Ocean Mining Requirements

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The particulars and procedures of deep ocean mining are presented. Emphasis is placed upon design uncertainties and their influence on operational efficiency. Requirements which have evolved as a consequence are identified and reviewed. Particular focus is directed towards navigation, communications, data transfer, accurate real-time weather monitoring, and prediction of sea and atmospheric conditions. It is concluded that deep ocean mining will be, to a large extent, dependent upon the transfer of operational information, its availability, accuracy, and reliability.

Introduction

MINERALS are the lifeblood of our industrial society. While land deposits of many vital minerals are dwindling, world population and expectations are rising at an unprecedented rate, making it imperative to develop new sources of supply for vital metals. Rich sources for four of these metals—copper, nickel, cobalt, and manganese—lie on the deep ocean floors. This potential has prompted technological development in deep ocean mining during recent years.

As the technology of deep ocean mining expanded, so did the area of uncertainties. Mining manganese nodules from a depth of 15,000 or more feet, in the open ocean, in commerical quantities, pushed ocean technology to its frontier—and, in some cases, beyond. The necessary engineering research required the expenditure of large sums of money. By 1977, over $150 million had been invested by U.S. industry in research and development with the end still not in sight. It is estimated that more than $750 million must be spent by an individual operator before the first commercially mined nodule will reach shore.

And the expenses will not end there. Each mine site will require $75 million or more for annual operating expenses. With these large investments and costs, it is essential that reliable, efficient, and timely sources of information be available for navigation and environmental forecasting. Additional requirements exist for rapid dependable communication with shore-based facilities.

This paper will explore the current state of deep ocean mining, with a description of a likely system and the part satellites can play in helping to extract needed resources from the ocean's floor.

Deep Ocean Mining

Potential Mine Site Locations

While deposits of manganese nodules are found worluwide, current interest is centered on an area in the southeastern North Pacific between Hawaii and the southwestern coastline of North America (Fig. 1). To be economically viable, a nodule deposit must have a minimum abundance of approximately two pounds per square foot with an assay of 1.4% nickel, 1.2% copper, and 0.2% cobalt.[1] In addition, the sea floor must be relatively free of escarpments, large basalt outcroppings, or other obstructions to an underwater collector. The general area between the Clarion and Clipper fracture zones fulfills all of these requirements.

The surface environment in this area is generally under the influence of the northeast trade winds, though during the summer months these tend to break down as the inter-tropical convergence zone moves north. The summer and fall months are also noteworthy for tropical storms. Because of the sparcity of meteorological observing stations in the mine site area, tropical storms and hurricanes pose a significant threat to both the safety and operating ability of any deep ocean mining venture.

During winter and spring, the southeastern North Pacific enjoys typical northeast tradewind weather. Swells are generally three to four feet with about two-foot wind waves superimposed; prevailing direction is from the northeast. Occasionally, strong outbreaks of polar air cause extratropical storms to form to the north which interrupt the trades and bring swells from the west or north. Actual frontal passages, as experienced in the mid-latitudes, are practically nonexistent.

The ocean floor in this area is nearly ideal for ocean mining. Only occasional basalt outcroppings interrupt a gently undulating bottom of silt and mud. No bottom currents have been detected and temperatures maintain a near-constant 40°F.

The basalt outcroppings are the major sea-floor environmental hazard. Once a specific mine site has been selected, extensive and accurate mapping will be required to identify areas where mining is impractical because of topography. This mapping presupposes navigational capabilities of the highest order in order to be of value; ideally, positioning ability must be within plus or minus 25 feet.

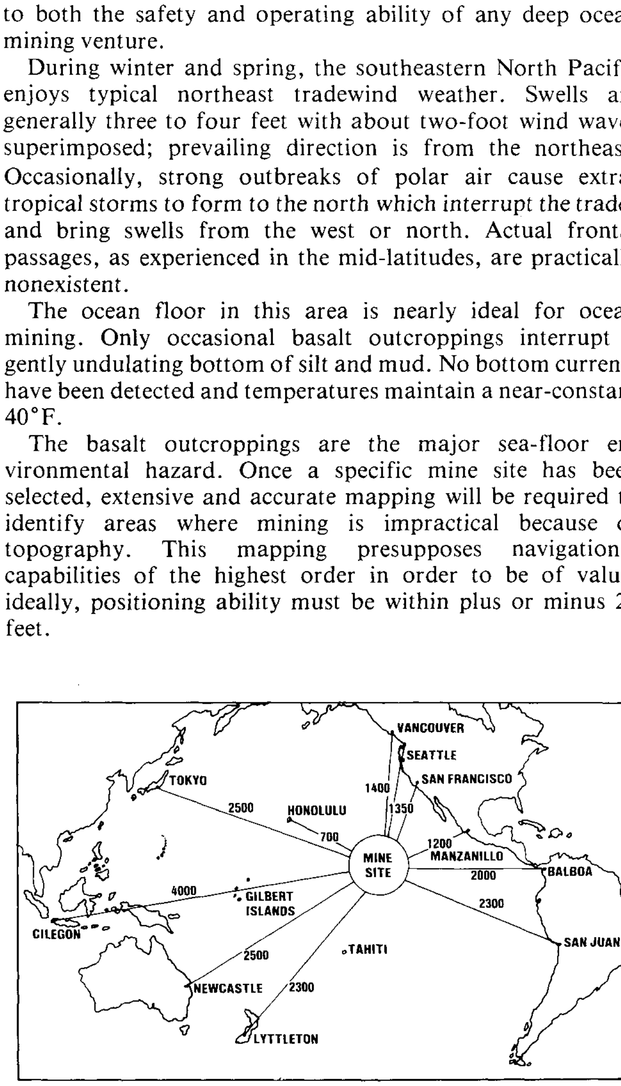

Fig. 1 Typical mine site location.

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Deep Ocean Mining Equipment

Commercial deep ocean mining will require equipment of a size and complexity unprecedented in ocean technology. Several approaches have been investigated, but the various consortia working in the field have generally settled upon either submerged centrifugal pumps or an air-lift concept to raise the manganese nodules to the surface. Actual system configurations and operating parameters are only generally disclosed; however, any mining system must consist of a nodule collector on the bottom, a lift system, surface vessel, and ocean transport.

Nodule Collector

Currently, two different collectors appear to be the most practical: a plow-type, which would scoop up bottom mud and nodules and then screen out the nodules prior to injecting them into the lift system; and a vacuum collector (Fig. 2), which would vacuum the ocean floor, concentrating the nodules for lifting to the surface.

Several studies have been published relating the theoretical optimum collector size to speed over the bottom for the most efficient retrieval of nodules. Reference 2 is work performed by Clauss in this area. Clauss based his work on a 5000 dry tons per day operation and a nodule abundance of two pounds per square foot. Using these assumptions, optimum collector size was 79 feet wide and tow speed was four feet per second.[2]

Obviously, the tradeoff between collector size and nodule harvesting speed is a complex problem. Total desired daily tonnage of nodules, power requirements, expected down times, lifting capabilities, and many other factors enter into the problem. As experience is gained through testing and actual mining operations, design changes and improvements will be made in the collector.

Lift System

At the present time, two methods look promising for lifting the manganese nodules from 15 to 20 thousand feet to the surface; these are submerged pumps and air lifting.

Submerged Pumps

Pumps have been used in the dredging industry for decades to remove solids from below the surface. The problem faced in the deep ocean mining industry is one of magnitude – depths are greater than 15,000 feet and tons of material a day must be lifted to make the project economically feasible.

Any pumping system used will, of necessity, be multistage, with the first (lowest) stage approximately one mile below the surface. Pressures at this depth are over 2400 pounds per square inch and the salt water presents a hostile environment to most materials. While pressure compensation will play a part, net differential pressures in the neighborhood of 1800 psia must be designed for. Add to this the problems of stress-induced fatigue and corrosion and the problems approach the frontiers of present-day technology.

Power requirements are also a quantum jump above current dreding use. While the total power required is directly proportional to the desired daily production rate, even a minimum production will require pumps and driving units far larger than presently in use. Individual pump motors will be on the order of 2000 to 3000 shaft horsepower and, in the case of centrifugal pumping, drive pumps with one- to two-foot impellers are required.

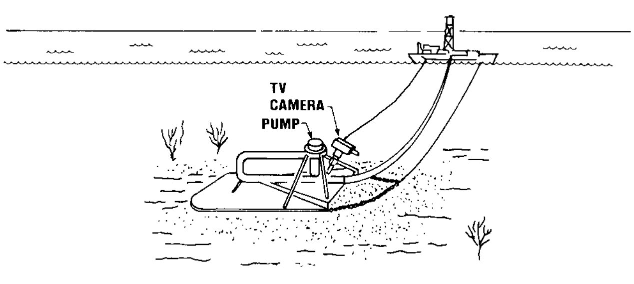

Fig. 2 Vacuum collector concept.

Air Lifts

The air lift is an alternative to mechanical pumping and is being investigated by groups involved in deep sea mining development. The largest system currently operating is land-based and located in the Soviet Union.[3] The air lift pumps 17,000 tons per day of coal from a shaft 1555 feet deep. This compares with the 5 to 15 thousand tons per day of nodules which must be lifted over 15,000 feet. Since the Russian air lift has been successfully operating for more than ten years, the concept is sound; unfortunately, the behavior of three-phase slurries (air/water/solids) is still not fully understood and, consequently, scaling up to the size required for deep ocean mining involves many questionable areas. Presently it appears that air compressors capable of delivering about 10,000 pounds per minute at 1000 psia to a depth of approximately 5000 feet will be required.

Mining Vessel and Ocean Transport

With the mining and ocean transport vessels, we are back in the normal world. Deep ocean drilling ships have developed to the point where established design criteria and performance requirements are close to those necessary for deep ocean mining. Problems exist, of course, in shipboard handling of an 80-foot collector and 15,000 feet or more of steel pipe, but these are comparatively straightforward engineering problems. The transfer of the mined nodules from the mining vessel to the ore carrier is another matter.

Transferring the vast amount of materials from one ship to another, at sea, will be a complex and potentially dangerous task. The ships must come alongside at a minimum distance in order to reduce the mechanical problems of transfer, but still maintain enough separation to preclude collision. Surface swells, waves, and wind will compound control problems and both ships will be moving at minimum steerage way. Currently, it appears bow thrusters, coupled with superb seamanship and dynamic positioning systems, will be necessary for this phase of deep ocean mining.

Port and Processing Facilities

Compared to the technological problems involved with the mining effort itself, the port and processing facilities are straightforward. Off-loading manganese nodules will be similar to the off-loading of any other ore, and processing facilities can easily be designed to fit the specific physical and chemical properties of the manganese nodules. Studies will be required, of course, to develop the most cost-effective techniques to use, but normal methods of analysis can be employed.

Satellite Support

The problems involved in collecting manganese nodules, lifting them to the surface, and transporting them to on-shore processing plants are being solved by a massive engineering research and development effort. However, to make the whole system work day in and day out, support is required which can be uniquely supplied by satellites. This support is in three areas: navigation, weather observations and predictions, and communications.

Navigation

Precise knowledge of a ship's location is required for survey work and mining operations. Present means of navigation allow positioning to within a quarter of a mile of a desired location; requirements for deep ocean mining are on the order of ± 25 feet.

Survey Work Navigating Requirements

Prior to actual mining operations, potential mine sites must be surveyed for nodule abundance, bottom contours, and possible obstacles. Optimum sizing of system components is highly sensitive to nodule abundance. As an example, Fig. 3 shows the relationship between required collector width and the necessary collection velocity to achieve a desired production rate (in this case, approximately 15 thousand tons per day). A change in average nodule abundance from 2.0 to 3.1 pounds per square foot has a significant impact on both collector width and speed. Because of this, the precise limits of minimum economic nodule abundance must be charted to preclude excessive operations in areas of low yield.

None of the collector designs currently being considered by various consortia are self-steering; consequently, bottom contours will have a profound effect on the actual over-the-bottom track of the collector. A one or two percent slope may cause the collector to move a thousand feet or more off to one side, thus inadvertently mining areas which might not be economical. Extensive efforts, therefore, have been made to accurately map the ocean bottom in areas of mining interest; if the positioning upon which these charts are based is in doubt, much of the work will have been in vain.

No collector can be economically designed to overcome every possible obstacle that it might run across. Instead, the collector is designed to trade off capital and operating cost against potential minable areas. If obstacles exist within a mine area beyond the design capabilities of the collector, they must be charted so that they can be avoided. Since the collector will be operating blind, it will be necessary to avoid charted escarpments and out-croppings by at least twice the uncertainty of their position; if a charted position can be off by 100 yards and current mining vessel position by the same, 200 yards is the minimum safe distance to approach an obstacle.

It becomes obvious that accurate charting has a direct impact on the economic feasibility of deep ocean mining. In order to extract the maximum potential yield from a suitable mine site, its economic limits must be determined; in order to determine collector wander, bottom contours must be mapped; in order to avoid obstacles yet achieve maximum coverage of the mine area, outcroppings and escarpments must be charted.

Operational Navigating Requirements

The navigational requirements for survey work are equally applicable to actual mining. The mine ship's position in relation to charted data must be known at all times. There is, however, an additional navigational requirement when mining operations commence—knowledge of actual collector track over the bottom.

Figure 4 shows what might be the paths of two adjacent tracks of a collector. The planned tracks would ideally be parallel and exactly one collector width apart; this would achieve 100% coverage. In reality, however, the spacing must be increased to account for collector wander and, of concern to us, navigational uncertainties.

Determining the optimum spacing between tracks is a complex problem involving trade-offs between nodule abundance, mine site size, collector wander, operational parameters such as optimum collector speed, system power requirements, desired daily production, and navigational accuracy. However, after all of the non-navigational parameters have been integrated, the optimum spacing will be directly proportional to the navigation accuracy obtainable. This means the amount of noncollected (and wasted) mineral resources will increase as the uncertainty of the mining vessel's minute-by-minute position increases. There is thus a direct dollar advantage to timely, accurate, navigational capabilities.

Weather Observations and Predictions

Unfortunately, the area of the world with the greatest potential for deep ocean mining is also the area with the least weather data available. The contribution which satellites can make in providing weather data is fundamental to both the design and operation of any deep ocean mining endeavor.

System Design

The surface environment in which a deep ocean mining system must operate has a direct impact on system design. A 15,000-foot or longer pipe string will be attached to a surface ship heaving and pitching in the open water. The power spectrum of these motion inputs must be analyzed and their effect on stresses within the pipe string and forces transmitted to the collector must be determined. At the present time, scarcity of historical data (and inaccuracies in what data base there is) preclude accurate knowledge of the conditions to be expected. This has led to over-design of critical components with a concommitant waste in procurement and operating costs.

Of equal concern is a firm knowledge of what can be expected concerning the duration and extent of severe weather. A mining system must be designed to achieve a targeted yearly production rate; down time due to severe weather must be made up by increased production capabilities the rest of the time. The contributions which satellites can make in this area is dramatically shown by the sudden increase in reported tropical storms over the eastern North Pacific during the late fifties and early sixties; this was the time when the first weather satellites were sent aloft. There were dozens of storms in this area which formed, developed, and dissipated without meteorologists even being aware of their existence.

Satellites are uniquely able to provide observations of wind, waves, and storms in an economical and timely fashion. This, in turn, will provide the data needed by engineers to design a safe economical mining system.

Operations

The operating deep ocean mining system is at the mercy of the surface environment. To operate safely and economically, accurate weather predictions are a necessity; but weather

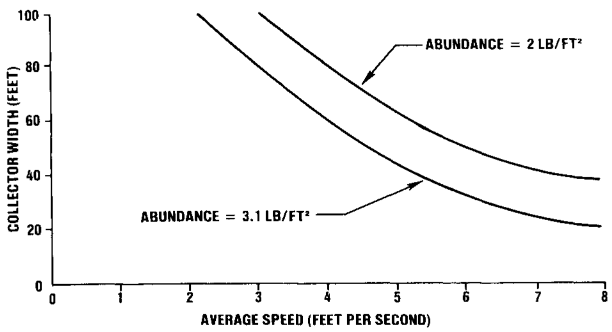

Fig. 3 Relationship between collector velocity and width.

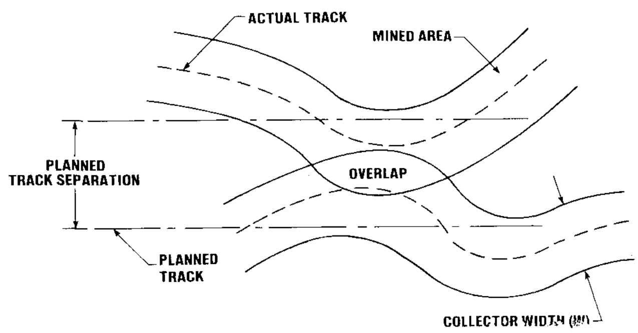

Fig. 4 Typical collector paths.

forecasting is, in the final analysis, only as good as the input data.

Satellite reconnaissance is the only economically feasible way to provide information on wave/swell heights, period, and direction, as well as surface and upper air conditions required for forecasting. Current predictive techniques use basic thermodynamic laws and equations to construct a three-dimensional forecast of the atmosphere. If the grid spacing of the input data is larger than the smallest significant dynamic occurrence, storms can "drop through" the grid. Satellite observations of the three-dimensional distribution of moisture, temperature, and motion will provide a quantum jump in base data for weather predictions. This, in turn, will give the deep ocean mining operating personnel a significant improvement in planning and operating abilities.

Besides the mining vessel itself, ore carriers will be plying back and forth. Already, optimum routing techniques are used for planning the courses of super-tankers. As weather prediction becomes more accurate through the use of satellite-supplied data, the ability to route the ore carriers so that storms are avoided and minimum fuel is used enroute will improve. This will provide significant economies and increased safety.

Finally, under the category of satellite-improved weather forecasting capabilities, is storm warnings. There is a definite trade-off point between the costs of losing a major piece of equipment from not securing mining operations for a storm and the costs of lost production. The trade-off point is determined by the accuracy of available forecasting techniques. Consider for example a grossly simplified case. A piece of equipment costs $100,000 and requires $50,000 to secure it against winds over 50 knots. If more than 67% of high wind forecasts are wrong, it is better to ignore the warnings. In actual fact, the relationship between capital cost, securing cost, and forecasting accuracy is far more complex, but the capabilities of satellites to increase forecasting accuracy has direct economic benefits in addition to basic safety for personnel.

Communication

A third area in which satellites will contribute to ocean mining is in communications. Direct ship-to-shore or ship-to-ship radio communications are not nearly as dependable as contact via satellite. An extensive communication network will be required for logistics, data transfer, and data analysis.

The mining vessel must be in constant contact with shore facilities to arrange for logistic support, ore transport scheduling, and decision making. If logistics can be controlled with sufficient dependability, the number of ore carriers required to transport the mined nodules to port may be reduced through more efficient utilization. Constant adjustments in scheduling will be required and the necessary coordination between mining vessel, ore transports, and shore facilities can only be accomplished if dependable high-speed communications are available.

The mining vessel will be generating a constant stream of data on variations in nodule abundance, production rates, and inventory. If computer links can be maintained via satellite, much of this data will be analyzed at shore facilities. This will reduce the amount of computer equipment (vulnerable in an ocean environment) required on board the ship. Results of the analyzed data, as well as decisions reached from the data, will then be transmitted back to the mining vessel.

Summary

The contributions of satellites will be basic to the success or failure of deep ocean mining. The navigational accuracy required can probably be supplied only by satellite; necessary weather data can be most economically obtained by satellite; and communications are a major capability of satellites. Together, space technology and deep ocean mining technology can make significant contributions to the world's supply of needed mineral resources.

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