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Deep Seabed Mining Environment: Preliminary Engineering and Environmental Assessment

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Engineering and Environmental Assessment of Deep-Sea Mining Workshop

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For the Ocean Mining Working Group of the International Society for Offshore and Polar Engineers, partly based on presentations and extensive discussions at and after the **Engineering and Environmental Assessment of Deep-Sea Mining Workshop**, The Third (1999) ISOPE Ocean Mining Symposium and Workshop (ISOPE OMS-99), held at the National Institute of Oceanography, Goa, India, November 8–10, 1999.

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Deep Seabed Mining Environment: Preliminary Engineering and Environmental Assessment

SUMMARY

Several groups of mining engineers and environmental scientists have been conducting studies for the assessment of environmental impact and additional disturbance on the deep seabed. These studies influence the development of an individual mining system and its subsystems for the collection, screening and lifting of deep-sea minerals and their transshipment on the ocean surface. Some experiments to assess and predict the potential impacts of deep seabed mining have also been conducted in the Pacific and Indian Oceans.

These studies have revealed several unknown physical, chemical, biological and geological conditions under which the mining system will have to operate, as well as potential impacts. However, owing to the uncertainty in design of the mining system and the difference in scale between commercial mining and test mining and its experiments, many of the results cannot be extrapolated or applied directly. Also, limitations of time and the operating mechanism of earlier experiments have left many questions unanswered—questions such as the potential impact of sediment-water discharge in the water column.

Hence, it is recommended that a large-scale environmental experiment be conducted in stages—first simulating the nodule pickup on the seafloor and the sediment discharge in the water column—at a selected site with a representative pickup system. The data generated through this experiment should be useful, not only in understanding the potential effects of large-scale mining on the marine ecosystem, but also in incorporating environmental design parameters in the development of various mining subsystems. As such an experiment will be cost-intensive, it is recommended it be undertaken by interested research groups willing to cooperate and share resources, manpower and costs.

1. BACKGROUND AND OBJECTIVES

Deep-sea mining has been a subject of interest for several research groups for over three decades, due to its potential for the economical recovery of large reserves of minerals that could provide an alternative resource of strategic metals for industrial development. A deep-sea mining operation would offer a variety of challenges, owing to distant locations (thousands of miles from the coast), deep-sea mineral occurrences (5 to 6 km of water depths), extreme physical and chemical conditions (high pressure, low temperature) and unknown environmental settings.

The International Society of Offshore and Polar Engineers (ISOPE) began the effort to bring the research scientists and engineers closer by offering opportunities—through its conferences and journal—for interaction, the exchange of ideas and the sharing of research results and plans. Subsequently, the full-fledged First Ocean Mining Symposium was initiated under the aegis of ISOPE and inaugurated in 1995 at Tsukuba, Japan, where the Ocean Mining Working Group (OMWG) was formed. This biennial symposium aims at providing researchers with a forum for the sharing and communicating of their recent results in this field. At the Second (1997) Ocean Mining Symposium at Seoul, it was decided to organize workshop(s) on topics of current interest in this field; such workshops would recommend a direction for research and activities, so that the common goal of effective ocean mining can be fulfilled.

With this objective, a workshop on “Engineering and Environmental Assessment of Deep Seabed Mining” was organized and held during the Third ISOPE Ocean Mining Symposium at the National Institute of Oceanography, Goa, India, on November 8–10, 1999. This report covers the workshop’s problem identification, discussions and recommendations regarding the environment. The compiled draft report has been further discussed and supplemented with the contributions of the symposium participants.

2. STATUS OF DEEP-SEA MINING AND RELATED STUDIES

Considerable progress has been made in the last three decades in the technological development and tests of ocean mining by different groups of research scientists and engineers in the United States, Canada, France, Germany, Japan, Russia, IOM (Poland and 6 other member countries), India, Korea and China. The efforts have been in 4 major areas:

- Survey and exploration
- Mining system development
- Mineral processing
- Environmental studies

The survey and exploration of deep-sea minerals have led to detailed studies on the distribution and grades of these minerals, their genesis and mineralogy, petrology and sedimentology of

associated substrates and bathymetry maps of the seafloor. In the quest for faster and more accurate surveys and data collection, a variety of survey equipment has been developed and used, ranging from free-fall devices, mechanical equipment, remotely operated vehicles, tethered online cameras to remotely sense backscatter and sub-bottom profiling data.

In the Pacific Ocean in the '70s, international consortia conducted some form of tests of prototype mining systems and components. However, subsequent progress has been slow since 1980, due to unfavorable metal-market conditions, which led to the virtual cessation of R&D activities by international consortia in the early '80s. While individual countries have entered the R&D arena since the '80s, there has been significant delay in the survey and mining R&D of deep-sea minerals. Some R&D activity, though at a much lower level, has been under way; today's researchers have narrowed it down to basically 2 miner/collector concepts (Chung and Tsurusaki, 1994; Chung, 1996): self-propelled seafloor miner vehicles (Brink and Chung, 1980) and tow-sled collectors (Chung and Tsurusaki, 1994). But their progress has been slow. On the other hand much progress has been made in the simulation of pipe system dynamics and control (Chung, 1997).

Some international consortia had developed manganese nodule processing techniques, including pilot processing tests. The results were not made available to non-members, however. Recently, some of the research groups have conducted laboratory-scale tests (Kojima, 1997; Zhong et al., 1999; Premchand and Jana, 1999). Tests by India and China may be scaled up to pilot-plant tests (Zhong et al., 1999; Premchand and Jana, 1999), but the unwanted tailings will constitute from 72% to 97% of the original ore, depending on the type of processing (Black, 1982). The safe disposal of these tailings into the terrestrial or marine environment, or their alternative uses, have not been studied to any sufficient extent.

Owing to growing concern for the environmental impact of deep-sea mining, multi-disciplinary environmental studies (oceanography, geology, geochemistry, ecology and geotechnical engineering) have been undertaken in different parts of the world oceans. Initial environmental impact studies were conducted during pilot-scale mining tests for manganese nodules in the '70s (DOMES, 1976; Burns et al., 1980; Ozturgut et al., 1980); they were followed by several experiments in the last decade, creating benthic disturbances in the Pacific and the Indian Oceans (Foell et al., 1990; Trueblood, 1993; Fukushima, 1995; Tkatchenko et al., 1996; Sharma and Nath, 1997). These studies include a collection of baseline environmental data in the proposed mining areas, and the creation of an experimentally disturbed area that is comparable to future mining and whose effects are monitored over a period of time. They aim to project the intensity of mining impacts on different environmental parameters as well as to evaluate the processes of restoration and re-colonization of the deep-sea environment and animal communities. The baseline seabed mining equipment here appears to be a tow-sled type collector.

The environmental studies conducted up to the present succeeded in identifying various effects on the fauna, the communities and their environment. The time has come to summarize the

results of this work and identify the areas that require further research. Future studies should also aim at data collection for the engineers, to assist in their design of systems with the least environmental disturbance.

A brief description of the studies conducted so far is given in the following paragraphs.

DOMES

The DOMES (1976) (Deep Ocean Mining Environment Study: 1972–81) conducted by NOAA (USA) monitored environmental impacts during 2 of the pilot-scale mining tests conducted by Ocean Mining Inc. and Ocean Mining Associates (OMA) in 1978 in the Pacific Ocean (Burns et al., 1980; Ozturgut et al., 1980). The study measured the concentration of particulate in the discharge, and assessed the biological impacts on the surface as well as benthic plumes.

DISCOL and ATESEPP

The **DIS**turbance and Re-**COL**onisation (DISCOL) experiment was conducted by the scientists of Hamburg University, Germany in the Pacific Ocean's Peru Basin during 1988–98. Collection of pre-disturbance baseline environmental data was followed by the disturbance caused by a plow harrow (Fig. 1) in a circular area of 10.8 km² (Foell et al., 1990) at 88° W–07° S in the Southeast Pacific Ocean. Post-disturbance studies were carried out to monitor the impact and re-colonization after 6 months, 3 years and 7 years, using sediment cores, deep-towed photographic systems, current meters and nephelometers. The results have shown that over a period of time, although certain groups of benthic organisms may show a quantitative recovery, the faunal composition is not the same as the undisturbed one (Schriever et al., 1997). This implies that complete re-colonization is a slow process and some of the benthic organisms may need more time to re-establish themselves in the disturbed areas in terms of density and diversity. The ATESEPP (German abbreviation of Impact of technical interventions into the deep sea of



Fig. 1 The plow harrow used during the German large-scale DISCOL-Experiment in 1989 to create a disturbance on the seafloor comparable to a future manganese nodule mining.

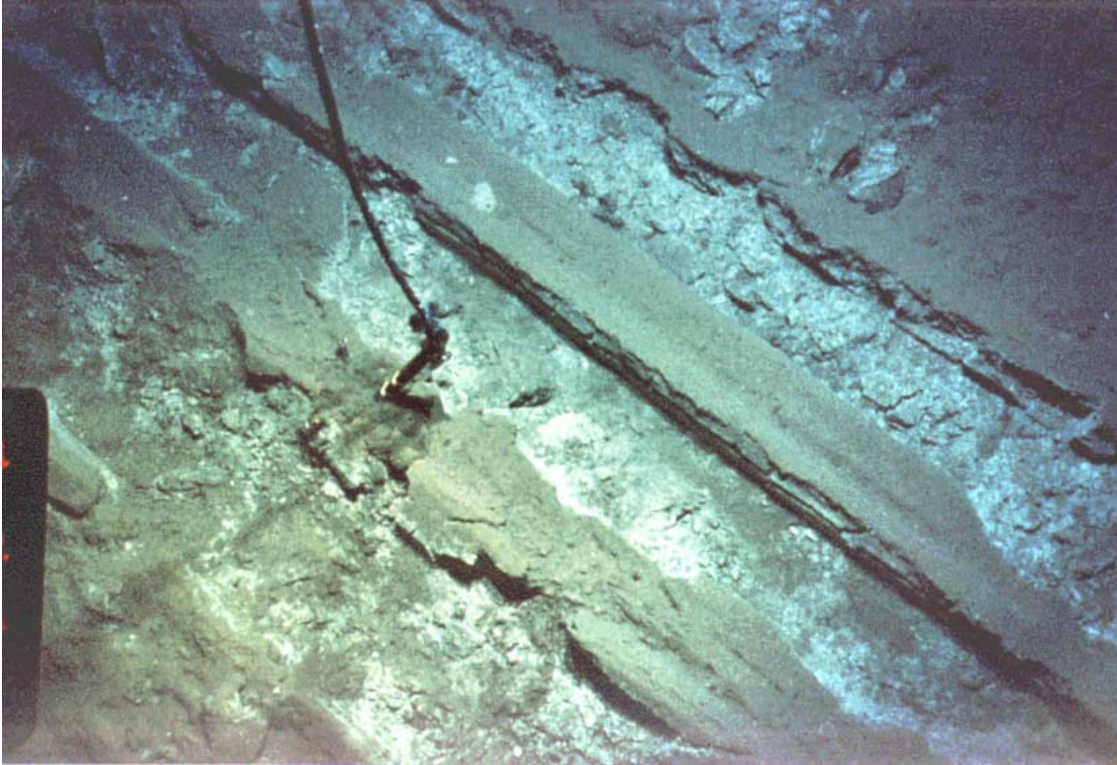


Fig. 2 Plough harrow track at 4135-m water depth. The top 15 cm of the semi-liquid and soft sediment layer are totally disturbed and transported away, and the manganese nodules are ploughed under and disappeared from the sediment surface: At 88° W–07° S in the Southeast Pacific Ocean.

the Southeast Pacific Ocean) project extended DISCOL's results with additional information of impacts in oceanography (sediment transport in the near and far field) and mechanical and geochemical aspects of the soil. Heavy impacts were observed on the geochemical regime after disturbance of the top 20 cm of the deep seafloor's sediment structure (Fig. 2). The results of this experiment demonstrated that the scale of disturbance and investigation was still too small. An experiment of this scale is cost-intensive and requires the participating groups' cooperation in sharing not only development and operational costs, but also expertise, manpower and other resources (Thiel et al., 1991).

NOAA-BIE

The benthic impact experiment (NOAA-BIE) by the National Oceanographic and Atmospheric Administration (NOAA, USA) was conducted in the Clarion Clipperton Fracture Zone (CCFZ) of the Pacific Ocean (1991–93). After baseline studies in a pre-selected area, the Deep-Sea Sediment Resuspension System—DSSRS (Brockett and Richards, 1994) was used 49 times in an area of 150 × 3000 m, and the post-disturbance sampling with CTD, sediment traps and core samples indicated changes in the faunal distribution in the area (Trueblood, 1993). The impact assessment after 9 months indicated that, while some of the meiobenthos showed a decrease in

abundance, the macrobenthos showed an increase in their numbers, probably because of increased food availability (Trueblood et al., 1997). Hence, mixed effects of re-sedimentation on benthic organisms could be expected, and the effects cannot be generalized. The re-sedimentation in turn would depend on the total volume of sediment re-suspended and the area's prevailing current patterns.

JET

Japan's deep-sea impact experiment (JET, 1994–97) was conducted by MMAJ (Metal Mining Agency of Japan), using the DSSRS, in the Pacific Ocean's CCFZ in 1994. Disturbance was created during 19 transects over 2 parallel tracks 1600 m long (Fukushima, 1995). The impact was assessed from sediment samples, deep-sea camera operations, sediment traps and current meters. Results (Fig. 3) show that, while the abundance of meiobenthos decreased in deposition areas immediately after the experiment and returned to original levels 2 years later, the species composition was not the same; in addition, the abundance of certain groups of mega and macrobenthos was still lower than in the undisturbed area (Shirayama, 1999). This observation further establishes that certain groups are more susceptible than others in adapting to changed conditions on the seafloor.



Fig. 3 An example seafloor photo taken 1 year after JET disturbance. Top part is a sediment recovered area with the hydraulic suction device. Middle part is a sledge track, 60 cm in width, of the disturber. The bottom is a piled and re-deposited area beside the sledge track. JET disturbance was taken place from the end of August to the beginning of September 1994 at 9°16.7' N–146°15.5' W.

IOM-BIE

A benthic impact experiment (IOM-BIE) was conducted by the Interoceanmetal (IOM) Joint Organization in the Pacific Ocean's CCFZ in 1995, using DSSRS (Fig. 4). In all, 14 tows were carried out on a site of 200×2500 m and the impact was observed from deep-sea camera tows and sediment samples (Tkatchenko et al., 1996). No significant change was observed in meiobenthos abundance and community structure in the re-sedimented area, but alteration in meiobenthos assemblages within the disturbed zone was observed (Radziejewska, 1997; Radziejewska and



Fig. 4 Track 4. Sea-bed image obtained by Neptun deep-sea camera system within IOM BIE test site during monitoring survey in 2000 (5 years after disturbance operations). Photograph shows re-establishment of the bottom within disturber tracks at 2×1.5 -m site, $119^{\circ}41.1'$ W– $11^{\circ}03.7'$ N: Continuous Deep-sea Camera (CDC) survey was made from the end of July to the beginning of August, 1995 (From V. Stoyanova, IOM).



Fig. 5 Benthic disturber “deep-sea sediment re-suspension system” used for the experiment.

Modlitba, 1999). This indicates that the intensity of disturbance and the proximity to the site could have variable effects on the composition of the faunal assemblages.

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The National Institute of Oceanography (Goa, India) conducted the Indian Deep-sea Environment Experiment (INDEX) for the Department of Ocean Development (Government of India) in 1997 in a pre-selected area in the Central Indian Ocean Basin after a detailed baseline study during 1995–97 (Figs. 5 and 6). The DSSRS was used 26 times in an area of 200×3000 m, during which about 6000 m^3 of sediment were re-suspended (Sharma and Nath, 1997). Post-disturbance impact assessment studies indicated vertical mixing of sediment, lateral distribution of suspended particles and differential effects on microbial, meio and macrobenthos both inside and outside the disturbance track (Ingole et al., 1999; Nair et al., 2000). Long-term monitoring of re-colonization and restoration of the benthic environment are planned (Sharma, 1999).

3. POTENTIAL EFFECTS OF DEEP SEABED MINING

It is anticipated that the potential for serious environmental impact will be greatest at the seafloor and at the depth zones of discharge of mine tailings and effluent (Thiel et al., 1997). Certainly, the impacts at the seafloor and in the water column cannot be avoided, but they must be taken into account during the development of the mining equipment and in designing the mining operations to minimize the effects. Because of the potential for relatively greater environmental harm in the depth zone from the surface to 1,000 m, it is strongly recommended that discharges be released below the depth of the oxygen-minimum layer (e.g. in 1,000 m in many parts of the Pacific Ocean). This has to be evaluated early in advance of commercial mining activities.



Fig. 6 Disturber track marks and ‘Sediment piles’ made by the movement of the disturber on the seafloor in the disturbed zone, August 1997: 10°01’ S–75°59’ E and 10°03’ S–76°02’ E in the Indian Ocean.

Some of the probable impacts at various levels in the water column are summarized as follows (ISA, 1999).

3.1 Potential Benthic Impacts

The primary benthic impacts from test mining during the exploratory phase can be as follows:

- (a) Direct impacts along the track of the nodule collector, where the sediments and associated fauna will be crushed or dispersed in a plume and the nodules removed.
- (b) Smothering or entombment of the benthic fauna away from the site of nodule removal, where the sediment plume settles.
- (c) Clogging of suspension feeders’ and dilution of deposit feeders’ food resources.

3.2 Potential Water-Column Impacts

Discharge of tailings and effluent below the thermocline may cause some environmental harm to the pelagic fauna:

- (a) Mortality to zooplankton species resident at mid-water depths or that migrate to these depths on a diel, seasonal or ontogenetic basis.

- (b) Effects on meso- and bathypelagic fishes and other nekton caused directly by the sediment plume or associated metallic species, or indirectly through impacts on their prey.
- (c) Impacts on deep-diving marine mammals, such as through impacts on abundance of their prey.
- (d) Impacts on bacterioplankton through the addition of fine sediment into meso- and bathypelagic zones.
- (e) Depletion of oxygen by bacterial growth on suspended particles.
- (f) Effects on fish behavior and mortality caused by the sediments or trace metals.
- (g) Mortality of and changes in zooplankton species composition caused by discharges.
- (h) Dissolution of heavy metals (e.g. copper and lead) within the oxygen-minimum zone and their potential incorporation into the food chain.
- (i) Possible clogging of zooplankton by filtering particles in the plume.

3.3 Potential Upper Water-Column Impacts

If tailings, sediments and effluent are discharged in near-surface waters or above the thermocline, there are additional impacts to those listed above:

- (a) Potential for trace-metal bioaccumulation in surface water due to discharges from the test mining.
- (b) Reduction in primary productivity due to shading of phytoplankton by the surface discharge.
- (c) Effects on phytoplankton from trace metals in the surface discharge.
- (d) Effects on behavior of marine mammals caused by the mining operation.

4. ENVIRONMENTAL CONSIDERATIONS FOR DEEP SEABED MINING

In order to limit the impacts to minimum levels, the following measures need to be taken in the design considerations of the deep-sea mining system:

- Minimize sediment penetration of collector and mining vehicle.
- Avoid disturbance of the more consolidated suboxic sediment layer.
- Reduce mass of sediment swirled up into the bottom near-water layer.
- Induce high rate of re-sedimentation from the plume behind the miner.
- Minimize the transport of sediment and abraded nodule fines to the ocean surface.
- Reduce the discharge of tailings into bathyal or abyssal depth.
- Reduce the drift of tailings by increasing their sedimentation rate.

5. ENGINEERING CONSIDERATIONS OF DEEP SEABED MINING

5.1 Type of Collector and Lift Mechanisms

The mechanism for disturbing the seabed was different between the DISCOL and other BIE-Experiments. In DISCOL, the emphasis was on plowing the seabed; the BIE-Experiments concentrated on sediment re-suspension. Both operations have based instruments on tow-type collectors and are complementary to each other in their kind of mining scenario. A combination of these could be a more realistic approach, with tow-type collectors to study the potential effects on the seafloor.

In addition to the disturbance from the seafloor collection activity, the disturbance from sediment separation at the seafloor level after collection adds sediment plume. For a self-propelled miner/collector system (Brink and Chung, 1980), the disturbance from the miner motion on the seafloor surface is different from that of the tow-sled collector. Further sediments are released from the nodules at the buffer above the seafloor. Discharge of fine sediment and broken nodule particles from the surface system can add disturbances near the surface or from the discharge level. In addition, if at-sea processing is conducted, a significant amount of the tailings and chemicals must be processed for safe disposal (Park, Min and Chung, 1997).

The following discussions on the effects of the environment on engineering design are based on tow-type collectors and limited to the seafloor.

5.2 Sediment Recovery and Discharge

The operation time of DISCOL and the BIEs, which lasted for 2 weeks (DISCOL) or several tens of hours (BIEs, 18–88 hours), respectively, is much shorter than any kind of a large-scale mining operation expected to last for about 300 days per year (Thiel et al., 1991). The distances covered by the paths of disturbers for different BIE experiments vary from 33 to 144 km in a narrow width of 200–300 m, and the equivalent areas are much smaller than the area to be covered during commercial mining in the order of 300–600 km² per year for example. Similarly, the volume of sediment recovered during these experiments, estimated at less than 1.5 m³/min from the reports, is equivalent to only a few percent of the estimated volume of sediment (54000 m³/day, i.e. 37.5 m³/min) to be recovered during a commercial mining operation (Yamazaki et al., 1991). Hence, all these experiments can be considered micro-scale experiments in terms of sediment re-suspension. In the future, it may be advisable to conduct a relatively larger-scale experiment, to study the impacts of such a disturbance on the benthic ecosystem.

5.3 Depth of Excavation of Miner

Although it is difficult to estimate the depths of sediment excavated during these BIE-experiments because of the different in-situ sediment properties and thicknesses, the average depths are

roughly estimated as 3 to 5 cm. This may be adequate for the recovery of nodules, as most of them range in size between 4 to 5 cm and are usually exposed at the surface. However, the recovery of buried nodules from 5 to 10 cm below the seafloor, as observed in the Central Indian Basin (Sharma, 1989), would add to the efficiency of the nodule collector. In the DISCOL area, the thickness of the semi-liquid layer is up to 12 cm (Schriever and Thiel, 1992) and the nodules are 12 to 20 cm in diameter. This indicates that it is possible during the mining operations for the miner to penetrate into the sediment up to this depth and disturb this layer totally.

5.4 Re-Sedimentation after Operation

The maximum thickness of re-sedimentation estimated in JET was 2.6 mm, about 13% of that expected in so-called commercial mining (Yamazaki and Kajitani, 1999). The thickness of the deep-sea sediment layer recovered by a commercial-scale collector was calculated as 57 mm on the basis of vertical profiles of vane-shear strength and sensitivity of the layer, and 1 kPa nodule pickup resistance (Yamazaki et al., 1991).

6. SOME UNANSWERED QUESTIONS

In spite of all experiments conducted and calculations based on still limited data for the possible effects of future mining activities, many questions remain unanswered, due to the limited scope of these studies. Some of the questions are:

1. What might be the effects of the surface discharge of effluents or debris mixed with bottom waters?
2. What might be the effects of movement of a collector mechanism or miner/collector vehicle tracking on the seafloor?
3. What should be the acceptable water level of discharge of effluents in the water column below the free surface?
4. What might be the impacts of discharges from nodule-transport pipe and other subsystems (for example, buffer) suspended in the water column?
5. How would the resettlement or redistribution of suspended sediments occur close to the seafloor?
6. What would be the net effect on the marine food chain of different subsystems and activities of deep-sea mining at various depth zones?
7. Could alternative uses be found for the large quantities of debris from deep-sea minerals?
8. What would be the ideal size of each mining area to allow re-colonization and restoration of the benthic communities?
9. What alterations in mining system design could be used to minimize the effects on the marine ecosystem? What engineering data should the environmental experiment provide?

10. Which key parameters would be useful as indicators of environmental impacts, and how should they be prioritized?
11. What results, data and statements should each contractor be required to deliver in order to claim mining regions?
12. What will be a likely mining system or systems in the next 20 years to determine a basis for environmental tests? How do we categorize and define potentially real mining system and miner or collector systems, and narrow these down to one or two systems?
13. What other environmental parameters do we expect in the case of at-sea processing?
14. How do we categorize and identify pollutant or effluent discharges from the ship, pipe, buffer and miner/collector for land processing and at-sea processing?
15. Upon generalizing nos. 13 and 14 above, how do we determine an approach to develop a disturbance-flow simulation model or component disturbance tests, and verify the simulation model?
16. How do we prepare disturbance and fine discharges and generalize the test parameters from the tow-sled collector and miner/collector vehicle?
17. How much room do we leave in environmental test planning for unidentified deep-sea questions?
18. How do we integrate the test data of bottom disturbance with other effects?

The following questions would also influence the engineering design and have not yet been addressed. For example:

1. What will be a likely mining system (or systems) in the next 20 years that can be a basis for environmental tests? It is difficult to specify “commercial scale” now, because commercial system size and type are likely different depending upon the use of nodule elements and production target, and can vary with the metal market situation. Thus, we should make some assumptions.
2. How do we generalize the test parameters from the tow-sled collector and miner/collector vehicle?
3. How much room do we leave in environmental test planning for unidentified deep-sea questions?
4. How do we integrate the test data of bottom disturbance with other effects in a more environmentally friendly mining system design and operations?

7. CONCLUSIONS AND RECOMMENDATIONS

The major conclusions and recommendations are as follows:

- The scale of the conducted experiments is too small for the potential disturbance caused by a nodule mining system to be represented.
- The time scales for the re-establishment of geochemical and ecological conditions after commercial mining disturbance will be very long, in the order of decades.
- It is scientifically proven that the benthic environment is going to be the most affected part of the entire ecosystem. It is strongly dependent on or influences the design.

However, there are many more questions that must be answered and more problems to be solved prior to the commencement of a commercial mining operation. Environmental scientists and engineers should work as a team so as to achieve the ultimate target of recovering minerals from the deep ocean with acceptable environmental impacts.

This ultimate target may be achieved with a focused effort to undertake a large-scale environmental experiment for the creation of a disturbance in the marine environment. The scale should be representative of commercial deep-seabed mining. An experiment of this scale is cost-intensive and would require cooperation in sharing not only the development and operational costs, but also the expertise, manpower and other resources among the participating groups.

A practical approach would be for the interested countries and groups to cooperate as a consortium in conducting this large-scale environmental study. A draft outline is given in Appendix 1. It needs to be further discussed by all participating parties to formulate a detailed plan for the experiment.

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APPENDIX 1. PRELIMINARY OUTLINE OF A PROPOSED ENVIRONMENTAL EXPERIMENT FOR SIMULATION OF DEEP SEABED MINING

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Title: Large-Scale Benthic Disturbance and Environmental Monitoring for Nodule Mining

Objectives: The primary objective is to conduct an experiment of the large-scale impact (at least 20×20 km) on and recovery potential of the deep-sea ecosystem due to sediment excavation, re-suspension and re-deposition. The secondary objective is to take into account the possible impact on the surface water and the water-column population at tailing discharge depths; these also have to be studied in detail.

Approach: Create a benthic disturbance whose scale and system are large enough to represent the expected industrial intrusion by commercial mining into the deep sea, using as baseline the results of and mistakes made during DISCOL/ATESEPP and all BIEs.

1. In order to assess the total impact of nodule mining, develop a system model of a commercial-scale miner and collector so as to simulate the disturbance caused by the miner and collector movement.
2. Identify the enterprises/parties interested in participating in such a large-scale experiment, such as Pioneer Investors, ISA, and others. Identify the resources—money, facilities, ships, know-how, equipment and manpower—that need to be available over several years.
3. Set up a joint working group to analyze the results of the DOMES, BIEs and DISCOL/ATESEPP experiments.
4. Identify further research gaps and design of a new large-scale project based on (3) above.
5. Develop a test system that creates a disturbance comparable to that expected from a commercial miner and collector system model.
Parallel to this, develop an Environmental Impact Assessment (EIA) schedule.
6. Jointly establish baseline studies in advance of the impact—share equipment, ships, facilities, manpower and costs.
7. Standardize sampling methods, sampling treatment, and the methods of identifying species according to international regulations (e.g. ICES, ISA), continuously checking their accuracy.
8. Use the baseline study results to establish a computational ecosystem model of the experimental area, and keep improving the model with the impact monitoring data.

9. Create a large-scale impact and jointly monitor it as well as the recovery potential of the impacted benthic community.
 - Identify the total area of direct impact by the disturber device as well as the depths of the disturbance.
 - Identify the total area impacted by re-sedimentation and the thickness of the re-sedimentation layer.
 - Determine the area and sediment depth of benthic recovery as a function of time after the impact.
 - Apply available continuous monitoring techniques such as lander systems to evaluate natural variability.
10. Develop accurate computational models of simulating disturbances and impact that can be applicable to a wider area, such as the C-C-F-Zone or CCFZ, for:
 - Identifying acceptable levels of environmental impact as a function of the geotechnical properties of sediments.
 - Providing guidelines for the design and operation of a mining system and subsystems within the acceptable level.
11. Jointly study the effects for a longer period after the end of the impact phase (15 to 20 years).

Justification: An international cooperative effort is required, as:

1. The scales of DISCOL and other BIEs are insufficient in size to predict the benthic impact of nodule mining.
2. The cost of a large-scale disturbance (including surface plume and nodule-and-sediment mixture lift) individually, by a single group or country, can be prohibitively high.
3. Large-scale deployment of infrastructure and manpower from different organizations would be required to undertake such an effort.

Funding source: Pioneer Investors and Contractors, International Consortium, The International Seabed Authority (ISA).

Place: C-C-F-Zone, Indian Site or ISA Reserved Area.

Initiative: ISOPE-Ocean Mining Working Group, International Consortia and/or International Seabed Authority.

