, over a longer period, how fisheries in economic zones can best be managed.

65. The Programme has two main and complementary elements: a medium-term action plan to meet immediate identified needs, supported by basic studies designed to analyse how fisheries in economic zones can best be developed and managed in the long term. The medium-term plan provides for five major types of activity related to immediate needs, each supported by the longer-term studies. They include undertaking, on request, interdisciplinary missions to help countries to prepare fisheries policies and plans; advising on specific questions ranging from resource assessment to national legislation and enforcement, training administrators and others responsible for the management and development of fisheries in exclusive economic zones; mobilizing bilateral and multilateral funding for fisheries and promoting collaboration in fisheries development and management through regional bodies and programmes.

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66. The basic long-term studies will centre primarily on issues arising in fisheries management at national, regional and subregional levels and the preparation of development options based on socio-economic and technical studies of all aspects of fisheries. This work will be carried out against a background of an increasing experience of the effects of extended jurisdiction on fisheries, an awareness of the special needs of developing countries and appreciation of the problems confronting fishery management. Both the medium-term and long-term activities will be designed principally to assist in the creation or improvement of national and subregional capacities to manage and develop marine fishery resources.

67. The Programme will be delivered in a decentralized manner through a network of multidisciplinary technical projects, based in the field and designed to respond to the specific needs of groups of countries in natural management areas, based upon such factors as shared stocks or fisheries, common problems or opportunities, and other natural affinities such as language, culture and traditions. Experience so far in offering preliminary assistance under the Programme of the Exclusive Economic Zone (EEZ) has clearly demonstrated this vital need for flexibility and for tailoring the assistance to match the identified and specific needs of each requesting country or group of countries.

4. Inter-Governmental Maritime Consultative Organization

(Prepared by IMCO)

68. One of the major objectives of IMCO is to provide technical assistance to developing countries in the field of maritime transport. The development of an efficient merchant marine is no easy task and perhaps one of the major problems is the recruitment of personnel with the skills, training and experience necessary in what is the most international industry in the world. The sea is no place for amateurs, still less for inefficiency. A country wishing to create a fleet must ensure that the fleet and the men who operate it conform to internationally agreed standards which are necessarily, and therefore intentionally, of a standard as high as practicable. It is very difficult therefore for developing nations to build up a merchant marine without assistance; even if the country has sufficient financial resources, it may lack the technical skill and expertise which are vital for success.

69. Since coming into existence in 1959, and particularly during the last few years, IMCO, as the United Nations agency exclusively concerned with shipping and the sea, has devoted a growing portion of its activities to the needs of developing nations. Under the broad headings of "Shipping", "Ports and Harbours" and "Marine Pollution", IMCO provides assistance in over 35 major areas of concern.

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5. World Health Organization

(Prepared by WHO)

70. During the past few years, WHO has considerably intensified its activities concerning pollution of coastal waters and the potential health hazards associated with bathing, shellfish and contamination of other marine food products. A number of projects have been started in collaboration with other international organizations as well as with national institutions in countries directly concerned with these problems.

71. Most of the current work of WHO in this field is being pursued as part of three major international activities: (i) the Mediterranean Action Plan; (ii) the Comprehensive Action Plan for the Protection of Regional Seas; and (iii) the Joint Group of Experts on the Scientific Aspects of Marine Pollution (GESMAP).

72. These activities are carried out jointly by the United Nations Environment Programme (UNEP), the specialized agencies, and the International Atomic Energy Agency (IAEA) and other bodies of the United Nations system. The United Nations Environment Programme has been responsible for the initiation of many of the projects on the Mediterranean and other regional seas. In addition to the three interagency programmes, WHO is also developing health criteria for coastal bathing waters.

73. Additionally, the WHO has initiated a programme, in conjunction with UNEP, to provide guidance on the application of environmental impact assessment techniques to coastal areas. This programme recognizes the need to assess the environmental impact as well as the economic benefits of coastal area projects and provides the procedures for developing and utilizing such assessments. The guidelines draw upon the expertise of other specialized United Nations agencies to provide examples of environmentally good and bad coastal area developments.

6. World Meteorological Organization

(Prepared by WMO)

74. The WMO programme for marine meteorology and related ocean activities received strong support at the Eighth World Meteorological Congress (April-May 1979) when it reaffirmed its policy that the programme should continue in such fields as marine meteorological services, marine climatology, sea-ice services and marine meteorological observations. Emphasis was also given to co-operative programmes with other international organizations such as the Integrated Global Ocean Station System (IOC/WMO IGOSS). In particular, the Congress stated that the three important considerations in developing the services programme should be the expansion of the scope of the services, their further specialization and promotion in developing regions. Thus, the marine environmental analysis and prediction services planned and co-ordinated by WMO through the Marine Meteorology Programme covers a large variety of marine meteorological and oceanographic parameters, including sea ice, waves, surface and sub-surface sea temperature and current, sea level and storm surge. Marine

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meteorological and related oceanographic services in maritime developing countries need to be gradually expanded in support of such activities as search and rescue, marine pollution clean-up operations, port and harbour activities, ocean engineering, tourism and recreation.

75. Environmental processes in coastal zones are very closely connected with the dynamics of the ocean and atmosphere. For example, the phenomenon known as "El Niño" near the west coast of South America may be mentioned. Investigations of vast spaces of high seas require international co-operation. The Integrated Global Ocean Station System is one of such international co-operative efforts which consists of observational arrangements and data processing systems as well as telecommunication arrangements. The concept of IGOSS also satisfies conditions for a long-term ocean monitoring system and contributes to climate-related research.

76. Assistance to maritime developing countries is provided in various ways, mainly through the provision of guidance material, expert missions, training of personnel and by means of regional seminars and co-ordination meetings.

77. Short-term expert missions are arranged on request to assist countries in the evaluation of their marine support requirements aimed at developing progressively suitable marine meteorological data acquisition and service systems. These missions are followed by long-term expert advisory missions, as necessary, at the request of the countries concerned.

78. Assistance intended to encourage training in the field of marine meteorology in developing countries forms part of the over-all WMO programme on Education and Training. It is mainly provided through aid programmes such as the Voluntary Co-operation Programme (VCP) and the United Nations Development Programme (UNDP). Such assistance includes provisions for on-the-job training of personnel in other countries where advanced facilities exist. In addition, regular training courses in meteorology are provided at the Regional Training Institutes specially established for the purpose in the developing regions of the world.

79. Transfer of technology in the marine field is also achieved through training seminars arranged on a regional basis. These seminars have proved to be particularly helpful to marine meteorologists in acquainting themselves with the latest forecasting techniques used in advanced countries. In addition, regional co-ordination meetings are arranged to assist countries in the implementation of services according to internationally accepted procedures and practices.

7. United Nations Educational, Scientific and Cultural Organization and the Intergovernmental Oceanographic Commission

(Prepared by UNESCO and the IOC)

80. The work carried out by the Division of Marine Sciences of UNESCO and the Intergovernmental Oceanographic Commission is of special relevance to the anticipated results of the Third United Nations Conference on the Law of the Sea, in regard to marine science research and associated transfer of technology as well as development of infrastructures. Similarly the activities meet

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recommendations for scientific and technological development as formulated by the United Nations Conference on Science and Technology for Development.

81. The general marine sciences programme (Division of Marine Sciences) gives special emphasis to: (i) establishment of a marine science programme and management of their marine resources and environment, especially coastal; and (ii) the strengthening of the marine science human resources and infrastructure of developing countries. The first aim is carried out in co-operation with scientific non-governmental organizations and provides a solid scientific content to the second objective. It also seeks to promote and provide a framework for larger extrabudgetary marine science development projects. The marine sciences in UNESCO have just undergone a major evolutionary step in their development, which can be seen in two aspects of the Division's activities: (i) the extrabudgetary marine science development programme has grown rapidly to significant size, and (ii) research guidelines concerning a suite of relevant marine ecosystems have been developed to provide substance to national infrastructure development.

82. The Intergovernmental Oceanographic Commission, which operates as an autonomous body within the Science Sector of UNESCO, is the only intergovernmental organization concerned with promoting co-ordinating oceanographic activities, including marine pollution research and monitoring, on a global scale.

83. The Commission's framework for co-operation among Member States and interested international organizations is the Long-term and Expanded Programme of Oceanic Exploration and Research (LEPOR), "designed to assist in a better understanding of the marine environment through science ...". 15/

84. During the second decade of its existence, the Commission promoted and co-ordinated the implementation of the International Decade of Ocean Exploration (IDOE), 1971-1980, as the acceleration phase of LEPOR. The International Decade of Ocean Exploration as part of the Long-term and Expanded Programme of Oceanic Exploration and Research (LEPOR/IDOE) was intended to improve the capability of all IOC member States, in the long term, to participate in oceanographic research activities of special interest to them, as well as to stimulate the acquisition of scientific knowledge of the oceans.

85. Within the framework of LEPOR, the Commission co-ordinates three global and six regional science programmes; three ocean services programmes including steadily expanding activities in the field of transfer of knowledge and technology through information management; and a broad programme in Training, Education and Mutual Assistance (TEMA) in marine sciences, which is implemented as a component of all other programmes. An important mechanism is the Voluntary Assistance Programme (IOC-VAP), which is now in operation but needs considerable further support to become fully effective.

15/ General Assembly resolution 2414 (XXIII), 17 December 1968

86. Further to the traditional activities above which have evolved over the past twenty or so years, the Commission must be fully aware of developments in the Third United Nations Conference on the Law of the Sea, especially those pertinent to marine scientific research and related aspects of transfer of technology. As the Conference is entering in its final phase, it is becoming increasingly clear that numerous tasks connected with the implementation of any Convention that may be concluded will devolve on existing international organizations. Presently, extensions of national jurisdiction include, depending on each case, development, conservation and management of marine resources and the protection of coastal zones and marine living resources from pollution. The larger zones falling under national jurisdiction require that a wide range of marine science activities, undertaken with the consent of the coastal State, are carried out following internationally agreed-upon procedures in planning, execution and evaluation of such marine field research projects.

87. As a special contribution to strengthening national capabilities in marine sciences, including a more effective study of the oceans within 200 miles, the Commission will, in different places of the world, start to develop programmes to assist developing Member States, at their request, in the framework of the Voluntary Assistance Programme (VAP). In this context steps are being taken to promote marine geological-geophysical investigations within zones under national jurisdiction, thus facilitating and accelerating the exploration and exploitation of mineral and hydrocarbon resources.

88. To foster and generate the exchange of technology which is of great importance to marine research and transfer of technology, greater emphasis will be placed on the improvement of specialized information services which will enable scientists working with national, regional and global programmes to benefit and contribute to a common base of knowledge through the Aquatic Sciences and Fisheries Information System (ASFIS), maintained and co-ordinated by FAO, with the joint sponsorship of the IOC and the United Nations/Ocean Economic and Technical Branch (OETB).

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APPENDIX III

A NOTE ON THE U.S. DEEP SEABED HARD MINERAL RESOURCES ACT

The Deep Seabed Hard Mineral Resources Act was signed into law on June 28, 1980. It establishes a legal structure pursuant to which United States citizens may proceed with the exploration for and commercial recovery of deep seabed hard minerals (commonly referred to as "manganese nodules"), pending conclusion of an acceptable Law of the Sea Treaty which would address the same issue. The Act authorizes the Administrator of the National Oceanic and Atmospheric Administration (NOAA) to issue to eligible U.S. citizens licenses for the exploration for deep seabed hard minerals (which licenses may not be issued before July 1, 1981) and permits for the commercial recovery of such minerals (which permits may not authorize commercial recovery to commence before January 1, 1988). The Act also authorizes NOAA, in consultation with the Secretary of State and the heads of other appropriate departments and agencies, to designate as reciprocating states those other nations which establish seabed mining programmes which are compatible with and recognize the U.S. programme. These reciprocal arrangements will provide a mechanism whereby each nation will recognize the rights of the others' miners.

Before the Administrator of NOAA may designate a nation as a reciprocating state, the Act directs the Secretary of State to judge such a nation's seabed mining programme on the basis of, among other criteria, compatability with the Act and implementing regulations. NOAA proposes that these functions be addressed in two ways. First, NOAA in co-operation with the State Department will shortly publish for public information and comment a set of broad criteria which will guide decisions relating to designations of reciprocating states. While these criteria will not take the place of NOAA's future commercial recovery regulations, they will supplement the exploration regulations by outlining the factors which will be considered. Second, NOAA will incorporate in reciprocating state agreements the requirement for later consultations to assure development of compatible commercial recovery regulations.

Regulations for the issuance of exploration licenses have been developed to establish a legal framework to facilitate the development of the new seabed mining industry in the United States, while assuring that such efforts proceed in a responsible and environmentally sensitive manner. The regulations are intended to provide the necessary degree of certainty to the industry, while also recognizing the need for flexibility in order to promote the development of deep seabed mining technology, and the usefulness of allowing initiative on behalf of miners to develop mining techniques and systems in a manner compatible with the requirements of the Act and the regulations. In this regard the regulations reflect an approach pursuant to the Act, whereby the issues discussed ultimately will be addressed and evaluated on the basis of the application and exploration plan submitted by each applicant.

The regulations deal only with the requirements of procedures pertaining to exploration licenses. NOAA determined that it was neither necessary nor desirable to propose regulations at this time for commercial recovery permits. This conclusion was based substantially on comments from interested persons that it would be premature to do so. The Act prohibits commercial recovery until January 1, 1988, and current explorers have indicated an intent not to file commercial recovery permit applications until at least 1984. NOAA's decision also was based on the agency's own realization that the deep seabed mining industry is still evolving and that more information must be developed to form a rational basis for future decisions by industry and by NOAA in its implementation of the Act. Therefore, any attempt at this time to promulgate commercial recovery regulations would likely be counterproductive for both NOAA and the industry. During the interim, NOAA and the industry will develop the more extensive information base necessary for a reasoned approach to commercial recovery regulations. Meanwhile, these proposed regulations will allow miners to establish needed priorities of right in selected seabed areas and to continue necessary exploration activities in accordance with the Act.

Extracts from: U.S. Department of Commerce. National Oceanic and Atmospheric Administration, Deep Seabed Mining: Regulations for Exploration Licenses, March 24, 1981.