STANDARDIZATION OF ENVIRONMENTAL DATA AND INFORMATION – DEVELOPMENT OF GUIDELINES

Standardization of Environmental Data and Information – Development of Guidelines

Proceedings of the International Seabed Authority's Workshop held in Kingston, Jamaica
25-29 June 2001

Prepared by
Office of Resources and Environmental Monitoring
International Seabed Authority, Kingston, Jamaica

ISA/02/02

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Foreword

Statement by the Secretary-General of the International Seabed Authority, Satya N. Nandan, welcoming participants to the Workshop to Standardize the Environmental Data and Information required by the Mining Code and the Guidelines for Contractors, Kingston, Jamaica 25 – 29 June 2001

I appreciate the fact that you have given your valuable time to participate in this Workshop and we are pleased to have you. This is one of a series of workshops that the International Seabed Authority has been conducting in relation to the mineral resources of the deep seabed and the protection and preservation of the marine environment.

The purpose of a workshop of this kind, is to provide scientists and experts an opportunity to exchange views on the work they have been doing and in this way to gain a better understanding of the ocean environment from each other. Our first workshop (1988) was in Sanya, China, where we reviewed the environmental research being undertaken in relation to activities in the deep seabed and we were able to identify the kinds of research, data and information that was needed. The outcome of that workshop was presented to the Legal and Technical Commission, which in turn was able to develop a set of guidelines on environmental studies and parameters for the establishment of baseline information.

The second workshop (1999) was about the state-of-the-art technology. We had useful discussions regarding the development of technology, the concepts in play and the progress made. The third workshop (2000) was about minerals other than polymetallic nodules. It dealt with polymetallic sulphides, crusts and other resources, covering such matters as the research being done and the implications for dependent biodiversity. Each of these workshops has proved to be useful and full of valuable information, providing an opportunity to exchange information among those working in this field.

The published proceedings have proven useful to those who are not here and, of course, to those who are present, since all the information is compiled into one volume. We are thereby developing a series of proceedings through which we are able to collate and collect information from different sources and disseminate it to whoever will find it useful. It is certainly useful to the Authority, the body through which States administer the mineral resources of the deep seabed, for you cannot administer something without knowing enough about it. Therefore, while lawyers and diplomats set the rules, we are now working within the framework of those rules to deal with the technical issues involved, a task for which these workshops have proven their value.

This workshop is a continuation of the process which began with the first workshop on the marine environment in relation to activities in the deep seabed. It was recognized at that workshop that some level standardization of information was necessary for three main reasons. First, individual researchers need an assurance that they are gathering information and data that meets international standards or that corresponds to what other scientists are gathering. Secondly, standardization provides researchers an opportunity to exchange information with their peers on a common basis, to discuss with them the various aspects of their activities, to learn from one another how to resolve problems and generally to gather information from other sources to see whether their experiences have been the same or different. Thirdly, as a recipient of information from different sources – pioneer investors and others – the Authority would find it difficult, without some standardization, to reconcile this information and draw conclusions from it. We would like to have such information in a standardized form so that we can make it generally available – at least, that which is not confidential – and use it for our own evaluations. I hope that, in the coming days, you will be able to arrive at some guidelines for us relating to this issue of standardization.

Thus, the purpose of this Workshop to Standardize the Environmental Data and Information Required by the Mining Code and the Guidelines for Contractors is to provide a basis for facilitating the work of contractors in establishing environmental baselines as well as subsequent monitoring of the effects of their activities on the marine environment, while at the same time allowing for comparisons in the different nodule-bearing provinces. Specifically, it is :

1) To propose standards for the measurement of the biological, chemical, geological and physical components of the marine environment essential for establishing environmental baselines and for environmental impact assessment.

2) To recommend general sampling designs for the acquisition of environmental baseline data and for conducting monitoring tests;

3) To recommend appropriate standardization strategies for ongoing efforts in taxonomy, sample processing and field collection of data if desirable, and

4) To recommend strategies that will facilitate the conversion of relevant data and information that have been acquired by the registered pioneer investors and concerned international scientific institutions into the standards proposed, thereby enabling the creation of a central database for subsequent use in managing impacts from deep seabed mining of polymetallic nodules when it occurs.

The objectives set for the Workshop are obviously ambitious. I do not know whether we shall achieve all of them but I hope that at the end of the day you will come up with something that will be helpful to us and to all of you in the field.

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Executive Summary

- ✍ A German researcher collecting animal specimens uses only a fifth of his sediment core from the deep ocean bottom before learning that his counts will not be statistically valid unless he uses all 2500 square centimetres of the core.

- ✍ An Indian scientist wishing to compare results on bottom-sediment density in the Indian and Pacific Oceans learns that he cannot because his Japanese counterparts in the Pacific have used different methods to take their measurements. One group removed the air from the sample before testing, while the other did not.

- ✍ A United States biologist who has identified a number of deep-sea worms from a Pacific site and wants to compare them with similar animals gathered at a second site has no way of matching them unless he works alongside another scientist residing elsewhere who has used different criteria to classify the second collection. As a result, he cannot immediately know whether the species he has collected also inhabit the second location or whether their range is more restricted.

These cases were cited by participants in the Workshop convened by the International Seabed Authority in June 2001 to discuss ways of standardizing the environmental data that must be gathered by contractors authorized by the Authority to explore for polymetallic nodules in seabed areas beyond national jurisdiction.

The Workshop brought together 39 engineers, scientists and other experts from 17 countries and the United Nations. Among them were participants from six of the seven entities approved for exploration contracts. Twenty-one formal presentations were made and discussed, most of them accompanied by papers. The proceedings in this volume reproduce all of those papers and summarize the discussions at the Workshop.

Mandates

The United Nations Convention on the Law of the Sea[1], in part XI dealing with the international portion of the deep seabed (known as "the Area"), provides in article 145 that:

“Necessary measures shall be taken in accordance with this Convention with respect to activities in the Area to ensure effective protection for the marine environment from harmful effects which may arise from such activities.”

Further, the Agreement relating to the Implementation of Part XI of the Convention provides in annex III, article 17.2(f):

“Rules, regulations and procedures shall be drawn up in order to secure effective protection of the marine environment from harmful effects directly resulting from activities in the Area or from shipboard processing immediately above a mine site of minerals derived from that mine site, taking into account the extent to which such harmful effects may directly result from drilling, dredging, coring and excavation and from disposal, dumping and discharge into the marine environment of sediment, wastes or other effluents.”

On 13 July 2000, the Authority approved a set of Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area.[2]. Regulation 31.4 provides, in part:

“Each contract shall require the contractor to gather environmental baseline data and to establish environmental baselines, taking into account any recommendations issued by the Legal and Technical Commission pursuant to regulation 38, against which to assess the likely effects of its programme of activities under the plan of work for exploration on the marine environment and a programme to monitor and report on such effects.”

According to regulation 31.6:

“Contractors, sponsoring States and other interested States or entities shall cooperate with the Authority in the establishment and implementation of programmes for monitoring and evaluating the impacts of deep seabed mining on the marine environment.”

Regulation 38.1 authorizes the Commission to “issue recommendations of a technical or administrative nature for the guidance of contractors to assist them in the implementation of the rules, regulations and procedures of the Authority”.

In accordance with these mandates, the Commission approved in April 2001 an initial set of recommendations to guide contractors in assessing environmental impacts[3]. In preparing these recommendations, it was assisted in part by guidelines drawn up by a workshop convened by the Authority in Sanya, China, in 1998[4]. Following the 2001 Workshop, the Commission approved a revised draft of its recommendations, which are awaiting action by the Council of the Authority in August 2002[5].

Contents of the proceedings

Part 1 of these proceedings sets out the legal and organizational framework for deep-sea environmental monitoring, summarizing the manner in which the Authority is to control prospecting, exploration and exploitation for nodules, with special reference to the regulations it adopted in 2000. Also included is a paper by Dr. Craig R. Smith, moderator of the Workshop, describing what is known and identifying what is not known about the nodule-bearing areas.

Part 2 includes information from scientists of six entities that have received the Authority's approval to enter into exploration contracts, as well as ocean researchers from other countries. They describe what they have done and some of the procedures they have followed while investigating environmental conditions in and around the seabed areas of interest to nodule prospectors in the Pacific and Indian oceans. The scientists came from China, France, Germany, India, Japan, Republic of Korea, Russian Federation and the United States.

Part 3 outlines some of the standards and techniques employed in research into individual sectors of the deep-sea environment: chemistry, sediment, biodiversity, seafloor fauna and the pelagic community in the water column. Most of the presenters emphasized that research into the difficult-to-reach ocean depths is still in its early stages and would benefit from improved standardization of methods.

Part 4 looks at designs for environmental sampling to ensure statistically valid results, and for a computerized database where the results of monitoring can be brought together, compared and made generally available. Also included are a paper and a discussion on standardization strategies.

The recommendations of the Workshop are set out in four reports, making up part 5. In addition to the overall report, there are reports from three working groups, on chemistry and geology, benthic biology and environment, and the water column. The working group reports contain detailed specifications for environmental monitoring in their respective spheres, while the overall report incorporates cross-sectoral ideas on ways to improve standardization in research on the deep-sea environment.

Each of the five parts is preceded by an introduction summarizing highlights of the papers, discussions and reports.

While discussing standardization, the Workshop dealt with a variety of issues of environmental monitoring related to exploration for and eventual exploitation of nodules. These may be divided into four categories: Why? What? How? When?

Environmental monitoring: Why?

The broad reason for monitoring the environment around potential nodule mine sites was established long ago in the Law of the Sea Convention and subsequent instruments: it is, to guard against harmful effects on the marine environment. The Secretary-General observed during the discussion that, while following the mandates in these instruments, the Authority would be wise to develop its own standards rather than have them imposed from outside by those who might question its status as a responsible actor in the oceans if it did not act.

The Legal and Technical Commission had previously distinguished between two purposes of monitoring, corresponding to different phases in the development of a mining industry: environmental baseline studies, to establish conditions in the area before it is disturbed by human activity, and monitoring during and after testing of collecting systems and equipment. The Workshop adhered to this distinction, concentrating on the first phase in view of the fact that no equipment tests are currently planned.

One participant pointed to the two main reasons for monitoring the water column: protection of aquatic health and protection of human health. While no one questioned the value of environmental monitoring, some stressed that contractors should not be expected to investigate every aspect of the oceans in their areas, however valuable such information might be to science. Increase in knowledge was an objective of humankind, one speaker said, while evaluating impact was an objective of a company or the Authority. Professor Smith, the moderator, summed up by saying that a balance had to be struck between what people would like to know about the oceans and what they needed to know about the environmental impact of mining.

Another note was struck by a scientist from a programme that had developed an innovative and more environmentally friendly type of nodule-collecting device. He pointed out that engineers could use environmental information in the design of their equipment and systems.

Environmental monitoring: What?

Most of the parameters to be monitored had already been listed by the Legal and Technical Commission in an explanatory commentary annexed to its environmental assessment recommendations. The working groups added precision to this list, specifying what ought to be sampled to ascertain chemical and geological conditions (sediment properties, sediment pore waters, water-column properties, trace metals in organisms); biological and habitat conditions (megafauna, macrofauna, meiofauna, microbial biomass, nodule fauna, demersal scavengers, habitat quality, sedimentation, bioturbation), and water-column conditions. The water-column group produced two lists, of basic oceanographic variables that all contractors should routinely monitor and optional variables that can provide further useful information.

Environmental monitoring: How?

Methods used to measure environmental variables are a key area for standardization, in the view of Workshop participants. Specific measurement techniques, sometimes with alternatives, are listed for each parameter in the working group reports. Rather than trying to devise new protocols laying out such procedures in detail, however, the Workshop suggested that existing protocols for oceanographic research be followed, notably those devised by the Intergovernmental Oceanographic Commission (IOC)[6].

As most ocean-related research has concentrated on the surface and upper waters, the participants acknowledged the lack of widely accepted procedures specifically directed toward deep-water studies. Accordingly, it recommended that the Authority organize workshops to develop environmental measurement standards where they do not exist. One example cited was sediment properties, for which parameters such as grain size and density are difficult to quantify.

Some vital procedures are not amenable to description in a "cookbook" of protocols, participants noted. It was stated, for example, that getting proper results from a box corer, a device dropped onto the ocean bottom to collect samples of sediment and animal life, depends on the skill of operators and scientists in lowering and raising the box and ensuring that it does not hit bottom too fast. To enhance skills in collecting and analytical procedures, the Workshop recommended that the authority promote the exchange of scientists on seagoing research cruises and the organization of cooperative cruises where different contractors could share ship time.

Participants who had been involved in past research projects were frank about their limitations, due largely to their inability to simulate the physical and temporal scales of actual mining but also to the fact that the experiments simply did not continue long enough (at least one because it ran out of funds). They suggested ways in which past mistakes and deficiencies could be avoided, and urged that several contractors get together on a joint project that no one of them had the resources to manage on its own.

In the meantime, smaller-scale, controlled experiments were suggested, notably a dose-response study to establish how organisms react to varying amounts of resedimentation of the kind that mining will produce. High hopes were held out for new molecular genetic techniques that will speed species identification at a much lower cost.

The Workshop also addressed the issue of how future deep-sea research should be organized and promoted. It called for cooperative research into specific questions concerned with the response of organisms to potential mining disturbances. It advanced two proposals in particular. One calls for the creation of an ISA database containing information gathered from all contractors and other organizations, in a format that could be readily searched and disseminated via the World Wide Web. The other proposal is for a system of taxonomic coordination, under which specialists in animal classification would be designated to assist contractors in identifying species and to oversee the preparation of voucher collections of type specimens.

Environmental monitoring: When?

Some participants felt that environmental research should be confined at this stage to baseline studies on a limited scale. Broader studies and impact assessments were premature, they argued, since there was no way to predict exactly where mining would occur or what type of equipment would be used. In the meantime, researchers should concentrate on basic studies of deep-sea life, about which little was known.

Several participants saw an opportunity in the fact that commercial mining, and even the testing of equipment, might be delayed for at least a decade or two. The interval could be used for thorough environmental studies which, several speakers noted, could take up to 8 or 12 years. The need for more time to assess long-term effects of mining-like disturbances was borne out by the conclusions of studies in the Central Pacific showing that animal populations in disturbed areas had not returned to normal by the time the studies ended seven years after the disturbances. A theoretical model of sampling design, presented to the Workshop, indicated that samples would have to be taken for eight years if the results were to be trusted. Under these circumstances, participants argued, large-scale environmental studies must begin as soon as possible if enough environmental information is to be gathered by the time commercial mining begins.

Notes and References

1. United Nations Office of Legal Affairs, Division for Ocean Affairs and the Law of the Sea (1997), *The Law of the Sea: United Nations Convention on the Law of the Sea* (United Nations, New York), 294 pp.

2. International Seabed Authority (2000), Regulations on prospecting and exploration for polymetallic nodules in the area (ISBA/6/A/18), *Selected Decisions and Documents of the Sixth Session* 31-68.

3. International Seabed Authority, Legal and Technical Commission, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area (ISBA/7/LTC/1), 10 April 2001.

4. *Deep-Seabed Polymetallic Nodule Exploration: Development of Environmental Guidelines* (1999), Proceedings of the International Seabed Authority's Workshop held in Sanya, Hainan Island, People's Republic of China (1-5 June 1998), ISA

(Kingston, Jamaica), 289 pp. The recommended guidelines are in chapter 9, pp. 219-239.

5. International Seabed Authority, Legal and Technical Commission, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area (ISBA/7/LTC/1/Rev.1), 10 July 2001. On 12 July 2001, the ISA Council deferred consideration of the recommendations until its eighth session (August 2002).

6. A. Knap et al. (eds.) (1996), *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements* (JGOFS report 19), vi+170 pp. (reprint of *IOC Manuals and Guides* 29 [United Nations Educational, Scientific and Cultural Organization, 1994]).

PART I

Regulations of the International Seabed Authority for Exploration for Deep Seabed Polymetallic Nodules and Recommendations for the Effective Protection of the Marine Environment from Harmful Effects which May Arise from Exploration/Mining

INTRODUCTION

The Workshop to Standardize the Environmental Data and Information Required by the Mining Code and the Guidelines for Contractors began with presentations describing the three documents that formed the backdrop for its work:

- Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area of the seabed beyond national jurisdiction, approved by the International Seabed Authority (ISA) on 13 July 2000[1];

- Guidelines for the assessment of the environmental impacts from the exploration for polymetallic nodules in the Area, recommended at a Workshop organized by the Authority at Sanya, China, in 1998[2]; and

- Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area, drafted by the Authority's Legal and Technical Commission (LTC)[3].

The Regulations and recommendations were outlined by Mr. Jean-Pierre Lenoble of France, member of the LTC, who chaired the Commission during much of the time it spent in drafting both of these documents.

He observed that the Regulations, under development for two decades since well before ISA came into existence, provided a total framework for the development of deep seabed exploration. They set out rules, to be followed by operators under contract with the Authority, for both prospecting and exploration – in other words, all activities relating to polymetallic nodules short of exploitation, which is to be dealt with in subsequent parts of an international mining code for the deep oceans.

He outlined the system under which commercial and non-commercial entities, governmental or non-governmental, may apply for exploration contracts with the Authority. As part of this process, each applicant must submit a plan of work detailing exactly where it proposes to explore and committing itself to monitoring the local marine environment so as to prevent harmful consequences. The plan of work and contract are subject to approval by the Authority before any exploration can take place. Once the contract is in force, the role of the Authority will be to follow the operator's activities closely by monitoring annual reports. In the event of an incident likely to cause environmental harm, the Authority may issue emergency orders to prevent, contain or repair the damage.

In discussing the Regulations, the Workshop concentrated not so much on their content as on how they would be applied and adapted to take account of the gradually emerging body of knowledge about the deep-sea environment. They were described as the second level of a hierarchy in which the top rung is occupied by the United Nations Convention on the Law of the Sea. The third level, of particular interest to the Workshop, consists of recommendations developed by LTC to guide contractors in carrying out their contractual obligations relating to the environment.

Outlining the recommendations, Lenoble cited their three main elements. The first prescribes criteria for the environmental baseline studies that contractors must conduct to gain precise information, to be shared with the Authority, about the pristine condition of the areas they plan to explore before any human activities take place. These studies are to be followed by environmental impact assessment during the course of exploration. Finally, the recommendations specify exactly what contractors should look for when monitoring any activities that might harm the environment.

Discussion in the Workshop highlighted the need for flexibility in developing and applying the recommendations. Participants expressed particular interest in the role that the international scientific community could play in this development and in advising the Authority on monitoring issues.

In this regard, the Secretary-General voiced the view that, after the years spent in setting up the legal framework, it was now time to reach out for help from the scientific community and the mining community. While the LTC and the Secretariat had the capacity to deal with scientific matters, the input of outside experts would be invaluable. In fact, the purpose of the series of workshops convened by the Authority was to seek such help in establishing indicators, guidelines and recommendations that would assist the Secretariat in evaluating the information submitted by contractors.

Dr. Craig R. Smith, Professor in the Department of Oceanography at the University of Hawaii, Honolulu, United States, discussed the guidelines for gathering environmental baseline data that had been developed by the 1998 Sanya Workshop. In a paper and oral presentation, he placed them in the broader context of the environmental impacts of seabed mining and how to monitor those impacts.

In his paper, he identified four sources of potentially harmful impacts. (1) Movement of the mining vehicle across the seabed would remove sediments and animal life from the ocean bottom. (2) The massive plume of suspended sediment generated by this process would bury the surrounding area under a blanket up to several centimetres thick. (3) Release of bottom water and sediment as the nodules were raised to the surface would alter light levels and metal concentrations, affecting food-web dynamics. (4) Release of tailings from the nodule-processing surface vessel would alter the characteristics of the water column above the mine site.

Dr. Smith pointed out that the limited amount of scientific knowledge about deep-sea ecology, largely due to the difficulty and expense of exploring such a remote environment, made it impossible to predict exactly what effects seabed mining might have on the animals dwelling or feeding there. He suggested several approaches to narrowing this knowledge gap, including systematized and standardized research efforts to identify seabed fauna and their distribution. In particular, he urged a centralized approach to taxonomy – the identification and classification of species – in which designated institutions would receive and study specimens from seabed contractors, who would support this work with annual financial contributions.

Dr. Smith reviewed in detail the proposals of the Sanya Workshop, which recommend precisely what types of data contractors should be asked to compile in their environmental baseline studies, and what collecting, sampling and processing methods they should use. He added his own supplementary suggestions for each of the areas to be monitored: physical and chemical oceanography, sediment properties and sedimentation, biological communities and bioturbation. He also offered ideas about the organization of an environmental database that would assemble existing and new information from contractors and make it available for retrieval. Going beyond the initial baseline studies, he offered five suggestions on how contractors should monitor the impact of mining tests, once they reach that stage of exploration.

In his oral presentation, Dr. Smith elaborated on six general characteristics of deep-sea ecosystems, with special reference to the Clarion-Clipperton Fracture Zone (CCFZ) in the Pacific Ocean, where most registered exploration areas are located.

(1) Low flux of particulate organic carbon (POC), a basic measure of life activity, results in low levels of productivity, phytoplankton crops and biological rates.

(2) Low physical energy leads to diminished currents and extremely stable sediments that rarely move about.

(3) High species diversity implies that many animals have restricted geographical ranges and are thus more susceptible to extinction if a significant part of their habitat is disturbed.

(4) Though the habitat is large and continuous, it also displays significant geographical variations in such factors as animal abundance, which in the CCFZ diminishes from north to south and from west to east.

(5) Temporal variations are seen on many time scales – seasonal, interannual and multidecadal – as demonstrated by the El Niño current and weather cycle.

(6) There are large gaps in human understanding of deep-sea phenomena.

He identified three ways in which the mining impacts discussed in his paper might harm marine life, particularly suspension feeders that depend on organic particles descending from surface waters and surface-deposit feeders that obtain their food from the seafloor. (1) Sediment raised from the bottom, mixing with the nutrient-rich particles from surface waters, would dilute the overall quality of the food resource. (2) Surface-dwelling animals would be buried by the redistributed sediment. (3) Animals in the immediate tracks of the mining vehicle would be obliterated.

In the ensuing discussion, various points were raised about the effects of the sediment disturbances and waste discharges likely to result from mining, and how they might be predicted.

-- Illustrating the difficulties that scientists face in investigating such matters, differing views were expressed about the validity of an experiment that sought to predict recolonisation rates (the speed with which animal populations return to previous levels after a cataclysmic event) by clearing an area of life and then counting the fauna that showed up in a centrally placed tray after different lengths of time.

-- In an exchange of views about the discharge of tailings (mineral waste) from a nodule-processing vessel, participants generally agreed that not enough was known to recommend whether the discharge should take place at the surface or at mid-water levels. It was suggested that, during their mining tests, contractors experiment at both locations to learn more.

– Conflicting results were disclosed from experiments that sought to determine whether repeated discharges of small amounts would cause more harm than a single large discharge. The conclusion was drawn that different groups of animals might be affected in different ways.

– Some participants thought that studies of natural resedimentation events such as volcanic ash deposits might help predict the effects of seabed mining, but Dr. Smith cautioned that effects could be quite different in shallow and deep waters.

Asked whether deep-sea animals had any economic value, Dr. Smith cited his own work in collecting specimens for a biotechnology company that had been introducing their cold-adapted enzymes into cold-water detergents and pharmaceuticals. He saw great potential in the huge genetic diversity of life at the ocean bottom.

Notes and References

1. International Seabed Authority (2000), Regulations on prospecting and exploration for polymetallic nodules in the area (ISBA/6/A/18), *Selected Decisions and Documents of the Sixth Session* 31-68.

2. *Deep-Seabed Polymetallic Nodule Exploration: Development of Environmental Guidelines* (1999), Proceedings of the International Seabed Authority's Workshop held in Sanya, Hainan Island, People's Republic of China (1-5 June 1998), ISA (Kingston, Jamaica), 289 pp. The recommended guidelines are in chapter 9, pp. 219-239.

3. International Seabed Authority, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area: prepared by the Legal and Technical Commission (ISBA/7/LTC/1), 10 April 2001; further revised and approved by the Commission as ISBA/7/LTC/1/Rev.1 of 10 July 2001. On 12 July 2001, the ISA Council deferred consideration of the recommendations until its eighth session (August 2002).

Chapter 1 The Legal Framework for Deep-Seabed Polymetallic Nodule Exploration

Mr. Jean-Pierre Lenoble
Member of Legal and Technical Commission (ISA), France

SUMMARY OF PRESENTATION

The Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area of the seabed beyond national jurisdiction, approved by the International Seabed Authority on 13 July 2000[1], provide a total framework for the development of deep seabed exploration. The scheme envisions a sequence of phases: notification of prospecting, application for approval of a plan of work for exploration in the form of a contract, and approval of the exploration contract. Beyond the exploration phase would come approval of a plan of work and a contract for exploitation – areas covered under the United Nations Convention on the Law of the Sea but not yet regulated by the Authority.

1. Prospecting

Normally, interested entities would carry out prospecting in an area to acquire sufficient information before seeking approval of a plan of work for exploration.

- Entities have an obligation to notify the Authority before prospecting.

- There is no limitation on size of area, but prospectors must specify the coordinates of the "broad area" of prospecting. Thus, they might simply say they would work somewhere in the Central Pacific Ocean or the Central Indian Ocean.

- Prospectors have no exclusive rights but are entitled to confidentiality for the data they acquire, lest another operator use such data to advance its own application for a plan of work.

- Prospectors must cooperate in international marine science training programmes for personnel of the Authority and of developing States.

- The Authority must be notified of any environmentally harmful incident arising from prospecting.

- Contractors are to submit annual reports to the Authority, without having to divulge the specifics of what they have learned.

- No time limit is fixed for prospecting, so that operators might prospect for one year or ten years.

2. Application for Approval of a Plan of Work for Exploration

Once a prospector has sufficient information about an area, it can apply to the Authority for approval of a plan of work for exploration – essentially, an exploration license.

- Applicants must be sponsored by a State member of the Authority.

- Applicants must demonstrate financial and technical capabilities.

- When proposing an area for exploration, the applicant shall divide it into two parts of equal estimated commercial value. The Authority then chooses one of the parts as a reserved area for eventual use by the Enterprise (its mining organ) or a developing State.

- The total area allocated to an applicant shall be less than 150,000 square kilometres -- a sizeable space for exploration that would subsequently be reduced as the mining phase approaches.

- Applicants must submit data on various characteristics of the area and their proposed activities, enabling the Authority to choose its portion. This data must include:

  - Geographical coordinates;

  - Location, survey and evaluation of polymetallic nodules:

    - Proposed technology for recovering and processing nodules;
    - Physical and geological characteristics (seabed topography, bottom currents);
    - Abundance of nodules;
    - Content of metals of economic interest;

- ✍ Estimation of the commercial value of the two parts;
- ✍ Description of the techniques to be used by the applicant.

- o Environmental parameters (seasonal and during test period) including:

  Wind speed and direction;
  Wave height, period and direction;
  Current speed and direction;
  Water salinity and temperature;
  Biological communities.

3. Registered Pioneer Investors

3.1. Relinquishment of the area

Special provisions in the Regulations deal with the category of applicant known as a "registered pioneer investor". Certain States whose nationals had already engaged in seabed activities before and during the 1980s were registered by the Preparatory Commission for the International Seabed Authority and the United Nations Tribunal on the Law of the Sea, in a process that took place after the signature of the Convention in 1982 and before its entry into force in 1994. The registration process, finally completed in 1987, was complicated by the existence of overlapping claims on the part of some pioneer investors, a situation that had to be resolved by mutual agreement.

Among the understandings reached among the registered pioneers was that the initial claim area of up to 150,000 km^2 was to be reduced over eight years to 75,000 km^2 through a process known as relinquishment. This called for:

- A 20 percent reduction after three years,

- Another 10% after the fifth year and

- A final 20% after eight years.

Some pioneers had already reduced their area in a deal with the Preparatory Commission. Two still have to relinquish some part of their area, but within one or two years everybody will be down to 75,000 km^2. The Authority might decide one day to fix this size as the maximum, for future contractors if not for present ones.

4. Contract for Exploration

With the entry into force of the Convention and the approval of plans of work in the form of contracts, a new phase has begun in which the pioneers have become the explorers.

4.1. Rights

- Contractors have an exclusive right to explore for polymetallic nodules in the contract area.

- Contracts are for 15 years, extendable by additional 5-year periods.

- Contractors have a priority right to a contract for exploitation in the allocated area.

4.2. Relinquishment

Contractors must relinquish portions of their area during the course of the contract:

- If more than 75,000 km^2, the initial allocated area must be reduced by 20% before the end of the third year from the date of the contract;

- Then by an additional 10% before the end of the fifth year;

- Further, after eight years, an additional 20% or such larger amount as would exceed the exploitation area decided upon by the Authority.

4.3. Plan of work

The plan of work of each contractor is to contain the following elements:

- A proposed exploration programme;

- A programme of activities for the immediate five years;

- A programme for environmental baseline studies;

- Preliminary assessment of the possible impact of the proposed exploration activities on the marine environment;

- Proposed measures to prevent, reduce and control pollution.

The **exploration programme** is to include:

- A general description and schedule for the proposed programme, including a more detailed programme of activities for the immediate five-year period;

- A description of studies to be undertaken in respect of the environmental, technical, economic and other factors which must be taken into account in exploration;

- A schedule showing anticipated yearly expenditures in respect of the programme of activities for the immediate five-year period.

Environmental baseline studies are to incorporate a programme for oceanographic and environmental studies in accordance with:

- The Regulations for polymetallic nodule exploration;

- Any environmental rules, regulations and procedures established by the Authority that would permit assessment of the potential environmental impact of the proposed exploration activities;

- Any recommendations issued by the Legal and Technical Commission of the Authority (to be taken into account by contractors).

Environmental impact is to be addressed by:

- Preliminary assessment of the possible impact of the proposed exploration activities on the marine environment;

- A description of proposed measures for the prevention, reduction and control of pollution and other hazards, as well as possible impacts, to the marine environment.

Revision and review:

- Modifications to the programme of activities can be made from time to time with the consent of the Authority.

- The plan of work is to be reviewed every five years, with a programme to be drawn up for the following five-year period, including a revised schedule of anticipated yearly expenditures, making any necessary adjustments to the previous programme.

5. Exploration Contract

5.1. Annual report

Each contractor is to report annually to the Authority on the following:

- ✍✍Exploration work during the previous year, including:
  - ✍✍ Maps, charts and graphs illustrating the work done and the results obtained;
  - ✍✍ The equipment used for exploration, including the test results of proposed mining technologies, but not equipment design data (to avoid disclosing what countries consider proprietary information);
  - ✍✍ A statement of the quantity of polymetallic nodules recovered as samples or for testing;
- ✍✍Training programmes for personnel of the Authority and developing countries: implementation and any proposed revisions or development;
- ✍✍Environmental studies: results of environmental monitoring programmes, including observations, measurements, evaluations and analyses of environmental parameters;

- Expenditures: actual and direct exploration expenditures in carrying out the programme of activities during the contractor's accounting year;

- Adjustment of the future programme: details of any proposed changes to the programme of activities and the reasons for such adjustments (including any indication that the contractor wished to stop exploring or proceed to exploitation).

5.2. Data to be submitted at the end of contract

- Copies of geological, environmental, geochemical and geophysical data acquired by the contractor;

- Estimation of mineable areas (grade and quantity of the proven, probable and possible polymetallic nodule reserves);

- Statement of the quantity of polymetallic nodules recovered as samples or for testing;

- Copies of geological, technical, financial and economic reports made by or for the contractor;

- Information in sufficient detail on the equipment used to carry out the exploration work, including the results of tests of proposed mining technologies, but not equipment design data.

5.3. Confidentiality of proprietary data

The Regulations provide for protecting the confidentiality of proprietary data supplied to the Authority by contractors, mostly about factors having an economic impact, such as quantity and grade of nodules. Information so classified would be treated as confidential and kept in the Authority's files. The Authority could make it available to consultants, for example, but on terms preserving confidentiality.

Data and information designated by the contractor, in consultation with the Secretary-General of the Authority, as being of a confidential nature, shall be considered confidential unless:

- It is generally known or publicly available from other sources,

- It has been previously made available by the owner to others without an obligation concerning its confidentiality, or

- It is already in the possession of the Authority with no obligation concerning its confidentiality.

Environmental data are not considered confidential.

5.4. Preservation and protection of the marine environment

- To protect the marine environment against harmful effects:

    - The Authority and States sponsoring seabed activities are to take a "precautionary approach" to such activities.

    - The Authority is to establish and review regulations and guidelines.

- Each contractor shall:

    - Take measures to prevent, reduce and control pollution and other hazards to the marine environment arising from its activities in the Area "as far as reasonably possible using the best technology available";

    - Establish environmental baselines (showing the existing natural state of an area) against which to assess the likely effects of its programme of activities on the marine environment;

    - Establish and implement a programme to monitor and report on such effects.

- The Legal and Technical Commission may draw up a list of exploration activities that may be considered to have no potential for causing harmful effects on the marine environment. Since much commonly used technology falls into this category, the aim is to free contractors from having to assess its impact, taking account of recommendations by scientists and the Commission.

- Before applying for exploitation rights, the contractor shall propose the designation of two areas for eventual comparison in order to identify what changes were due to mining:

- “Impact reference zones” to be used for assessing the effect of exploitation activities on the marine environment;

- “Preservation reference zones” in which no mining shall occur, to ensure representative and stable biota on the seabed in order to assess any changes in the flora and fauna of the marine environment.

5.5. Emergency orders

- Each contractor shall establish in advance a contingency plan to respond effectively to incidents likely to cause serious harm to the marine environment arising from the contractor’s activities – for example, if during mining operations a ship begins to leak fuel. The plan would list various problems that could occur and specify possible remedies so that the Authority would know in each case how the contractor might react to prevent, contain or minimize the pollution.

- Each contractor shall report to the Secretary-General any incident arising from its activities that has caused or is likely to cause serious harm to the marine environment.

- If a contractor reports an incident arising from its activity that had caused or was likely to cause serious harm to the environment, a complicated process would be set in motion involving the Council, the Secretary-General, and the Legal and Technical Commission. The Council might determine that the contractor was taking adequate measures or, if not, it might take the lead by issuing emergency orders to prevent, contain, minimize or repair the harm.

SUMMARY OF DISCUSSION

Financial obligations of contractors

Responding to a question, Mr. Lenoble noted that, during the exploration phase, contractors bore no financial obligations towards the Authority in terms of royalties. However, they did have to commit themselves to the plan of work, including a five-year programme of activities and a schedule of expenditures that they would submit to the Authority for its approval. Once this was approved, they would be expected to follow it, on the understanding that it could later be modified, along with its financial provisions.

Environmental data from contractors

Questions were raised about ways of improving the submission of environmental data to the Authority. Lenoble observed that the pioneer investors had already submitted some data during the registration process, but much of this was out of date. Subsequent studies had been published, but the Authority would have to discuss with contractors how such information might be made available, bearing in mind that some of it came from independent scientists and institutions and did not belong to the contractors.

Impact and preservation reference zones

Lenoble observed that contractors did not have to designate impact reference and preservation reference zones until they decided to proceed with exploitation. In any case, it would not be wise to define such zones, or even specify their size, before it was known exactly where mining would occur and what technologies would be used.

Preservation reference zones were conceived as areas that would not be impacted by mining or by associated surface or deep-water plumes. It would be difficult to find such areas, since they also had to be representative of mining areas.

Review of applications

Explaining the procedure to be followed in reviewing applications for plans of work, Lenoble said that if a contractor failed to provide sufficient information according to the terms of the Regulations, the Authority would seek additional information or clarification. The Legal and Technical Commission would judge the response, acting as an adviser to the Council. If suitable information was not submitted within a specified time limit, the application could be denied. If the information were deemed acceptable, the process would continue. The Council would make the final decision, in light of recommendations by the Commission and the Secretary-General.

Seven applications had been received so far. All had been approved during the Preparatory Commission phase, and six contracts had already been signed.

Regulations and recommendations

Much of the discussion centred on the concept behind the Authority's environmental recommendations and the way they fit into the scheme for regulating exploration of the seabed.

Mr. Lenoble recalled that the Regulations had emerged from a long process, begun some two decades ago in bodies of the Preparatory Commission. Time was needed to gain better knowledge, on environmental aspects among others, to make the Regulations more effective. Regulations devised too early – this might even be true of some articles of the Convention itself – might have to be changed later, and it was always more difficult to modify an existing rule than to define a new one. For that reason, most members of the Legal and Technical Commission felt it would be wasteful to fix regulations too soon. What was needed was an ongoing programme to acquire knowledge, for example from mining tests, which would help in formulating future regulations.

He described the hierarchy in instruments governing seabed operations, starting with the Law of the Sea Convention, followed by the Authority's regulations. The third level consisted of recommendations to contractors that were not considered obligatory but should normally be followed. Finally came explanations of the regulations, which would specify alternative approaches to such matters as measurement techniques, with choices left to individual scientists.

In the discussion, flexibility in the application of regulations was cited as desirable. For instance, environmental monitoring in one area might produce data that would make subsequent studies elsewhere either unnecessary or more relevant. Contractors bore a responsibility to do the best job they could in environmental assessment, but it would be counterproductive to over-regulate this process in a way that would unduly burden them. That was seen as the point of decoupling technical recommendations from regulations. In this regard, Lenoble noted that the Regulations allowed for programme adjustments from time to time, which could be made through discussions between the Authority and contractors.

Explaining the concept of recommendations, the Secretary-General noted that they were prepared by the Legal and Technical Commission, which could revise them from time to time. They would not necessarily be adopted by the Council, though the Council might examine and comment on them or send them back to the Commission. The aim of the recommendations was to bring about some uniformity while taking account of new developments and information. Though they were not legally binding, the recommendations, as the expression of a group of scientists and technicians based on available information, set forth elements of persuasion to guide contractors. They had been called guidelines at first, but that term had been dropped because it had different connotations in different languages. Recommendations should be seen as indications of how a contractor should proceed in the light of available information and the considered view of the Commission.

Asked what would happen if a contractor decided to ignore the recommendations, the Secretary-General replied that contractors would be well chosen and thus presumably law-abiding. There would be no rush to penalize anybody, but contractors would be expected to be circumspect when considering practical recommendations drawn up by scientists from several countries. Recalling that contractors would be chosen after assessing their financial and technical capabilities, Lenoble remarked that if something unforeseen occurred the Secretary-General could take the matter up with the contractor and, if necessary, could propose action by the Council, including suspension of the contract.

Contractors were obliged to assess the environmental impact of mining, monitor their operations and act to reduce the effects, he observed. They would do so in the light of available scientific and technical knowledge. However, contractors were technical mining people not thoroughly conversant with environmental science. Thus, support from the scientific community would be needed to increase the knowledge of ecosystems and provide a sound basis for decisions. As rapid development of mining was not foreseen, there was still time to advance such knowledge so that, for example, a better choice could be made about depth of discharge of the mining plume.

Reference

1. International Seabed Authority (2000), Regulations on prospecting and exploration for polymetallic nodules in the area (ISBA/6/A/18), *Selected Decisions and Documents of the Sixth Session* 31-68.

Chapter 2 Overview of the Authority's Regulations and Recommendations to Ensure the Effective Protection of the Marine Environment from Harmful Effects That May Arise from Activities in the Area

Mr. Jean-Pierre Lenoble
Member of Legal and Technical Commission (ISA), France

SUMMARY OF PRESENTATION

The Legal and Technical Commission (LTC) of the International Seabed Authority is in the process of elaborating a document called "Draft recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area"[1]. This working document, formerly called guidelines for contractors, has arisen from the work done at the 1998 Workshop held by the Authority at Sanya, China, on the development of environmental guidelines for deep-seabed polymetallic nodule exploration in the area of the seabed beyond national jurisdiction[2]. The Commission has reconsidered this paper in light of the Regulations on Prospecting and Exploration of Polymetallic Nodules in the Area, adopted by the Authority on 13 July 2000[3] (discussed in chapter 1 above).

The LTC proposes to present to the Council at its seventh session in July 2001 a revised paper that will take into account the results of the present Workshop.

1. Scope

The recommendations for contractors consist of three elements:

- Environmental baseline studies,
- Environmental impact assessment during exploration,
- A monitoring programme during and after activities that have potential for causing harmful effects on the marine environment.

2. Environmental baseline studies

2.1. Objective and types

The objective of environmental baseline studies is to establish the initial state of the marine environment before activities of the contractor that have potential for causing harmful effects on this environment. The studies are to encompass:

- Physical oceanography,
- Chemical oceanography,
- Sediment properties,
- Biological communities,
- Bioturbation,
- Sedimentation.

2.2. Physical Oceanography

- **Objective**: estimate the potential influence of the plume of discharged material during mining.
- **Requirement**: collect information on the oceanographic conditions along the entire water column, including the current, temperature and turbidity regime.
- Current measurements shall be adapted to the bottom topography and to the hydrodynamic activity in the upper water column.
- Currents and particulate matters shall be measured at the depth of the forecast discharge of collecting systems and equipment.
- Particulate matter distribution shall also be measured along the water column.

2.3. Chemical oceanography

- **Objective**: assess the possible influence of the modification of the water composition on biological activity.

- **Requirement**: collect information on the water column chemistry, including the water overlying the nodules.

2.4. Sediment properties

- **Objective**: predict the behaviour of the discharge plume.

- **Requirement**: determine the basic properties of the sediment in order to characterize the surficial sediment deposits and the potential source of deep-water plume.

- **Measurements**:

    - Soil mechanics: specific gravity, bulk density, shear strength, grain size and depth change of oxic to suboxic conditions;

    - Content of organic and inorganic carbon, nutrients (phosphate and nitrate), silicate and carbonate;

    - Composition of the pore water in the sediments.

2.5. Biological communities

- **Objective**: determine the natural state and variability of the biological communities to assess the effects of the activities.

- **Requirement**: collect data on the seafloor communities relating to megafauna, macrofauna, meiofauna, microbial biomass, nodule fauna and demersal scavengers.

- **Observation and sampling**:

    - Collect biological samples representative of the variability of bottom topography, sediment characteristics, abundance and types of nodules, using the following equipment and techniques (as recommended by the Sanya Workshop):

- ✍ Megafauna: photographic transects;
- ✍ Macrofauna (less than 250 microns): box cores;
- ✍ Meiofauna (250-32 µm): cores;
- ✍ Microbial biomass: adenosine triphosphate assay;
- ✍ Nodule fauna: selected nodules on top of box cores;
- ✍ Demersal scavengers: time-lapse camera during at least one year.

- o Assess benthic, benthopelagic, mesopelagic and bathypelagic communities;
- o Analyse trace metals in dominant species;
- o Record sightings of marine mammals, identifying the relevant species and behaviour;
- o Evaluate temporal variations.

2.6. Bioturbation

- **Objective**: determine the natural activity and its variability to assess the effects of the activities (mostly from the bottom plume).
- **Requirement**: gather data on the mixing of sediments by organisms.
- **Measurement**: profiles of excess Pb-210 activity from cores.

2.7. Sedimentation

- **Objective**: determine the natural activity and its variability to assess the effects of the activities (mostly from the mid-water plume rather than any surface plume, since the discharge is likely to occur further down the water column);
- **Requirement**: measure the particulate flux by sediment traps on a mooring line.

3. Environmental Impact Assessment During Exploration

3.1. Activities not requiring environmental impact assessment

A number of activities that have long been used in scientific and industrial surveys are considered as having no recognisable environmental impact on the marine environment. These include:

- Gravity and magnetometric observations and measurements;
- Bottom and sub-bottom acoustic or electromagnetic profiling or imaging without the use of explosives;
- Water and biotic sampling and mineral sampling of a limited nature such as those obtained using core, grab or basket samplers to determine seabed geological or geotechnical properties;
- Meteorological observations and measurements, including the setting of instruments;
- Oceanographic, including hydrographic, observations and measurements and the setting of instruments;
- Television and still photographic observation and measurements;
- Shipboard mineral assaying and analysis (so long as the components analysed are not cast overboard);
- Positioning systems, including bottom transponders and surface and subsurface buoys.

3.2. Activities requiring environmental impact assessment

- Dredging to collect nodules for on-land studies for mining and/or processing (i.e., dredging for several hundred tons of nodules);
- Use of special equipment to study the reaction of the sediment to disturbance made by collecting devices (such as dredges) or running gears;

?? Testing of collection systems and equipment.

The environmental impact assessment and the associated monitoring programme shall be submitted to the Secretary-General of the Authority at least one year before the activity takes place or, in the case of integrated tests, at least two years in advance. This would give the Authority time to consult specialists with a view to possible adjustments of the monitoring programme.

The contractor shall include specification of events (such as pollution incidents) that could cause suspension or modification of the activities owing to serious environmental harm if the effects of the events cannot be adequately mitigated.

3.3. Information to be provided by the contractor

3.3.1. Preliminary information

Before running tests, the contractor must submit information indicating what it expects will happen. Such provisional information will include:

?? Location of the mining test and boundaries of the test area;

?? Probable duration of the test;

?? Test plans (collecting pattern, perturbed area, etc.);

?? Nodule collection technique (passive or active mechanical dredge, hydraulic suction, water jets, etc.);

?? Depth of penetration into the sea-bed;

?? Running gear (skis, wheels, caterpillars, Archimedes screws, bearing plates, water cushion, etc.) that contacts the seabed, in order to gauge the nature of the impacts;

?? Methods for separation on the seafloor of the nodules from the sediment, including washing of nodules, volume of the discharge of sediment mixed with water, concentration of particles in the discharged mixture, height of discharge above the seafloor, etc.;

?? Nodule crushing methods, if any;

?? Methods for transporting the nodules to the surface;

?? Separation on the surface vessel of the nodules from the fines and sediment;

?? Methods for retention of the abraded nodule fines and sediment;

?? Volume and depth of overflow discharge, concentration of particles in the discharged water, and chemical and physical characteristics of the discharge.

3.3.2. Observations and measurements while performing the specific activity

As results are likely to differ from expectations, it will be important to make observations and measurements while performing the specific activity, including these:

?? Width, length and pattern of collector tracks on the seafloor;

?? Depth of penetration into the sediment, and lateral disturbance on both sides of the collector;

?? Volume of sediment and nodules taken by the collector;

?? Ratio of sediment separated from the nodule on the collector, volume of sediment rejected by the collector, size and geometry of the discharged plume, and behaviour of the plume behind the collector;

?? Area and thickness of resedimentation from the side of the collector tracks to the distance where resedimentation is negligible;

?? Volume of overflow discharge from the surface vessel, concentration of particles in the discharged water, chemical and physical characteristics of the discharge, and behaviour of the discharged plume in surface- or mid-water (bearing in mind that not only particulate matter but also the temperature and composition of the discharged water might affect the surface- or mid-water).

3.3.3. Observations and measurements after performance of the specific activity

?? Thickness of redeposited sediment at the side of the collector tracks;

?? Behaviour of the various types of benthic fauna subjected to this resedimentation;

?? Changes in the benthic fauna along the collector tracks, including possible recolonisation;

?? Possible changes in the benthic fauna (through a chain of reactions) in adjacent areas apparently not perturbed by the activity;

?? Changes in water characteristics at the level of the discharge from the surface vessel during the mining test;

?? Possible changes in the behaviour of the corresponding fauna (if there are fauna at that depth).

3.4. Data collection, reporting and archival protocol

The types of data to be collected, frequency of collection and analytical techniques must follow the best available methodology and an international quality system using certified operations and laboratories.

All data relating to the protection and preservation of the marine environment, other than equipment design data, shall be transmitted to the Secretary-General to be freely available for scientific analysis and research, subject to the confidentiality requirements contained in the Regulations.

Contractors shall transmit to the Secretary-General any other non-confidential data in their possession that could be relevant for protection and preservation of the marine environment.

How to handle the data is the topic of this Workshop.

SUMMARY OF DISCUSSION

Biological communities

One participant questioned the lower size limit of 32 microns proposed for the meiofauna category, stating that while it might be appropriate for some environments such as the deep sea, such a small sieve size was difficult to work with and contractors would find it much easier to shift up to 45 µm. This comment was based on experiments on sieve size carried out in the Clarion-Clipperton Fracture Zone (CCFZ), in which the smaller size had been found to be unnecessary.

Mr. Lenoble responded that the LTC regarded this as a provisional recommendation that might change as a result of scientific observation and technological developments. Commission members had noted differences in the scientific literature over the distinction between meiofauna and megafauna; the borderline might differ according to species or the techniques used. The LTC sought to define a general philosophy, leaving such matters as choice of techniques and depth of core sampling to the scientific community and the Workshop.

The absence of any mention of voucher collections for resolving taxonomic problems was noted. Voucher collections were defined as sets of animal specimens maintained by curatorial institutions and available for general use as standards to identify species, much like the standard metre kept in Paris. A participant observed that describing animals by their structure could be supplemented by molecular genetic techniques, which could help biologists know that what one group identified as species A at one site was the same species found elsewhere, thus clarifying its range.

Lenoble observed that such matters were beyond the expertise of contractors, who would have to rely on specialists with their own links to the world scientific communities and their knowledge of international practices. As the recommendations specified, contractors had to make use of the best available methodology when collecting data. He suggested that the Workshop make recommendations about international cooperation to deal with the problem of taxonomy, a specialized area outside the province of the Authority.

Environmental baseline studies

One participant cited the difficulties involved in using baseline studies to ascertain the impacts of exploration and mining. How was it possible to fix a baseline at a certain point in time, given all the uncertainties involved in parameters such as oceanography, sediment properties, biological communities and bioturbation, and the lack of knowledge about those parameters?

Adaptability of recommendations

Lenoble stressed that the recommendations were not meant to be binding and in any case should be reviewed every five years. The annual reporting system would present opportunities to discuss matters with contractors, whose own environmental monitoring programmes were subject to review and modification in a five-year cycle. The LTC viewed the recommendations as rules emanating from the scientific community that were proposed to the contractors as guidance for their work. As such, they could be adjusted in the light of new knowledge that could affect such matters as measurement systems and techniques.

Role of scientific community

A question was asked as to what kind of review would take place when a contractor submitted a proposal to meet the environmental guidelines in a particular way. Lenoble replied that the Authority would review the proposal with the help of the LTC, which would normally be able to take a decision. However, if something was not clear, the Authority might consult scientific experts or convene a workshop, in which the scientific community could voice its feelings about what the contractors were doing. While it was the task of the Authority rather than the scientific community to establish regulations, neither the Authority nor contractors, on their own, should determine what should be observed or what kind of information should be collected.

In this regard, a suggestion was advanced that, for continuity and for perception of fairness to the contractors, a small scientific commission might be set up to review contractors' proposals in parallel with or after a review by LTC.

The Secretary-General responded that the LTC, composed of scientists and engineers as well as legal people, should have sufficient capability to deal with scientific matters, with the help of analysis from the Secretariat of the Authority. At the same time, after years spent in setting up the legal framework, it was time to reach out to the scientific community, the mining community and others for their input. The purpose of the series of workshops convened by the Authority was to seek help in establishing indicators, guidelines and recommendations against which the Authority and the Commission should be able to evaluate the information submitted by contractors.

Notes and References

1. International Seabed Authority, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area: prepared by the Legal and Technical Commission (ISBA/7/LTC/1), 10 April 2001; further revised and approved by the Commission as ISBA/7/LTC/1/Rev.1 of 10 July 2001. The present paper refers to the April 2001 version of the recommendations. On 12 July 2001, the ISA Council deferred consideration of the recommendations until its eighth session (August 2002).

2. *Deep-Seabed Polymetallic Nodule Exploration: Development of Environmental Guidelines* (1999), Proceedings of the International Seabed Authority's Workshop held in Sanya, Hainan Island, People's Republic of China (1-5 June 1998), ISA (Kingston, Jamaica), 289 pp. The recommended guidelines are in chapter 9, pp. 219-239.

3. International Seabed Authority (2000), Regulations on prospecting and exploration for polymetallic nodules in the area (ISBA/6/A/18) approved by the Authority on 13 July 2000, *Selected Decisions and Documents of the Sixth Session* 31-68.

Chapter 3 Current State of Knowledge of Deep-Sea Ecosystems, Proposed Technologies for Polymetallic Nodule Mining and Expected Impacts From Mining Tests During Exploration

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1. General Considerations

1.1. Environmental impacts of nodule mining

Seafloor mining of polymetallic nodules has the potential to impact vast areas of the deep-sea ecosystem [1] The nodule resources occur in deep oceanic waters (greater than 4000 metres) far removed from the continents (i.e., beyond major influence of coastal productivity and terrigenous sedimentation); thus, they are found in some of the least studied habitats in the biosphere. Current claims under the jurisdiction of the International Seabed Authority (ISA) include vast abyssal tracts in the North Pacific Ocean within the Clipperton-Clarion Fracture Zone (CCFZ) as well as in the north central Indian Ocean[2] If a substantial portion of the claim areas in the Pacific and Indian Oceans are one day exploited, nodule mining could yield one of the largest areal impacts for a single type of commercial activity on the face of the earth.

The main environmental impacts of nodule mining are expected at the seafloor, with less intense and persistent effects in the water column.[3] Major potential impacts include:

i. Removal of surface sediments, polymetallic nodules and associated biota from multiple patches tens to hundreds of square kilometres in area. Seabed sediments remaining in these patches will be compressed and broken up by passage of the mining vehicle.

ii. Creation of a massive near-bottom sediment plume as a consequence of nodule removal. Sediment in the plume will redeposit on the surrounding seafloor, burying the sediment/water interface and biota under sediment blankets ranging in thickness from a few grains to several centimetres. A diffuse plume will persist in the benthic boundary layer for weeks to months, potentially travelling hundreds of kilometres.[4]

iii. In the surface ocean, release of bottom water entrained with lifted nodules, as well as sediments and nodule fragments, may enhance nutrient and heavy-metal concentrations, and reduce light levels; these alterations may affect, among other things, rates of primary production, food-web dynamics and survival of larval fish in oceanic surface waters. Settling of sediments and nodule fragments from this discharge into the oxygen-minimum zone may lead to the release of heavy metals.

iv. The discharge of tailings from nodule processing will (by future ISA regulations) occur in the deep ocean below the oxygen-minimum zone (i.e., typically below a depth of 1200 m). Once again, a large sediment plume will be formed, altering suspended particle concentrations, potentially influencing mid-water food webs and yielding sediment redeposit ion on the underlying seafloor.[5]

Following several decades of nonexclusive prospecting for polymetallic nodules at the abyssal seafloor, mining claimants are now entering the exploration stage of nodule mining. In accordance with regulations developed by ISA[6] (discussed in chapter 1 above), exploration is the

> "searching for deposits of polymetallic nodules in the Area with exclusive rights, the analysis of such deposits, the testing of collecting systems and equipment, processing facilities and transportation systems, and the carrying out of studies of the environmental, technical, economic, commercial and other appropriate factors that must be taken into account in exploitation" (regulation 1.3(b)).

Exploration can occur only after approval by ISA of an application from the potential contractor explaining, among other things, (1) a plan of work, (2) what baseline studies will be conducted and (3) a preliminary assessment of possible environmental impacts of the proposed exploration activities. The plan of work for exploration will be for 15 years, and may be extended for an additional 5 years. The size of exploration areas will not exceed 150,000 km^2, i.e., an area equivalent to a square of 387 km on a side. Exploration contractors will be required to report annually in writing to ISA on the results of their monitoring programme, including submission of monitoring data and related information. In addition to baseline monitoring, contractors will be required to generate an environmental impact assessment for all aspects of test mining and then to monitor the environmental impacts of any mining tests.

1.2. Gaps in knowledge of deep-sea ecosystems

Although a number of scientific environmental studies have been conducted in the claim areas in the North Pacific and Indian Oceans, numerous important ecological aspects of these abyssal habitats remain very poorly understood. Poorly understood characteristics include:

i. Community structure, at the species level, of dominant faunal elements at the seafloor, in particular the macrofauna (animals less than 2 cm and >250 microns in smallest dimension) and meiofauna (animals <250 µm and >42 µm in smallest dimension). Species-level structure is poorly known because of the shortage of taxonomic experts to identify the deep-sea fauna and because most species collected in the nodule provinces are new to science (they have not been formally described in the scientific literature).

ii. Geographical ranges of the dominant macrofaunal and meiofaunal species likely to be impacted (and potentially exterminated) by nodule mining. Without knowledge of the ranges of dominant species living in the claim areas, it is impossible to realistically predict the likelihood of extinction from large-scale habitat disturbance such as that resulting from nodule mining.

iii. Resistance and resilience (i.e., recovery times) of seafloor communities to nodule-mining disturbance. Although a number of simulated impact studies have been conducted[7] they have not reproduced the full scale and intensity of actual mining disturbances, and have been forced to work with relatively low levels of sampling replication.

1.3. Importance of standardization

Because of the great financial and logistical difficulties of studying the deep ocean, the broad geographical scales of potential mining impacts and the limited nature of the deep-sea ecological database, it is critical that environmental studies of nodule-mining impacts should collect and report data using standardized approaches. This will allow comparison of baseline and impact assessments from contractors from a variety of countries, working in far-flung claim areas and at disparate times. It should facilitate development of a broad synthetic view of open-ocean ecology and nodule-mining impacts, which will aid substantially in sound management of the environmental impacts of commercial mining.

It is worth noting that similar standardization concerns have been addressed in all large-scale international oceanographic research programs such as the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE). In these programmes, common sampling, sample-processing and data-reporting protocols have been adopted, and intercalibration studies have been conducted to ensure standardization[8] .

Thus, while standardization issues for the collection of environmental data may appear mundane, their resolution is essential to international cooperation and collaboration, and to obtaining a broad synthetic view of the potential environmental impacts of seafloor nodule mining.

1.4. Levels of technology

Acquisition of oceanographic data has often been limited by technology, with major breakthroughs in understanding following technological innovations. Examples include: (1) recognition of the prevalence and speed of carrion scavenging at the deep-sea floor following development of the "monster camera"[9] (2) the discovery of extraordinary deep-sea species diversity after development of the epibenthic sled[10] (3) enhanced appreciation of the importance of fronts, eddies, and other meso- and synoptic-scale oceanographic features to phytoplankton blooms and fishery exploitation following developments in remote sensing (e.g., satellite imagery). Thus, in conducting environmental studies for nodule exploration, there is strong motivation to use the best available technology to collect the highest quality data.

However, for scientific endeavours (e.g., baseline studies) that may collect data over many years, it may be counterproductive (and unnecessarily expensive) to upgrade data-collection technologies at every opportunity. Given acceptable data quality, use of a single sampling technology allows comparison of data patterns over long periods[11] Thus, careful thought must be given before upgrading sampling technology in the middle of an environmental study (e.g., baseline monitoring by a single contractor) or within the framework of series of studies (e.g., baseline monitoring of widely separated claim areas) for which a broad synthesis in space and time is desired. Once standards for environmental studies are adopted, any desired changes (e.g., in sampling apparatus) should be reviewed by scientific experts to determine how such changes will influence comparisons with existing data sets.

Thus far, baseline and impact studies for polymetallic nodule mining have not been conducted using standardized approaches. Thus, in general I recommend adoption of state-of-art technology for use in environmental studies during the exploration phase of mining.

2. Baseline-Data Requirements by Sector

During and after the ISA workshop in Sanya, China in June 1998 to discuss "deep-sea polymetallic nodule exploration: development of environmental guidelines", a number of guidelines for baseline-data collection were formulated. These recommended guidelines were categorized as pertaining to:

- Physical oceanography,
- Chemical oceanography,
- Sediment properties,
- Biological communities,
- Bioturbation and
- Sedimentation.

The recommended guidelines, and papers and discussions explaining their rationale, are presented in the published proceedings of the Workshop[12] Revised and abbreviated recommendations, together with some explanations, were later prepared by the Legal and Technical Commission (LTC) of ISA[13] (discussed in chapter 2 above). In this section, I quote the requirements set out in the LTC document, outline the more detailed guidelines recommended by the Sanya Workshop and offer suggestions (*in italics*) where additional specifications appear warranted. In section 3 following, I discuss major remaining issues for baseline-data collection, including frequency and duration of baseline monitoring, taxonomic standardization and the general requirements of an environmental database.

2.1. Physical oceanography

The LTC recommendations for physical oceanographic baseline-data collection are as follows (paragraph 8(a)):

"(i) Collect information on the oceanographic condition along the entire water column, including the current, temperature and turbidity regimes above the seafloor;

(ii) Adapt the current measurement programme to the topography and regional hydrodynamic activity in the upper water column and on the sea surface;

(iii) Measure the currents and particulate matters at the depth of the forecasted discharge during the testing of collecting systems and equipment;

(iv) Measure the particulate distribution to record particulate concentration along the water column".

To meet these requirements, the following guidelines were recommended by the Sanya Workshop:

To characterize the physical regime, a minimum of four current-meter moorings are required, with at least one (the "long mooring") reaching pycnocline depths (i.e., 50- 100 m). Scales of separation of current-meter moorings should be of the order of 50-100 km. The long mooring should contain at least eight current meters (including one within the pycnocline and one at the forecasted discharge depth) and each of the remaining moorings should have at least six meters. Each mooring should have a current meter at the following altitudes above the seafloor: 1-3, 5, 15, 50 and 200 m, and 1.2-2 times the height of the highest topographic element in the claim area. In addition, each mooring should include a transmissometer. *Three of the transmissometers should be deployed at*

50-m altitude (i.e., within the bottom boundary layer) and one at the forecasted discharge depth.

In addition, conductivity-temperature-depth (CTD) profiles and sections should be obtained from the sea surface to the seafloor, to characterize the stratification of the entire water column. Satellite-data analysis is also recommended for understanding synoptic-scale surface activity in the claim area.

The duration of current-meter mooring deployments, and the frequency and duration of CTD profiling and satellite-data analyses, need to be specified. These will depend on the time scales of processes and variability deemed relevant to establishing baseline conditions, which could include variability associated with seasonal changes, interannual changes such as El Niño and La Niña, and interdecadal oscillations such as climate regime shifts[14] . In addition, the types of satellite-data analyses (e.g., ocean colour from the Sea-viewing Wide Field-of-view Sensor [SeaWIFS] project, sea surface temperature) must be specified.

2.2. Chemical oceanography

The LTC recommendation for chemical oceanographic baseline-data collection is as follows (paragraph 8(b)):

> "collect information on the water column chemistry, including the water overlaying the nodules."

To meet these chemical requirements, the following guidelines were recommended by the Sanya Workshop:

To characterize processes of chemical exchange between the sediment and water column, dissolved oxygen concentrations, concentrations of nutrients including nitrate, nitrite, phosphate and silicate, as well as total organic carbon (TOC) should be measured in the "water overlying nodules". *Presumably, "water overlying nodules" means water in the benthic boundary layer and these parameters can be measured from CTD rosette samples.*

To characterize water-column chemistry, vertical profiles of the concentrations of dissolved oxygen, nutrients (including nitrate, nitrite, phosphate and silicate) and TOC are required, as well as temperature and salinity profiles. These measurements should address temporal variability and "transect physical oceanographic structures". *As in the case of the physical oceanography measurements, frequency and duration need to be specified. In addition, some important depths for chemical measurements need to be delineated, e.g. within the oxygen-minimum zone and around the depth of forecasted discharge.*

2.3. Sediment properties

The LTC recommendations for sediment-property baseline data are as follows (paragraph 8(c)):

> "determine the basic properties of the sediment, including measurement of soil mechanics, to adequately characterize the surficial sediment deposits and the potential source of deep-water plume; sample the sediment taking into account the variability of the sediment distribution".

The Sanya Workshop recommended the following guidelines to meet these requirements:

At no fewer than four stations, these sediment properties should be measured: water content, specific gravity, bulk density, shear strength, grain size and the sediment depth of change from oxic to suboxic conditions. In addition, sediment profiles of organic and inorganic carbon, and pore-water profiles of phosphate, nitrate, silicate, alkalinity and the "redox system" should be measured to at least 20 centimetres or to below the sub-oxic layer, whichever is deeper. Measurements of the "geochemistry of pore water" down to at least 20 cm, or below the sub-oxic layer (whichever is deeper), are also recommended.

The distribution of these measurements in space and time needs to be specified, as does the type of grain-size analysis. For modelling suspended sediment dispersion and redeposition, grain-size analyses of natural sediments are much more useful than analyses of disaggregated sediments (i.e., sediments dispersed by treatment with H_2O_2 to remove organic matter, and sonication). In addition, the term "geochemistry of pore water" is so vague that it is not clear which geochemical parameters should be measured (most likely pore-water concentrations of Fe, Mn, SO_4, H_2S and other redox-sensitive substances important in microbial metabolism).

2.4. Biological communities

The LTC recommendations for baseline studies of biological communities are as follows (paragraph 8(d)):

> "(i) Gather data on biological communities, taking samples representative of the variability of bottom topography, sediment characteristics, and abundance and types of nodules;
>
> (ii) Collect data on the seafloor communities specifically relating to megafauna, macrofauna, meiofauna, microbial biomass, nodule fauna and demersal scavengers;
>
> (iii) Assess benthic, benthopelagic, meso- and bathypelagic communities;
>
> (iv) Record levels of trace metals found in dominant species;
>
> (v) Record sightings of marine mammals, identifying the relevant species and behaviour;
>
> (vi) Establish at least one station to evaluate temporal variations".

The Sanya Workshop recommended detailed guidelines for baseline studies of the seafloor community and the pelagic community. These are summarized and discussed below.

2.4.1. Seafloor community

For the seafloor community, it is recommended that baseline biological monitoring include a minimum of four stations (i.e., study sites) in each claim area, with at least one station surveyed annually for at least three years (to evaluate interannual variability). At each station, sampling should be randomised, with key environmental factors such as nodule coverage, topographic relief and depth incorporated into the sampling design. A number of more specific recommendations are then made with reference to seven biological categories: (1) megafauna, (2) macrofauna, (3) meiofauna, (4) microbial biomass, (5) nodule fauna, (6) demersal scavengers, and (7) trace metals in bentho-, meso- and bathypelagic organisms.

2.4.1.1. Megafauna

Megafaunal abundance, biomass, species structure and diversity are to be evaluated using at least five randomly oriented photographic transects per study site, with each transect at least 1 km long. Individual photographs should view an area about 2m wide, and be able to resolve organisms >2 cm in smallest dimension. The photographic transects should also be used to evaluate the abundance and size distribution of nodules and surface-sediment structure. *Protocols for quantifying the megafaunal parameters should be specified, for example by citing a published study whose methods are to be used.*

In addition, to characterize large areas of the seafloor within the claim area, megafaunal surveys should be undertaken within a randomised-block design. It is recommended that a "deep-towed photographic system with side-scan sonar travelling about 3 m above the seafloor be used to give a general idea of the ecology of the region". Megafauna, organism traces and surface-sediment structure should be recorded in these surveys. *The number of blocks and the number and length of surveys per block need to be specified. For example, it might be suggested that each claim area be divided into 20 blocks (yielding 7500 km^2 per block for a 150,000 km^2 claim area), and then at least three surveys, each at least 5 km long, be conducted at random locations within each block. This type of survey is likely to be compatible with exploration for nodule resources.*

2.4.1.2. Macrofauna

Macrofaunal abundance, species structure, biomass, diversity and depth distribution (suggested depths of 0-1, 1-5 and 5-10 cm) are to be based on at least ten box-core samples (each 0.25 m^2 in area) per study area. Cores should be randomly distributed within each study area, and samples gently processed on nested 500- and 250-µm sieves. *Consideration should be given to standardizing box-core deployment protocols, because box-core sample quality is very sensitive to bow-wave effects and horizontal motions over the seafloor. Some criteria concerning acceptability of a sample may be necessary (a box core with a disturbed surface is far from quantitative). I also recommend that the* *sediment/water interface of each box-core sample be photographed immediately after recovery to aid in evaluating sample quality. In addition, some standardization of sample processing (e.g., sieving before or after fixation, sorting methods) should be specified, for example by citing the methods of a particular scientific study. Finally, taxonomy (species identification) needs to be standardized within and across claim areas. (See the discussion of taxonomic standardization in section 3.2 below.)*

2.4.1.3. Meiofauna

Data on the abundance, biomass, species structure and depth distribution (suggested depths of 0-0.5, 0.5-1.0, 1-2 and 2-3 cm) of meiofauna (animals <250 µm and >32 µm) are to be obtained from ten multiple cores per study area, each tube from a separate, randomly distributed multiple-core lowering. It is recommended that meiofauna be processed on nested sieves of 1000, 500, 250 and 32 µm. *Multiple-core tube size (10-cm diameter?) and lowering protocols should be standardized or a relevant paper cited. In addition, taxonomy needs to be standardized within and across claim areas. (See the discussion of taxonomic standardization in section 3.2 below.)*

2.4.1.4. Microbial biomass

It is recommended that profiles of microbial biomass be determined using adenosine triphosphate (ATP) or other standard microbial assay for ten multiple-core tubes per study area, with each tube taken from separate, randomly located multiple-core deployment. Suggested depth intervals for profiles are 0-0.5, 0.5-1.0, 1-2, 2-3, 3-4 and 4-5 cm. *The protocols for ATP analysis need to be specified, e.g. by reference to a suitable methods paper*[15]

2.4.1.5. Nodule fauna

It is recommended that the faunal abundance and species structure associated with ten randomly selected nodules from ten box cores per study area (the same cores used for macrofauna) be sampled and analysed. *I recommend using the methods of Mullineaux (1987)*[16]

2.4.1.6. Demersal scavengers

It is recommended that a time-lapse camera be installed in the study area for at least one year to examine the physical dynamics of surface sediments, resuspension events and megafaunal activity. Baited camera systems are also recommended to characterize the mobile scavenger community. *I suggest that these studies be conducted at the site where interannual (i.e., three-year) studies are conducted. Time-lapse camera protocols should be standardized; I recommend following the procedures of either Gardner et al. (1984)[17] or Smith et al. (1994)[18]. The number and protocols of baited camera deployments should be standardized. I suggest one seven-hour baited camera drop at each of four baseline stations in the claim area using the protocols of Hessler et al. (1978)[19] or other baited camera studies discussed in Gage and Tyler (1991)[20]. It may also be desirable to use baited traps[21] to collect scavengers for identification and heavy-metal analyses (see next paragraph).*

2.4.1.7. Trace metals in bentho-, meso- and bathypelagic organisms

It is recommended that trace-metal concentrations be measured in dominant bentho-, meso- and bathypelagic species. *Much more specific recommendations are required concerning (1) which trace metals to analyse, and (2) how many individuals from how many, and what types of, species should be analysed. One possibility would be to analyse trace metals (to be specified) from at least five individuals from each of the three most dominant species collected as macrofauna, demersal scavengers, and in the meso- and bathypelagic communities.*

2.4.2. Pelagic community

For the pelagic community, guidelines for baseline monitoring recommended by the Sanya Workshop are very limited. The pelagic community is subdivided into (1) deep water, (2) surface water and (3) marine mammals.

2.4.2.1. Deep water

For deep-water communities, the Workshop stated that the "community structure of deep zooplankton and fish around the depth of the plume and in the benthic boundary layer need to be assessed". It also recommended that "the fish community" in the upper 1500 m of the water column be assessed with depth-stratified sampling (at least three depth strata), with sampling on a diel basis and examining "temporal variability". *The design of this deep-water sampling programme needs much more specification.*

2.4.2.2. Surface water

For surface-water studies, the Workshop recommended that the plankton community in the upper 200 m be characterized in terms of phytoplankton composition, biomass and production; zooplankton composition and biomass, and bacterioplankton biomass and productivity. In addition, temporal variation in the plankton community in surface waters should be studied, including use (and validation) of remote sensing. *The surface-water studies need to be better defined in terms of parameters to be measured and sampling design in space and time.*

2.4.2.3. Marine mammals

As the final component of biological community assessment, the Workshop recommended that observations of marine mammals be made (i.e., sightings and behaviours recorded) during baseline studies, in particular during transits between stations. It also recommended that temporal variability be assessed. *These recommendations need to be more specific regarding the types of data to be recorded and how temporal variability should be assessed. I recommend that input be obtained from a marine mammalogist (e.g., Dr. Douglas DeMaster) on these points.*

2.5. Bioturbation

The requirement for baseline evaluation of bioturbation, as recommended by LTC, is as follows (paragraph 8(e)):

> "gather data of the mixing of sediment by organism[s]".

The Sanya Workshop recommended evaluation of bioturbation rates using excess Pb-210 profiles from multiple cores. Five replicate profiles per station are recommended, each from separate, randomly located multiple-core lowering. Excess Pb-210 activity should be evaluated on at least five levels per core (suggested depths 0-1, 2-3, 4-5, 6-7, 9-10 and 14-15 cm) and mixing intensities evaluated from standard advection-diffusion models. *The number of stations within the claim area at which bioturbation should* *be measured must be specified. I recommend a minimum of four stations, corresponding in number and location to those recommended for seafloor-community studies (see section 2.4.1 above). Because Pb-210 mixed layer depths appear to be shallow in the CCFZ[22], I also recommend that the depth levels within cores for Pb-210 assays be more concentrated near the sediment/water interface (i.e., at 0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.5 and 2.5-5 cm). Because of the long characteristic time scale of excess Pb-210 activity (~100 years), bioturbation intensities need to be evaluated only once at each station for baseline purposes.*

2.6. Sedimentation

The baseline requirement for evaluation of sedimentation, as recommended by LTC, is as follows (paragraph 8(f)):

> "gather data of the flux of materials from the upper-water column into the deep sea".

The Sanya Workshop recommended that two sets of sediment traps be deployed on two moorings for at least 12 months. One trap on each mooring should be at a depth of ~2000 m to characterize mid-water particle flux and one trap on each mooring should be ~500 m above the seafloor (and outside of the benthic boundary layer) to evaluate deep-particle flux. Traps should sequentially sample at no longer than one-month intervals. Traps may be deployed on the current-meter moorings. *More detailed trap protocols and the measurements to be made on the collected material must be specified. I suggest adopting the JGOFS protocols[23] for deep sediment traps, an d that variables measured include the fluxes of total mass, particulate organic carbon mass, calcium carbonate, biogenic silica and excess Pb-210 (again using JGOFS protocols).*

3. Other Issues for Baseline-Data Collection

3.1. Frequency, duration and spatial distribution

Variability in baseline conditions within claim areas can result from seasonal, interannual (e.g., El Niño, La Niña) and decadal (e.g., climatic regime shifts) phenomena.[24] It is neither feasible nor desirable to evaluate variations in all the baseline parameters on all these time scales, so certain time scales must be targeted for particular parameters. Because response times (e.g., recovery times following disturbance) are thought to be slow for abyssal seafloor communities[25] seasonal baseline studies at the seafloor are probably not warranted. In contrast, environmental processes in the surface ocean may vary substantially on a seasonal basis, altering community response to nodule-mining impacts (e.g., release of iron-rich tailings in surface waters). Environmental conditions throughout the water column may change as a consequence of decadal climatic regime shifts. Spatial variations will also occur in 150,000-km^2 claim areas as a function of bottom topography, general hydrographic regimes and even latitudinal differences.

As a starting point for discussion, I offer the following general design for baseline monitoring:

Within each claim area, four stations should be established, 50-100 km apart. Stations should be established where bottom topography and nodule cover appear to be typical of the general area on 50-100 km scales (based on data collected during the prospecting phase). Ideally, one station might be located at a random point in each of four equally sized quadrants of the claim area. Current-meter moorings would then be deployed at all four stations, with sediment traps on two of the moorings. The long mooring, with sediment traps, would be deployed for three years (and serviced once a year), while the other mooring would be deployed for one year. Physical and chemical oceanography parameters would be measured in the water column at all stations in winter and summer for two years (i.e., over two winter-summer cycles); community studies in surface waters would also be conducted on seasonal cruises. Seafloor community studies, and evaluation of sediment properties and bioturbation, should be conducted at least once at all four stations (in the first year). In addition, megafaunal, macrofaunal, meiofaunal, microbial, demersal-scavenger and sediment-pore-water parameters would be assessed once a year for two additional years at the station with the long mooring to evaluate interannual variability.

I would also recommend that the location at a study site (or station) of individual seafloor samples (e.g., box cores and multiple cores) be randomised on a one-kilometre scale to assess within-site spatial variability.

This would lead to an overall baseline environmental programme of three years, with sampling cruises at 0, 0.5, 1.0, 1.5, 2 and 3 years from the start.

3.2. Taxonomic standardization

I strongly recommend a centralized approach to taxonomic identification, in which a particular taxonomist or museum is made responsible for identifying material from all claim areas. This is essential to developing consistency among contractors in species-level identification and for establishing the geographic ranges of important (e.g., indicator) species.

One approach would be for each contractor to contribute about 50,000 United States dollars per year during the four years of baseline monitoring to a central taxonomic facility centred at a museum (e.g., the Smithsonian Institution, Washington, or the Natural History Museum, London). With five contractors, an annual budget of some $US250,000 per year would be allocated, which should be adequate to establish a broad-based taxonomic centre addressing taxonomy from meiofaunal nematodes to megafaunal holothurians. Contractors would then send sorted sample material to the taxonomy centre for identification, establishment of species ranges and species descriptions. Principal taxonomists (e.g., for polychaetes, isopods, nematodes, etc.) would establish priorities for identifying the most relevant samples in order to efficiently resolve patterns of local species diversity and biogeographic patterns. The taxonomy centre would also be responsible for mustering taxonomic expertise to handle baseline material by recruiting and training graduate students and postdoctoral scholars, including scientists from the countries of contractors. Ultimately, such a taxonomy centre could provide the multiple services of consistent taxonomic identification, description of key species, resolution of biogeographic patterns and training of an international cadre of young taxonomists (of whom there is a great shortage worldwide).

3.3. Requirements of an environmental database

The requirements of an environmental database require some discussion because several factors must be considered in its design. These include the following:

i. The nature of existing data to be entered. Substantial amounts of environmental physical, chemical and biological data have already been collected in the areas currently of interest for exploration contracts. These data have been collected according to a variety of standards. Nonetheless, they may be very useful to the design of baseline and monitoring programmes conducted during exploration.

ii. The general manner in which data are likely to be searched or accessed, i.e., the categories of identifiers to be associated with each datum. Important reference categories will include:

- General data type (i.e., physical, chemical, biological, satellite, cruise log, etc.), with nested specific parameters (e.g., oxygen concentration in the water column, macrofaunal abundance in individual box cores, etc.);
- Geographic location (latitude and longitude);
- Date of collection;
- Contractor's name;
- Claim area;
- Cruise number (an alphanumeric code identifying both ship and voyage);
- Station number (e.g., an alphanumeric code identifying contractor, ship, cruise number and cruise operation number);
- Depth in the water column.

Ideally, the database would be set up so that each datum could be searched and accessed by any combination of the above categories. For example, an investigator who wanted to view abundance of macrofauna in all box cores collected within a certain region and a certain period could search the database by inputting (1) a latitudinal and longitudinal range, and (2) a parameter name, i.e., "macrofaunal abundance". The result would be a table of macrofaunal values (macrofaunal abundances) with associated data (geographical location, date of collection, depth, etc.).

Set-up of the database will require (1) input concerning existing and future data types to be entered, (2) consideration of the most useful and preferred outputs, and (3) guidance from an experienced creator of databases.

4. Recommendations for Monitoring Mining – Test Impacts

Until the details of test-mining plans are known, it is difficult to make many recommendations regarding monitoring of mining-test impacts. Clearly, parameters and methodologies used in developing environmental baselines must also be applied in test-mining impact studies to allow broad ecological comparisons. Several other general recommendations are possible:

i. An environmental baseline should be established in the test-mining area for at least two years before the tests. This will allow evaluation of pre-disturbance spatial and temporal variability.

ii. The monitoring of test mining should include deployment of current meters, transmissometers and sediment traps to evaluate the size and behaviour over time of the sediment plume both within the benthic boundary layer and at the level of tailings discharge.

iii. Resedimentation thicknesses must be measured using multiple techniques and mapped to allow evaluation of dose-response patterns of various components of the benthic biota. The frequency and intensity of individual deposition events should also be evaluated.

iv. The sampling design for biological communities should include (a) sample collection from at least five points along the redeposition gradient and (b) sampling in at least two control (i.e., unimpacted) areas for the duration of the impact study.

v. Seafloor communities along the deposition gradient, as well as in control areas, should be sampled at least at the following approximate intervals after disturbance: <1 month, 6 months, 2 years, 4 years and 8 years. After 8 years, community recovery should be evaluated to determine whether sampling over longer periods (e.g. 16 years) is necessary to evaluate time scales of recovery following the mining disturbance.

PRESENTATION ON DEEP-SEA ECOSYSTEM KNOWLEDGE AND MINING –TEST IMPACTS

Dr. Smith began his presentation by stating that he would concentrate on current knowledge of deep-sea ecosystems with special reference to the so-called nodule province or nodule mining areas, while dealing briefly with nodule mining technologies and discussing critical information needed to predict mining impacts.

Past and current syntheses of the potential impacts of mining suggested that seafloor ecosystems in particular would be most seriously threatened by nodule mining, for which reason they must be a major focus of any environmental baseline monitoring and impact assessment. In light of the long history of seafloor studies, in nodule mining areas as well as the deep sea in general, and because many contractors would be collecting environmental data, there was a great need for standardization so that inter-comparisons could be made and a broader synthesis obtained about the natural state of deep-sea ecosystems and potential mining impacts.

In discussing the current understanding of deep-sea ecosystems, Smith focussed on the Clipperton-Clarion Fracture Zone (CCFZ) in the Pacific Ocean, observing that many of the general ecological insights gained there might also apply to the Indian Ocean, although there would be differences. The area of maximum commercial interest in the CCFZ was a large swath from about 6-20 degrees north latitude and about 110- 180? west longitude -- a significant part of the North Pacific.

He elaborated on six general characteristics of deep-sea ecosystems: (1) extremely low productivity, especially in the CCFZ, caused by low flux of particulate organic carbon (POC), resulting in low standing crops and biological rates; (2) low physical energy, though this element was somewhat controversial for the CCFZ; (3) high species diversity; (4) the large and continuous nature of the habitat, although there were gradients and patchiness that must be considered in any environmental monitoring programme and standards; (5) temporal variability, with productivity patterns changing on a variety of time scales, and (6) the poorly understood nature of the ecology.

Low productivity

In general, the CCFZ was an area of low phytoplankton standing stock and relatively low productivity. Since the bulk of the organic matter that supplied the benthos with energy sank from the surface waters, the relatively low productivity at the surface translated to low POC flux and low productivity at the seafloor. This was one of the most important environmental parameters controlling the biology of the deep-ocean floor.

Smith cited data collected along an equatorial Pacific (EqPac) transect examined by the Joint Global Ocean Flux Study (JGOFS), an international programme studying fluxes in the ocean. On its north side, the transect extended into the CCFZ. At 9? N, at the southern border of the CCFZ, sediment traps more than 700 metres above the seafloor recorded about 0.1 millimole of carbon per square metre per day, a relatively low flux that translated to about 3 grams per year. This was about 1/7th of the flux of equatorial upwelling in the middle of the Pacific or about 1/30th of the flux reaching the deep-sea floor on the continental margins, for example off California. Interestingly, the flux was only a little higher than that measured north of Hawaii in a supposedly oligotrophic area. As far as Smith knew, this was the only site in all of the CCFZ that had long-term particulate organic flux data to the seafloor.

A consequence of the low POC flux in the CCFZ was that a number of biological rates were also low, among them respiration. Measurements of respiration rate of organic carbon per square metre at the seafloor were roughly comparable to the POC flux, demonstrating again that this was an area of low metabolic activity.

The low POC flux apparently also resulted in a very small body size of animals. At selected CCFZ sites, the mean body size of benthos macrofauna was between 0.07 and 0.4 milligram per individual, very small compared to continental slope and shallow water sites. The small size of animals in the deep sea, particularly in the CCFZ, had consequences for their fragility -- how easily they might be damaged by nodule mining, for example.

Another consequence of the low flux was that the number of animals in any particular size class was quite low compared to such areas as the equatorial Pacific. Data on macrofauna from both the North Atlantic and North Pacific oceans showed a linear relationship between POC flux and biomass or abundance. Moreover, temporal variations in the flux of organic matter at the seafloor were also broadly correlated with changes in the abundance and biomass of animals on the seafloor. Megafauna showed a similar pattern, and similar figures could be constructed for the bacteria and Archaea living on the sediments.

Most of the seabed macrofauna in the CCFZ were deposit feeders -- animals that fed on organic matter sinking to the seafloor, ingesting it along with sediment particles. The vast bulk of animals in the CCFZ in the macrofaunal size class were surface-deposit feeders, focusing their foraging at the sediment/water interface on material recently settled to the seafloor. Another subset of the macrofauna, subsurface-deposit feeders that ingested sediments below the sediment/water interface, were relatively rare compared to other sedimentary environments.

Deposit feeders in the deep sea were particle selective, as demonstrated by a variety of particle-associated tracers, for example chlorophyll *a* or radionucleides such as Th-234. They fed on recently deposited particles – presumably organically rich particles such as phytoplankton detritus -- that had settled to the seafloor within the previous 100 days or so. Because they needed to feed on recently arrived material, any dilution of such food, for example by sediments resuspended from the seafloor during mining, was likely to have a major deleterious impact on their ability to feed and to grow.

Another consequence of lower POC flux, in addition to low respiration rates and biomass, was the fact that bioturbation occurred at a low rate. Radiotracer profiles to examine the rates at which sediments were stirred by animal activity indicated that at 9? N, at the northern end of the EqPac transect, bioturbation rates for Pb-210 were roughly one order of magnitude lower than at 5? N, a short distance to the south, where productivity and flux rates were substantially higher. The low rates at which sediments were mixed had consequences for the rate at which redeposited material might be integrated into the sediment column.

In addition to the basic mixing rates, the penetration depths of particle-associated radiotracers were also low. One important parameter for modelling chemical distribution in sediments and the fate of redeposited material on the seafloor was the depth at which animals were mixing with sediment. Once again, as in abundance and biomass, mixed layer depth was strongly correlated with POC flux. Data correlating POC flux to the Pb-210 depth in sediment showed that, in the CCFZ, mixed layer depths were shallow -- only about 2 centimetres -- consistent with a low energy and biomass regime.

Growth and recolonisation rates of animals in the deep sea in general, and by inference in the CCFZ, were also low. One could only speculate on the rates of recolonisation following a large-scale disturbance in the deep sea. This phenomenon might be studied by placing trays of azoic sediment (sediment without animals) on the seafloor, thereby mimicking the effect of a large-scale disturbance, and then examining the recolonisation rate over time. Data from such an experiment, using a tray 0.5 cm on a side, showed a slow recovery to background community conditions (abundance of animals in the surrounding sediment). The data, applying to macrofauna, were from all around the deep sea, including depths of 1000-2000 m, in areas that had higher energy flux and presumably a higher recolonisation rate than the CCFZ. Even in such productive environments, it took about eight years for the macrofauna to recolonise. The point was not that such a rate should be applicable to a mining disturbance but rather that recolonisation rates in the deep sea were slow following an intense disturbance. The same trays in shallow water might show a recovery to background conditions in a matter of weeks to a few months. Whether or not meiofauna showed the same response as macrofauna, the fact remained that if a deep-sea community were severely disturbed by removing a high percentage of the fauna over a large area, recovery times would be lengthy.

It would be important to factor that conclusion into any design of impact experiments. Even though the DISCOL (Disturbance Recolonization) and JET (Japan Deep-Sea Impact Experiment) projects and others showed that the intensity of disturbance in terms of generated plume was moderate compared to what could be expected from mining, recovery times were long. Differences in communities could be expected eight years after even the moderate level of disturbance produced by DISCOL.

Turning next to the high species diversity in the CCFZ, Smith cited data on polychaete worms – a major component of macrofauna – showing that a collection of 163 individuals had yielded anywhere from about 47 to about 82 different species. Thus, on a local scale, diversity was high compared to many other ecosystems. Implied in that species diversity was a lot of genetic diversity. Another aspect of diversity that was much more controversial and difficult to estimate was how many species inhabited a given region, at each of the collection sites. A post-doctorate scholar of Smith's, Adrian Glover, using controversial techniques, had estimated the number of polychaete species in Area A of DOMES (Deep Ocean Mining Environmental Study) at between 200 and 500. Thus, there might be thousands of macrofaunal species in that single area, although nobody had a good sense of how many species occurred at any of the sites studied in the CCFZ. Without understanding levels of biodiversity, it was difficult to predict the potential for species extinctions.

Low physical energy

The deep sea in most regions was also regarded as having low levels of physical energy. With slight currents producing low amounts of sediment transport, most of the structure was considered to be formed either by animals -- biogenic structures such as worm tubes -- or by manganese nodules. When pairs of time-lapse photographs were taken between 124 and 202 days apart at three sites within the nodule province, the earlier and later photos in each pair looked much alike. Sediment structures had changed little, suggesting that on roughly one-year time scales there was little remobilisation of sediment and that biogenic structure was a primary source of animal habitat.

Photographs from another site in the nodule province, of a large biogenic structure that was probably a worm mound, showed nodules sitting high up on the sediment – evidence viewed to mean that the animals rarely experienced resuspension events. As nodules grew at rates of roughly 1 millimetre per million years and were denser than the sediment, if resuspension events were occurring one would expect the nodules to be buried. Nevertheless, the concept of low energy and high physical stability of the seafloor in the nodule provinces was somewhat controversial at this point, because some current meter and sedimentological data, particularly from the eastern CCFZ, suggested that, at least on geological time scales and possibly even annually, resuspension and sediment transport events might be occurring.

The issue was important because, if the community was stable and never experienced resuspension over long periods -- years, decades or centuries -- then resuspension resulting from mining was likely to have significant ecological impact. On the other hand, if resuspension and redeposition were routine in major areas of the nodule province, the animals in those habitats were likely to be pre-adapted to dealing with some of the disturbances that might result from mining. In summary, most deep-sea biologists viewed the CCFZ as stable but there might be some recent evidence to the contrary in portions of the nodule province.

Geographical variation

Speaking next of the large, continuous nature of the CCFZ habitat, Smith observed that, while many people thought of the deep sea as relatively uniform, there were gradients, both longitudinally and latitudinally. One way to observe such gradients was to look at the abundance of animals on the seafloor. As noted above, the abundance of animals was generally correlated with POC flux in the deep sea, so that macrofaunal abundance in particular could be used to say something about the POC flux regime.

Looking at data on animal abundance at a number of stations in the CCFZ, moving from Echo 1 in the east to DOMES A in the west, he noted a change by roughly a factor of four in regard to macrofauna: 64 animals per square metre in the west and up to 260 animals in the east. This implied differences in a variety of environmental characteristics, particularly POC flux to the seafloor. Moving to the EqPac station at 9° N in the eastern CCFZ also showed a four- to fivefold change in abundance. In addition to those longitudinal changes, moving just four degrees from north to south into the zone influenced by equatorial upwelling demonstrated a sixfold change in abundance from EqPac 9° N to EqPac 5° N. So there clearly were gradients in the abundance of animals as one moved through the CCFZ, and presumably also in a number of environmentally important factors such as POC flux. Other evidence showed that there was not just one continuous fauna from one end of the CCFZ to the other.

High species diversity

Smith next cited data on overlaps in species lists of polychaete fauna at various Domes A and Echo 1 sites, showing that from 5-15 percent of the species at each site were not found at other CCFZ sites. If the fauna were identical and broadly distributed throughout the zone, one could argue that mining in different areas would not cause species extinction, as long as there were some preservation reference areas in other parts of the zone. Nevertheless, levels of atomicity -- the amount of species turnover as one moved from one end of the zone to the other -- were highly controversial and difficult to assess. These areas had been poorly sampled: Domes A was represented by about 47 box-core samples and Echo 1 by something like 2 box cores. Thus, one could argue that some species were simply rare and that sufficient sampling would eventually generate the same species lists at different sites. Such an argument might be valid until more detailed or more exhaustive research had been conducted in the nodule province.

One could also make the opposite argument, that these species lists and identities were based on morphological species -- preserved animals brought into the laboratory and identified under the microscope -- whereas it was becoming increasingly evident from molecular studies that many of the populations identified as a single species based on morphology were actually multiple-species complexes. Molecular genetics based on DNA sequences showed much greater diversity and much more restricted species distribution than biologists had been led to believe from morphology-based taxonomy, so from that perspective the percentage of endemics could be much higher. Until proper studies were conducted to look at the molecular genetics of species ranges, it would not be known whether predictions of the levels of species turnover across the region were conservative or otherwise.

Temporal variability

It was increasingly evident that, on a variety of scales -- seasonal, interannual, sometimes decadal and even multidecadal -- the productivity regime in the North Pacific Ocean including the CCFZ was changing over time. As the amount of organic carbon sinking to the seafloor and the deep sea changed, community structure was also likely to vary. To understand, predict and monitor the effects of mining, those effects would have to be distinguished from natural temporal variability.

Citing data from a number of stations across the central North Pacific, from the slope off California to the North Pacific central gyre, Smith noted that the amount of oxygen respired varied over relatively short time scales, as did POC flux. There was also evidence of longer time scales of variability, including major changes on a decadal scale in the productivity of the North Pacific Ocean. North Pacific salmon catches off Alaska and Washington had shown major shifts about 1976-77 and again in 1985-86, related to long-term climatic changes and primary production of POC flux. Similar changes in productivity on decadal time scales were also likely to be impacting the CCFZ. For example, they affected the lobster fishery in Hawaii, the survivorship of monk seals and many components of the pelagic food web. While salmon offered the most elegant example, it was likely that decadal time-scale variations in the flux of POC to the seafloor in the CCFZ would result in temporal variability in the abundance and potentially the species structure of seafloor ecosystems.

Knowledge limitations

Concluding his discussion of current views about deep-sea biology, Smith cautioned that everything he had talked about was poorly understood. Little was known about deep-sea ecosystems in general and the CCFZ in particular. Even though the CCFZ had been the focus of environmental studies for decades, it was still one of the remotest parts of the seafloor; it was difficult to reach by ship and an expensive place to work in. Consequently, there was only a rudimentary understanding of how the ecosystem functioned and how it might be impacted by mining.

Mining technologies

Turning to projected seabed-mining technologies, Smith noted that they included bucket lines dragged over the seafloor by two ships, devices towed by a ship that picked up nodules and pumped them to the surface vessel, and autonomous or tethered vehicles moving on the seafloor to pick up nodules. From the standpoint of environmental impact, all such systems were likely to do two things: remove the manganese nodules -- the goal of the whole process – and remove habitat of the nodule fauna. In addition, all systems would result in removal of a relatively wide and potentially contiguous layer of 2-3 cm of sediment. As it was difficult to collect nodules without picking up sediment at the same time, surface sediments would be removed in the direct track of the mining apparatus. If nodule resources appeared to be patchy over kilometre scales, there would be much impetus to keep mining tracks relatively contiguous, so many of the resources would be left on the seafloor after mining. A third consequence of major relevance to environmental impacts was the production of tailing discharge: mining would suck up much sediment, creating a plume of resuspended sediment at the seafloor. Further, tailings would be discharged when nodules were processed by the surface vessel; presumably, most of this discharge would occur somewhere in the mid-water, below the oxygen-minimum zone. All of these processes -- the removal of seafloor sediments, the creation of a seafloor plume associated with collection, and discharge of a plume in mid-water or at the surface -- had major potential to impact biological communities.

Expected impacts from mining

According to one estimate of the scale of a single operation, for mining to be economically feasible roughly one square kilometre of seafloor had to be mined each day. Assuming 300 days of operation a year, about 300 km^2 would be mined annually by a single mining operation. If 2.5 cm of sediment were removed during mining, about 6 million m^3 of sediment per year would be resuspended from a single mining operation. Modelling of the deep-sea plume, including the area it would cover, was extremely problematic without knowledge of how it would be released from the mining head, flocculation, behaviour of particles and the settling behaviour of deep-sea sediments. One model estimated that, if the tailings were released at the surface, an instantaneous plume would cover an area of 85 by 20 km.

To give an idea of the scale of potential burial processes from resedimentation, 6 million m^3 of sediment dispersed over a broad area could bury about 6000 km^2 under 1 mm of sediment. According to current thinking, a 1-mm deposition layer might have a significant impact on the deposit-feeding biology of much of the community. Over the 20-year life of a mining operation there would be the potential to bury something like 120,000 km^2 under 1 mm, assuming that the sediment cloud was relatively widely dispersed. These numbers might be thought of as a worst-case scenario rather than a real prediction, but the potential impacts from a dispersed plume of sediment from a full-scale mining operation were large. As test mining was likely to be about one-fifth the scale of actual mining and might go on for something like three to six months, the predicted impacts from test mining had to be scaled down, but there clearly remained a chance that they would be large. Such tests would be useful from an environmental perspective, because until disturbances approaching the scale of a real mining operation were generated, i.e., until near-scale mining operations took place, there could not be a good predictive understanding of mining impacts.

What were some of the impacts that might occur from mining? First, and perhaps most significant, there was a potential for interference with surface-deposit feeding and suspension feeding, through dilution of food materials by lower quality sediment resuspended from the seafloor. Sediments 1-2 cm down in the sediment column had low food value, so that when they were resuspended and mixed with the surface layer of food material, the food resources of deposit feeders would be diluted – potentially a widespread and severe problem in a food-poor environment like the CCFZ. The second impact, intermediate in significance, was entombment and burial of small animals associated with low bioturbation rates. Disappearance rates of seafloor biogenic structures in the CCFZ suggested that these animals might be very sensitive to physical burial. If on the other hand it turned out that major areas of the CCFZ experienced resedimentation events on a more routine basis, entombment and burial might not be such a big issue. A third major impact from nodule mining, of less importance than the others, was the physical removal by the mining device of the nodules, surface sediments and animals. The community in the tracks -- the areas directly mined by the mining head -- would be severely impacted: macrofauna would be wiped out, while some of the meiofauna might go through the mining head and survive, but in general the zone mined would be heavily devastated.

What critical information was needed to predict mining impacts on both the sediment and the nodule biota? One major open question was the dose-response function for the benthic community given a single deposition event. How much sediment redeposition was required to cause a particular degree of impact, as measured in percentage of mortality? The dose-response function was important for extrapolating from small to large disturbances and for predicting the effect of a plume dispersed at the seafloor. Another major unknown was the effects of chronic disturbance. How frequently must modest deposition events -- of less than 1 mm, for example -- occur for their effects to become chronic, in other words non-independent? A one-time deposit of 1 mm of sediment might have a modest effect on the community, but with repeated monthly deposits of 1 mm at a given site, the effects might become non-independent, producing much more mortality. The nature of chronic effects was important in knowing how to manage mining: whether it should be limited to one area for a while and then be moved 10 or 100 km away in order to minimize environmental impacts. A third major gap in knowledge concerned the time scales of community recovery following various intensities of disturbance. Although there had been some clever mining impact studies, it was still not known what the recovery times might be from a major mining-like disturbance in the CCFZ. Some things were known – for example, if nodules were removed, it would take millions of years before they grew back, so that the nodule fauna there would require millions of years to recover, whereas the sediment biota would recover over much shorter periods.

Smith cited other major open issues: What were the typical latitudinal and longitudinal ranges of benthic species in the CCFZ and what were their rates and spatial scales of gene flow? In practical terms, these questions translated to how large an area could be devastated by mining without causing species extinctions. In addition, what were the natural patterns and scales of benthic community variability in space and time?

There was an increasing appreciation that productivity regimes in the open ocean varied on seasonal, interannual (e.g., El Niño) and decadal scales, including specific decadal oscillation, and they were likely to vary with global warming. A recent study showed that changes in temperature of the surface ocean altered the amount of carbon exported from it, so that even on global warming time scales there would be changes. The major challenge was to understand natural patterns of variability in time and space in these systems in order to be able to remove natural variability from any anthropogenic influences due to mining.

SUMMARY OF DISCUSSION

CCFZ variability

A participant observed that the CCFZ seemed to be a transition zone between the equatorial region and the central gyres, with characteristics of both. Oceanic productivity was generally much lower than in coastal regions but there seemed to be a gradient from exceptionally low productivity in the central gyre to areas of intermediate character.

Smith agreed that the CCFZ was an enormous zone with longitudinal and especially latitudinal gradients in POC flux and many other parameters. As one moved from east to west and from south to north, there were dramatic reductions in the rain rate of organic matter and in productivity. The latitudinal gradients were probably quite a bit steeper that the longitudinal ones, although the flux measured in the JGOFS study was similar to that measured north of Hawaii, which was supposed to be an oligotrophic site.

Recolonisation rates

Questions were raised about the idea of studying recolonisation rates by placing trays of azoic sediments onto the seabed in a patch where the native sediment had been removed. One participant thought that might work for the larger animals but might be misleading for smaller ones such as the meiofauna, because they probably came up from underneath rather than from outside, even if the trays were placed in the middle of a large patch.

Smith responded that an experiment in which the top few millimetres of sediment were removed along with all the fauna over a large area of perhaps one kilometre in diameter should give a good idea of recolonisation rates. If the area was recolonised in a week, recovery from a large-scale disturbance might be relatively fast. If it took ten years, recovery might be relatively slow. One thing that had been learned in regard to standardization and the design of monitoring and impact studies was that different components of the ecosystem would not respond in the same way and might need to be monitored with different techniques and time scales.

Tailings discharge

A question was raised about whether mining tailings were likely to be discharged at the surface or in mid-water. Smith replied that, as he understood current thinking, surface discharge should be minimized though some was inevitable. One approach, for purposes of discussion, might be that, since a big plume was being created by mining in the benthic boundary layer, the discharge should take place in the part of the environment already sullied.

Mr. Lenoble observed that for the time being there was no regulation about this problem because most regulations dealt only with exploration. Companies active in this sphere were thinking of ways to reduce surface discharge but there had been little or no testing; they would have time to do that during the 15-year exploration phase. The discharge at the surface would come not only from the sediment but also from the fine particles of manganese hydroxide produced during the transportation and manipulation of the nodules. There would in fact be another discharge, at the bottom during nodule collection, when some separation would take place between nodules and sediment to avoid raising most of the sediment to the surface, thereby reducing surface discharge. The problem at the bottom would be to try to discharge the sediment in such a way as to avoid making a big plume above the seabed and to avoid dispersion of the sediment by having the plume flatten quickly to the bottom.

Another participant commented that the discharge level was more of an environmental than an engineering issue, since a system could be designed either way. It was premature to specify the level, given the lack of environmental knowledge.

Smith agreed that a recommendation as to the location of the discharge would be premature. However, perhaps the Workshop might propose some scenarios for discharge experiments. Otherwise, if there were only one or two cases of test mining, with no recommendations about discharge depth and monitoring, there would be no opportunity to study whether the effects were severe in a particular part of the water column. More was known about the likely effects of surface water discharge, for example in terms of potential iron enrichment causing turbidity, but to really understand the effects in the mid-water, some kind of discharge would have to be tested there. There was a need for guidance regarding discharge experiments during test mining, so that there would be enough understanding to make a suggestion or regulation from an environmental perspective about where discharge should occur.

The Secretary-General said contractors would have to address the discharge issue in their environmental statement at the end of the exploration phase, when applying for exploitation. While it was premature to deal with the topic now given the lack of knowledge, it should be flagged for action close to the end of the exploration phase, when mining systems were to be tested. Some indication should be given as to how it would be dealt with then.

Chronic versus single discharge

A participant cited information from the United Kingdom Ministry of Agriculture that, in the case of dumping dredges and their effects on meiofauna, it seemed better to keep hitting the same area with small doses every so often rather than hitting one area with a huge dose all at once. However, he did not know how that related to mining. This might be another case where animals of different sizes, or perhaps different taxa, reacted differently.

Smith responded that, in contrast, many studies of shallow-water communities showed low levels of chronic disturbance to be more deleterious than one large dose, at least for macrofauna, and particularly deposit feeders and suspension feeders. The different results might be due to the animals' feeding strategies, since deposit feeders' food resources were diluted and those of suspension feeders were damaged by a sediment plume. Experimentation at the seafloor would be needed to understand this issue.

Natural resedimentation events

In connection with the threat from resuspended plumes, a geologist wondered whether studies were being conducted of the effects of naturally occurring instantaneous deposits such as the asphalt from the 1991 eruption of Mount Pinatubo (Philippines). Smith replied that natural events had been used to look at resedimentation impacts, but not in habitats ecologically analogous to areas like the CCFZ. The ecology of the oligotrophic deep sea was so different from that of shallow waters or even the continental slope that it was difficult to extrapolate results.

A biologist suggested that turbidite flows might be the nearest natural event to deep-sea mining. A paper on one such event, at least 1000 years ago on the Madeira Abyssal Plain (MAP) in the northeast Atlantic Ocean,[26] concluded that it had badly affected polychaetes but the diversity of nematodes had been reduced only slightly (see chapter 16 below). This followed a pattern seen in shallow water, that larger animals such as polychaetes were much more affected by such events than nematodes. One reason might have to do with how they fed: nematodes were suspension feeders, not surface feeders. Another explanation might concern scale: a nematode was readily picked up and placed elsewhere, just as a high wind that might blow a man over and break his skull merely moved an insect from one place to another.

Another participant noted that there had been studies of volcanic ash deposition in a shallower environment, foram distributions, turbidite flows, slumping and mass wasting. However, many such events were difficult to date because they had happened so long ago. The authors of the paper on the MAP site were unsure whether the effects they had observed were due to low production or to the historical event. Not only were these events in different environments, they also seemed like a fundamentally different kind of phenomenon because they involved burial or deposition on top, not completely rechurning the sediments. Thus, in terms of both habitat and kind of disturbance, it was hard to compare such natural phenomena with what might be expected from mining.

Economic value of seabed biota

Asked whether the life on the ocean bottom had any economic value aside from its worth as an ecosystem, Smith responded by citing biodiversity and the use of genetic diversity in biotechnology. He mentioned his collaboration with a biotechnology company from San Diego, California, that was interested in prospecting an extreme environment for unusual genes that could be used in products such as cold-water detergents. Its interest in the deep sea was due to the tremendous diversity and extreme biological conditions there, including low temperature and high pressure. The CCFZ contained great evolutionary diversity and considerable genetic resources of potential use in biotechnology. The company wanted him to collect samples wherever he went in the deep ocean, to be screened for unusual enzymes. Samples had been collected in the Antarctic and off the coast of California. A number of products had already been geared up for marketing, including a cold-adapted enzyme for use in cold-water detergents. Other enzymes were for use in pharmaceuticals and in almost any low-temperature application. The huge diversity of animals and probably of bacteria in the deep-sea sediment might have a major economic potential.

No fishes of current economic importance inhabited the deep seabed, due to the low productivity of the environment. Rat-tails were commercially fished in the slope off California at depths of 2000-3000 m, and as some of the same genera and possibly the same species were found in the CCFZ, there might be a potential to fish those. However, the biomass of fish in that region was so low – perhaps a few kilograms per square kilometre -- that they would probably never be commercially fished, and if they were, they would be quickly fished out.

Seabed biology

Responding to questions about animal life at the ocean bottom, Smith said not much was known about life spans. Data from a 7-8-mm-long abyssal clam in the North Atlantic Ocean suggested that it might live 100 years but the error bars on that estimate were so broad that the life span might be only 10 years. Nor was there much information about how far individual animals moved around over the course of their lives or how many other species they interacted with. As to interactions between water-column and benthic biota, animals such as scavenging arthropods that fed at bait on the seafloor could also be caught 1 km above in the water column. However, the intensity of such interactions and exchanges and their importance to the community were not well understood. Food-chain relationships were also poorly understood but there were predators living in the sediment and benthopelagic species using benthic biota as a food source. For example, some arthropods fed on infauna polychaetes and some rat-tails had sediment in their guts. There was a feeling that deep-sea ecology was very sensitive but not enough was known to make firm predictions.

Likening the situation of seabed mining to that on land, a participant remarked that one might have to wait until a new forest grew before learning how long a destroyed forest community would take to recover. In the case of the seabed, it might take a million years to recover the original community if all the manganese nodules were removed.

Smith replied that that was certainly true for the nodule fauna, which were probably the most poorly studied of the seafloor biota. Citing doctoral work on nodule fauna by Mullineaux at Scripps Institution of Oceanography (University of California, San Diego)[27], he said there was preliminary evidence that nodule fauna might be more widely distributed than sediment fauna. The investigator had found what looked like much the same animal communities on nodules about 4000-5000 miles apart in the Central Pacific Ocean and the CCFZ. This matter was worth investigating in more detail.

Another participant thought the size and shape of the nodules made a difference. Nodules in the South Pacific Ocean looked quite different from those in the CCFZ. Bussau[28] had identified nematode species that lived only in the crevices of nodules and not in the sediment. After mining, these animals would have lost their living space.

Scope of environmental research

A participant commented that, whereas most environmental impact research was concerned with such issues as before-and-after assessment, Smith was raising strategic questions such as species range and dose response. As these were not questions to be answered by typical environmental impact assessment approaches, there would be a need for longer-term research programmes to deal with strategic matters. Agreeing, Smith favoured a pooling of resources by contractors with a view to studying the sorts of issues he had mentioned that were difficult to resolve. A distinction should be drawn between baseline monitoring to be carried out at every site and sampling or dose-response studies at a single site whose results could be generalized. Topics such as species range – how broadly species were distributed – required sampling at a number of sites and should be integrated into each baseline study.

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Chapter 3 Current State of Knowledge of Deep-Sea Ecosystems, Proposed Technologies for Polymetallic Nodule Mining and Expected Impacts From Mining Tests During Exploration

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1. General Considerations

1.1. Environmental impacts of nodule mining

Seafloor mining of polymetallic nodules has the potential to impact vast areas of the deep-sea ecosystem [1] The nodule resources occur in deep oceanic waters (greater than 4000 metres) far removed from the continents (i.e., beyond major influence of coastal productivity and terrigenous sedimentation); thus, they are found in some of the least studied habitats in the biosphere. Current claims under the jurisdiction of the International Seabed Authority (ISA) include vast abyssal tracts in the North Pacific Ocean within the Clipperton-Clarion Fracture Zone (CCFZ) as well as in the north central Indian Ocean[2] If a substantial portion of the claim areas in the Pacific and Indian Oceans are one day exploited, nodule mining could yield one of the largest areal impacts for a single type of commercial activity on the face of the earth.

The main environmental impacts of nodule mining are expected at the seafloor, with less intense and persistent effects in the water column.[3] Major potential impacts include:

i. Removal of surface sediments, polymetallic nodules and associated biota from multiple patches tens to hundreds of square kilometres in area. Seabed sediments remaining in these patches will be compressed and broken up by passage of the mining vehicle.

ii. Creation of a massive near-bottom sediment plume as a consequence of nodule removal. Sediment in the plume will redeposit on the surrounding seafloor, burying the sediment/water interface and biota under sediment blankets ranging in thickness from a few grains to several centimetres. A diffuse plume will persist in the benthic boundary layer for weeks to months, potentially travelling hundreds of kilometres.[4]

iii. In the surface ocean, release of bottom water entrained with lifted nodules, as well as sediments and nodule fragments, may enhance nutrient and heavy-metal concentrations, and reduce light levels; these alterations may affect, among other things, rates of primary production, food-web dynamics and survival of larval fish in oceanic surface waters. Settling of sediments and nodule fragments from this discharge into the oxygen-minimum zone may lead to the release of heavy metals.

iv. The discharge of tailings from nodule processing will (by future ISA regulations) occur in the deep ocean below the oxygen-minimum zone (i.e., typically below a depth of 1200 m). Once again, a large sediment plume will be formed, altering suspended particle concentrations, potentially influencing mid-water food webs and yielding sediment redeposit ion on the underlying seafloor.[5]

Following several decades of nonexclusive prospecting for polymetallic nodules at the abyssal seafloor, mining claimants are now entering the exploration stage of nodule mining. In accordance with regulations developed by ISA[6] (discussed in chapter 1 above), exploration is the

> "searching for deposits of polymetallic nodules in the Area with exclusive rights, the analysis of such deposits, the testing of collecting systems and equipment, processing facilities and transportation systems, and the carrying out of studies of the environmental, technical, economic, commercial and other appropriate factors that must be taken into account in exploitation" (regulation 1.3(b)).

Exploration can occur only after approval by ISA of an application from the potential contractor explaining, among other things, (1) a plan of work, (2) what baseline studies will be conducted and (3) a preliminary assessment of possible environmental impacts of the proposed exploration activities. The plan of work for exploration will be for 15 years, and may be extended for an additional 5 years. The size of exploration areas will not exceed 150,000 km^2, i.e., an area equivalent to a square of 387 km on a side. Exploration contractors will be required to report annually in writing to ISA on the results of their monitoring programme, including submission of monitoring data and related information. In addition to baseline monitoring, contractors will be required to generate an environmental impact assessment for all aspects of test mining and then to monitor the environmental impacts of any mining tests.

1.2. Gaps in knowledge of deep-sea ecosystems

Although a number of scientific environmental studies have been conducted in the claim areas in the North Pacific and Indian Oceans, numerous important ecological aspects of these abyssal habitats remain very poorly understood. Poorly understood characteristics include:

i. Community structure, at the species level, of dominant faunal elements at the seafloor, in particular the macrofauna (animals less than 2 cm and >250 microns in smallest dimension) and meiofauna (animals <250 µm and >42 µm in smallest dimension). Species-level structure is poorly known because of the shortage of taxonomic experts to identify the deep-sea fauna and because most species collected in the nodule provinces are new to science (they have not been formally described in the scientific literature).

ii. Geographical ranges of the dominant macrofaunal and meiofaunal species likely to be impacted (and potentially exterminated) by nodule mining. Without knowledge of the ranges of dominant species living in the claim areas, it is impossible to realistically predict the likelihood of extinction from large-scale habitat disturbance such as that resulting from nodule mining.

iii. Resistance and resilience (i.e., recovery times) of seafloor communities to nodule-mining disturbance. Although a number of simulated impact studies have been conducted[7] they have not reproduced the full scale and intensity of actual mining disturbances, and have been forced to work with relatively low levels of sampling replication.

1.3. Importance of standardization

Because of the great financial and logistical difficulties of studying the deep ocean, the broad geographical scales of potential mining impacts and the limited nature of the deep-sea ecological database, it is critical that environmental studies of nodule-mining impacts should collect and report data using standardized approaches. This will allow comparison of baseline and impact assessments from contractors from a variety of countries, working in far-flung claim areas and at disparate times. It should facilitate development of a broad synthetic view of open-ocean ecology and nodule-mining impacts, which will aid substantially in sound management of the environmental impacts of commercial mining.

It is worth noting that similar standardization concerns have been addressed in all large-scale international oceanographic research programs such as the Joint Global Ocean Flux Study (JGOFS) and the World Ocean Circulation Experiment (WOCE). In these programmes, common sampling, sample-processing and data-reporting protocols have been adopted, and intercalibration studies have been conducted to ensure standardization[8] .

Thus, while standardization issues for the collection of environmental data may appear mundane, their resolution is essential to international cooperation and collaboration, and to obtaining a broad synthetic view of the potential environmental impacts of seafloor nodule mining.

1.4. Levels of technology

Acquisition of oceanographic data has often been limited by technology, with major breakthroughs in understanding following technological innovations. Examples include: (1) recognition of the prevalence and speed of carrion scavenging at the deep-sea floor following development of the "monster camera"[9] (2) the discovery of extraordinary deep-sea species diversity after development of the epibenthic sled[10] (3) enhanced appreciation of the importance of fronts, eddies, and other meso- and synoptic-scale oceanographic features to phytoplankton blooms and fishery exploitation following developments in remote sensing (e.g., satellite imagery). Thus, in conducting environmental studies for nodule exploration, there is strong motivation to use the best available technology to collect the highest quality data.

However, for scientific endeavours (e.g., baseline studies) that may collect data over many years, it may be counterproductive (and unnecessarily expensive) to upgrade data-collection technologies at every opportunity. Given acceptable data quality, use of a single sampling technology allows comparison of data patterns over long periods[11] Thus, careful thought must be given before upgrading sampling technology in the middle of an environmental study (e.g., baseline monitoring by a single contractor) or within the framework of series of studies (e.g., baseline monitoring of widely separated claim areas) for which a broad synthesis in space and time is desired. Once standards for environmental studies are adopted, any desired changes (e.g., in sampling apparatus) should be reviewed by scientific experts to determine how such changes will influence comparisons with existing data sets.

Thus far, baseline and impact studies for polymetallic nodule mining have not been conducted using standardized approaches. Thus, in general I recommend adoption of state-of-art technology for use in environmental studies during the exploration phase of mining.

2. Baseline-Data Requirements by Sector

During and after the ISA workshop in Sanya, China in June 1998 to discuss “deep-sea polymetallic nodule exploration: development of environmental guidelines”, a number of guidelines for baseline-data collection were formulated. These recommended guidelines were categorized as pertaining to:

- Physical oceanography,
- Chemical oceanography,
- Sediment properties,
- Biological communities,
- Bioturbation and
- Sedimentation.

The recommended guidelines, and papers and discussions explaining their rationale, are presented in the published proceedings of the Workshop[12] Revised and abbreviated recommendations, together with some explanations, were later prepared by the Legal and Technical Commission (LTC) of ISA[13] (discussed in chapter 2 above). In this section, I quote the requirements set out in the LTC document, outline the more detailed guidelines recommended by the Sanya Workshop and offer suggestions (*in italics*) where additional specifications appear warranted. In section 3 following, I discuss major remaining issues for baseline-data collection, including frequency and duration of baseline monitoring, taxonomic standardization and the general requirements of an environmental database.

2.1. Physical oceanography

The LTC recommendations for physical oceanographic baseline-data collection are as follows (paragraph 8(a)):

> "(i) Collect information on the oceanographic condition along the entire water column, including the current, temperature and turbidity regimes above the seafloor;
>
> (ii) Adapt the current measurement programme to the topography and regional hydrodynamic activity in the upper water column and on the sea surface;
>
> (iii) Measure the currents and particulate matters at the depth of the forecasted discharge during the testing of collecting systems and equipment;
>
> (iv) Measure the particulate distribution to record particulate concentration along the water column".

To meet these requirements, the following guidelines were recommended by the Sanya Workshop:

To characterize the physical regime, a minimum of four current-meter moorings are required, with at least one (the "long mooring") reaching pycnocline depths (i.e., 50- 100 m). Scales of separation of current-meter moorings should be of the order of 50-100 km. The long mooring should contain at least eight current meters (including one within the pycnocline and one at the forecasted discharge depth) and each of the remaining moorings should have at least six meters. Each mooring should have a current meter at the following altitudes above the seafloor: 1-3, 5, 15, 50 and 200 m, and 1.2-2 times the height of the highest topographic element in the claim area. In addition, each mooring should include a transmissometer. *Three of the transmissometers should be deployed at*

50-m altitude (i.e., within the bottom boundary layer) and one at the forecasted discharge depth.

In addition, conductivity-temperature-depth (CTD) profiles and sections should be obtained from the sea surface to the seafloor, to characterize the stratification of the entire water column. Satellite-data analysis is also recommended for understanding synoptic-scale surface activity in the claim area.

The duration of current-meter mooring deployments, and the frequency and duration of CTD profiling and satellite-data analyses, need to be specified. These will depend on the time scales of processes and variability deemed relevant to establishing baseline conditions, which could include variability associated with seasonal changes, interannual changes such as El Niño and La Niña, and interdecadal oscillations such as climate regime shifts[14] *. In addition, the types of satellite-data analyses (e.g., ocean colour from the Sea-viewing Wide Field-of-view Sensor [SeaWIFS] project, sea surface temperature) must be specified.*

2.2. Chemical oceanography

The LTC recommendation for chemical oceanographic baseline-data collection is as follows (paragraph 8(b)):

> "collect information on the water column chemistry, including the water overlaying the nodules."

To meet these chemical requirements, the following guidelines were recommended by the Sanya Workshop:

To characterize processes of chemical exchange between the sediment and water column, dissolved oxygen concentrations, concentrations of nutrients including nitrate, nitrite, phosphate and silicate, as well as total organic carbon (TOC) should be measured in the "water overlying nodules". *Presumably, "water overlying nodules" means water in the benthic boundary layer and these parameters can be measured from CTD rosette samples.*

To characterize water-column chemistry, vertical profiles of the concentrations of dissolved oxygen, nutrients (including nitrate, nitrite, phosphate and silicate) and TOC are required, as well as temperature and salinity profiles. These measurements should address temporal variability and "transect physical oceanographic structures". *As in the case of the physical oceanography measurements, frequency and duration need to be specified. In addition, some important depths for chemical measurements need to be delineated, e.g. within the oxygen-minimum zone and around the depth of forecasted discharge.*

2.3. Sediment properties

The LTC recommendations for sediment-property baseline data are as follows (paragraph 8(c)):

> "determine the basic properties of the sediment, including measurement of soil mechanics, to adequately characterize the surficial sediment deposits and the potential source of deep-water plume; sample the sediment taking into account the variability of the sediment distribution".

The Sanya Workshop recommended the following guidelines to meet these requirements:

At no fewer than four stations, these sediment properties should be measured: water content, specific gravity, bulk density, shear strength, grain size and the sediment depth of change from oxic to suboxic conditions. In addition, sediment profiles of organic and inorganic carbon, and pore-water profiles of phosphate, nitrate, silicate, alkalinity and the "redox system" should be measured to at least 20 centimetres or to below the sub-oxic layer, whichever is deeper. Measurements of the "geochemistry of pore water" down to at least 20 cm, or below the sub-oxic layer (whichever is deeper), are also recommended.

The distribution of these measurements in space and time needs to be specified, as does the type of grain-size analysis. For modelling suspended sediment dispersion and redeposition, grain-size analyses of natural sediments are much more useful than analyses of disaggregated sediments (i.e., sediments dispersed by treatment with H_2O_2 to remove organic matter, and sonication). In addition, the term "geochemistry of pore water" is so vague that it is not clear which geochemical parameters should be measured (most likely pore-water concentrations of Fe, Mn, SO_4, H_2S and other redox-sensitive substances important in microbial metabolism).

2.4. Biological communities

The LTC recommendations for baseline studies of biological communities are as follows (paragraph 8(d)):

> “(i) Gather data on biological communities, taking samples representative of the variability of bottom topography, sediment characteristics, and abundance and types of nodules;
>
> (ii) Collect data on the seafloor communities specifically relating to megafauna, macrofauna, meiofauna, microbial biomass, nodule fauna and demersal scavengers;
>
> (iii) Assess benthic, benthopelagic, meso- and bathypelagic communities;
>
> (iv) Record levels of trace metals found in dominant species;
>
> (v) Record sightings of marine mammals, identifying the relevant species and behaviour;
>
> (vi) Establish at least one station to evaluate temporal variations”.

The Sanya Workshop recommended detailed guidelines for baseline studies of the seafloor community and the pelagic community. These are summarized and discussed below.

2.4.1. Seafloor community

For the seafloor community, it is recommended that baseline biological monitoring include a minimum of four stations (i.e., study sites) in each claim area, with at least one station surveyed annually for at least three years (to evaluate interannual variability). At each station, sampling should be randomised, with key environmental factors such as nodule coverage, topographic relief and depth incorporated into the sampling design. A number of more specific recommendations are then made with reference to seven biological categories: (1) megafauna, (2) macrofauna, (3) meiofauna, (4) microbial biomass, (5) nodule fauna, (6) demersal scavengers, and (7) trace metals in bentho-, meso- and bathypelagic organisms.

2.4.1.1. Megafauna

Megafaunal abundance, biomass, species structure and diversity are to be evaluated using at least five randomly oriented photographic transects per study site, with each transect at least 1 km long. Individual photographs should view an area about 2m wide, and be able to resolve organisms >2 cm in smallest dimension. The photographic transects should also be used to evaluate the abundance and size distribution of nodules and surface-sediment structure. *Protocols for quantifying the megafaunal parameters should be specified, for example by citing a published study whose methods are to be used.*

In addition, to characterize large areas of the seafloor within the claim area, megafaunal surveys should be undertaken within a randomised-block design. It is recommended that a "deep-towed photographic system with side-scan sonar travelling about 3 m above the seafloor be used to give a general idea of the ecology of the region". Megafauna, organism traces and surface-sediment structure should be recorded in these surveys. *The number of blocks and the number and length of surveys per block need to be specified. For example, it might be suggested that each claim area be divided into 20 blocks (yielding 7500 km^2 per block for a 150,000 km^2 claim area), and then at least three surveys, each at least 5 km long, be conducted at random locations within each block. This type of survey is likely to be compatible with exploration for nodule resources.*

2.4.1.2. Macrofauna

Macrofaunal abundance, species structure, biomass, diversity and depth distribution (suggested depths of 0-1, 1-5 and 5-10 cm) are to be based on at least ten box-core samples (each 0.25 m^2 in area) per study area. Cores should be randomly distributed within each study area, and samples gently processed on nested 500- and 250-µm sieves. *Consideration should be given to standardizing box-core deployment protocols, because box-core sample quality is very sensitive to bow-wave effects and horizontal motions over the seafloor. Some criteria concerning acceptability of a sample may be necessary (a box core with a disturbed surface is far from quantitative). I also recommend that the* *sediment/water interface of each box-core sample be photographed immediately after recovery to aid in evaluating sample quality. In addition, some standardization of sample processing (e.g., sieving before or after fixation, sorting methods) should be specified, for example by citing the methods of a particular scientific study. Finally, taxonomy (species identification) needs to be standardized within and across claim areas. (See the discussion of taxonomic standardization in section 3.2 below.)*

2.4.1.3. Meiofauna

Data on the abundance, biomass, species structure and depth distribution (suggested depths of 0-0.5, 0.5-1.0, 1-2 and 2-3 cm) of meiofauna (animals <250 µm and >32 µm) are to be obtained from ten multiple cores per study area, each tube from a separate, randomly distributed multiple-core lowering. It is recommended that meiofauna be processed on nested sieves of 1000, 500, 250 and 32 µm. *Multiple-core tube size (10-cm diameter?) and lowering protocols should be standardized or a relevant paper cited. In addition, taxonomy needs to be standardized within and across claim areas. (See the discussion of taxonomic standardization in section 3.2 below.)*

2.4.1.4. Microbial biomass

It is recommended that profiles of microbial biomass be determined using adenosine triphosphate (ATP) or other standard microbial assay for ten multiple-core tubes per study area, with each tube taken from separate, randomly located multiple-core deployment. Suggested depth intervals for profiles are 0-0.5, 0.5-1.0, 1-2, 2-3, 3-4 and 4-5 cm. *The protocols for ATP analysis need to be specified, e.g. by reference to a suitable methods paper*[15]

2.4.1.5. Nodule fauna

It is recommended that the faunal abundance and species structure associated with ten randomly selected nodules from ten box cores per study area (the same cores used for macrofauna) be sampled and analysed. *I recommend using the methods of Mullineaux (1987)*[16]

2.4.1.6. Demersal scavengers

It is recommended that a time-lapse camera be installed in the study area for at least one year to examine the physical dynamics of surface sediments, resuspension events and megafaunal activity. Baited camera systems are also recommended to characterize the mobile scavenger community. *I suggest that these studies be conducted at the site where interannual (i.e., three-year) studies are conducted. Time-lapse camera protocols should be standardized; I recommend following the procedures of either Gardner et al. (1984)[17] or Smith et al. (1994)[18]. The number and protocols of baited camera deployments should be standardized. I suggest one seven-hour baited camera drop at each of four baseline stations in the claim area using the protocols of Hessler et al. (1978)[19] or other baited camera studies discussed in Gage and Tyler (1991)[20]. It may also be desirable to use baited traps[21] to collect scavengers for identification and heavy-metal analyses (see next paragraph).*

2.4.1.7. Trace metals in bentho-, meso- and bathypelagic organisms

It is recommended that trace-metal concentrations be measured in dominant bentho-, meso- and bathypelagic species. *Much more specific recommendations are required concerning (1) which trace metals to analyse, and (2) how many individuals from how many, and what types of, species should be analysed. One possibility would be to analyse trace metals (to be specified) from at least five individuals from each of the three most dominant species collected as macrofauna, demersal scavengers, and in the meso- and bathypelagic communities.*

2.4.2. Pelagic community

For the pelagic community, guidelines for baseline monitoring recommended by the Sanya Workshop are very limited. The pelagic community is subdivided into (1) deep water, (2) surface water and (3) marine mammals.

2.4.2.1. Deep water

For deep-water communities, the Workshop stated that the “community structure of deep zooplankton and fish around the depth of the plume and in the benthic boundary layer need to be assessed”. It also recommended that “the fish community” in the upper 1500 m of the water column be assessed with depth-stratified sampling (at least three depth strata), with sampling on a diel basis and examining "temporal variability". *The design of this deep-water sampling programme needs much more specification.*

2.4.2.2. Surface water

For surface-water studies, the Workshop recommended that the plankton community in the upper 200 m be characterized in terms of phytoplankton composition, biomass and production; zooplankton composition and biomass, and bacterioplankton biomass and productivity. In addition, temporal variation in the plankton community in surface waters should be studied, including use (and validation) of remote sensing. *The surface-water studies need to be better defined in terms of parameters to be measured and sampling design in space and time.*

2.4.2.3. Marine mammals

As the final component of biological community assessment, the Workshop recommended that observations of marine mammals be made (i.e., sightings and behaviours recorded) during baseline studies, in particular during transits between stations. It also recommended that temporal variability be assessed. *These recommendations need to be more specific regarding the types of data to be recorded and how temporal variability should be assessed. I recommend that input be obtained from a marine mammalogist (e.g., Dr. Douglas DeMaster) on these points.*

2.5. Bioturbation

The requirement for baseline evaluation of bioturbation, as recommended by LTC, is as follows (paragraph 8(e)):

> "gather data of the mixing of sediment by organism[s]".

The Sanya Workshop recommended evaluation of bioturbation rates using excess Pb-210 profiles from multiple cores. Five replicate profiles per station are recommended, each from separate, randomly located multiple-core lowering. Excess Pb-210 activity should be evaluated on at least five levels per core (suggested depths 0-1, 2-3, 4-5, 6-7, 9-10 and 14-15 cm) and mixing intensities evaluated from standard advection-diffusion models. *The number of stations within the claim area at which bioturbation should* *be measured must be specified. I recommend a minimum of four stations, corresponding in number and location to those recommended for seafloor-community studies (see section 2.4.1 above). Because Pb-210 mixed layer depths appear to be shallow in the CCFZ[22], I also recommend that the depth levels within cores for Pb-210 assays be more concentrated near the sediment/water interface (i.e., at 0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.5 and 2.5-5 cm). Because of the long characteristic time scale of excess Pb-210 activity (~100 years), bioturbation intensities need to be evaluated only once at each station for baseline purposes.*

2.6. Sedimentation

The baseline requirement for evaluation of sedimentation, as recommended by LTC, is as follows (paragraph 8(f)):

> "gather data of the flux of materials from the upper-water column into the deep sea".

The Sanya Workshop recommended that two sets of sediment traps be deployed on two moorings for at least 12 months. One trap on each mooring should be at a depth of ~2000 m to characterize mid-water particle flux and one trap on each mooring should be ~500 m above the seafloor (and outside of the benthic boundary layer) to evaluate deep-particle flux. Traps should sequentially sample at no longer than one-month intervals. Traps may be deployed on the current-meter moorings. *More detailed trap protocols and the measurements to be made on the collected material must be specified. I suggest adopting the JGOFS protocols[23] for deep sediment traps, an d that variables measured include the fluxes of total mass, particulate organic carbon mass, calcium carbonate, biogenic silica and excess Pb-210 (again using JGOFS protocols).*

3. Other Issues for Baseline-Data Collection

3.1. Frequency, duration and spatial distribution

Variability in baseline conditions within claim areas can result from seasonal, interannual (e.g., El Niño, La Niña) and decadal (e.g., climatic regime shifts) phenomena.[24] It is neither feasible nor desirable to evaluate variations in all the baseline parameters on all these time scales, so certain time scales must be targeted for particular parameters. Because response times (e.g., recovery times following disturbance) are thought to be slow for abyssal seafloor communities[25] seasonal baseline studies at the seafloor are probably not warranted. In contrast, environmental processes in the surface ocean may vary substantially on a seasonal basis, altering community response to nodule-mining impacts (e.g., release of iron-rich tailings in surface waters). Environmental conditions throughout the water column may change as a consequence of decadal climatic regime shifts. Spatial variations will also occur in 150,000-km^2 claim areas as a function of bottom topography, general hydrographic regimes and even latitudinal differences.

As a starting point for discussion, I offer the following general design for baseline monitoring:

Within each claim area, four stations should be established, 50-100 km apart. Stations should be established where bottom topography and nodule cover appear to be typical of the general area on 50-100 km scales (based on data collected during the prospecting phase). Ideally, one station might be located at a random point in each of four equally sized quadrants of the claim area. Current-meter moorings would then be deployed at all four stations, with sediment traps on two of the moorings. The long mooring, with sediment traps, would be deployed for three years (and serviced once a year), while the other mooring would be deployed for one year. Physical and chemical oceanography parameters would be measured in the water column at all stations in winter and summer for two years (i.e., over two winter-summer cycles); community studies in surface waters would also be conducted on seasonal cruises. Seafloor community studies, and evaluation of sediment properties and bioturbation, should be conducted at least once at all four stations (in the first year). In addition, megafaunal, macrofaunal, meiofaunal, microbial, demersal-scavenger and sediment-pore-water parameters would be assessed once a year for two additional years at the station with the long mooring to evaluate interannual variability.

I would also recommend that the location at a study site (or station) of individual seafloor samples (e.g., box cores and multiple cores) be randomised on a one-kilometre scale to assess within-site spatial variability.

This would lead to an overall baseline environmental programme of three years, with sampling cruises at 0, 0.5, 1.0, 1.5, 2 and 3 years from the start.

3.2. Taxonomic standardization

I strongly recommend a centralized approach to taxonomic identification, in which a particular taxonomist or museum is made responsible for identifying material from all claim areas. This is essential to developing consistency among contractors in species-level identification and for establishing the geographic ranges of important (e.g., indicator) species.

One approach would be for each contractor to contribute about 50,000 United States dollars per year during the four years of baseline monitoring to a central taxonomic facility centred at a museum (e.g., the Smithsonian Institution, Washington, or the Natural History Museum, London). With five contractors, an annual budget of some $US250,000 per year would be allocated, which should be adequate to establish a broad-based taxonomic centre addressing taxonomy from meiofaunal nematodes to megafaunal holothurians. Contractors would then send sorted sample material to the taxonomy centre for identification, establishment of species ranges and species descriptions. Principal taxonomists (e.g., for polychaetes, isopods, nematodes, etc.) would establish priorities for identifying the most relevant samples in order to efficiently resolve patterns of local species diversity and biogeographic patterns. The taxonomy centre would also be responsible for mustering taxonomic expertise to handle baseline material by recruiting and training graduate students and postdoctoral scholars, including scientists from the countries of contractors. Ultimately, such a taxonomy centre could provide the multiple services of consistent taxonomic identification, description of key species, resolution of biogeographic patterns and training of an international cadre of young taxonomists (of whom there is a great shortage worldwide).

3.3. Requirements of an environmental database

The requirements of an environmental database require some discussion because several factors must be considered in its design. These include the following:

i. The nature of existing data to be entered. Substantial amounts of environmental physical, chemical and biological data have already been collected in the areas currently of interest for exploration contracts. These data have been collected according to a variety of standards. Nonetheless, they may be very useful to the design of baseline and monitoring programmes conducted during exploration.

ii. The general manner in which data are likely to be searched or accessed, i.e., the categories of identifiers to be associated with each datum. Important reference categories will include:

- General data type (i.e., physical, chemical, biological, satellite, cruise log, etc.), with nested specific parameters (e.g., oxygen concentration in the water column, macrofaunal abundance in individual box cores, etc.);
- Geographic location (latitude and longitude);
- Date of collection;
- Contractor's name;
- Claim area;
- Cruise number (an alphanumeric code identifying both ship and voyage);
- Station number (e.g., an alphanumeric code identifying contractor, ship, cruise number and cruise operation number);
- Depth in the water column.

Ideally, the database would be set up so that each datum could be searched and accessed by any combination of the above categories. For example, an investigator who wanted to view abundance of macrofauna in all box cores collected within a certain region and a certain period could search the database by inputting (1) a latitudinal and longitudinal range, and (2) a parameter name, i.e., "macrofaunal abundance". The result would be a table of macrofaunal values (macrofaunal abundances) with associated data (geographical location, date of collection, depth, etc.).

Set-up of the database will require (1) input concerning existing and future data types to be entered, (2) consideration of the most useful and preferred outputs, and (3) guidance from an experienced creator of databases.

4. Recommendations for Monitoring Mining – Test Impacts

Until the details of test-mining plans are known, it is difficult to make many recommendations regarding monitoring of mining-test impacts. Clearly, parameters and methodologies used in developing environmental baselines must also be applied in test-mining impact studies to allow broad ecological comparisons. Several other general recommendations are possible:

i. An environmental baseline should be established in the test-mining area for at least two years before the tests. This will allow evaluation of pre-disturbance spatial and temporal variability.

ii. The monitoring of test mining should include deployment of current meters, transmissometers and sediment traps to evaluate the size and behaviour over time of the sediment plume both within the benthic boundary layer and at the level of tailings discharge.

iii. Resedimentation thicknesses must be measured using multiple techniques and mapped to allow evaluation of dose-response patterns of various components of the benthic biota. The frequency and intensity of individual deposition events should also be evaluated.

iv. The sampling design for biological communities should include (a) sample collection from at least five points along the redeposition gradient and (b) sampling in at least two control (i.e., unimpacted) areas for the duration of the impact study.

v. Seafloor communities along the deposition gradient, as well as in control areas, should be sampled at least at the following approximate intervals after disturbance: <1 month, 6 months, 2 years, 4 years and 8 years. After 8 years, community recovery should be evaluated to determine whether sampling over longer periods (e.g. 16 years) is necessary to evaluate time scales of recovery following the mining disturbance.

PRESENTATION ON DEEP-SEA ECOSYSTEM KNOWLEDGE AND MINING –TEST IMPACTS

Dr. Smith began his presentation by stating that he would concentrate on current knowledge of deep-sea ecosystems with special reference to the so-called nodule province or nodule mining areas, while dealing briefly with nodule mining technologies and discussing critical information needed to predict mining impacts.

Past and current syntheses of the potential impacts of mining suggested that seafloor ecosystems in particular would be most seriously threatened by nodule mining, for which reason they must be a major focus of any environmental baseline monitoring and impact assessment. In light of the long history of seafloor studies, in nodule mining areas as well as the deep sea in general, and because many contractors would be collecting environmental data, there was a great need for standardization so that inter-comparisons could be made and a broader synthesis obtained about the natural state of deep-sea ecosystems and potential mining impacts.

In discussing the current understanding of deep-sea ecosystems, Smith focussed on the Clipperton-Clarion Fracture Zone (CCFZ) in the Pacific Ocean, observing that many of the general ecological insights gained there might also apply to the Indian Ocean, although there would be differences. The area of maximum commercial interest in the CCFZ was a large swath from about 6-20 degrees north latitude and about 110- 180? west longitude -- a significant part of the North Pacific.

He elaborated on six general characteristics of deep-sea ecosystems: (1) extremely low productivity, especially in the CCFZ, caused by low flux of particulate organic carbon (POC), resulting in low standing crops and biological rates; (2) low physical energy, though this element was somewhat controversial for the CCFZ; (3) high species diversity; (4) the large and continuous nature of the habitat, although there were gradients and patchiness that must be considered in any environmental monitoring programme and standards; (5) temporal variability, with productivity patterns changing on a variety of time scales, and (6) the poorly understood nature of the ecology.

Low productivity

In general, the CCFZ was an area of low phytoplankton standing stock and relatively low productivity. Since the bulk of the organic matter that supplied the benthos with energy sank from the surface waters, the relatively low productivity at the surface translated to low POC flux and low productivity at the seafloor. This was one of the most important environmental parameters controlling the biology of the deep-ocean floor.

Smith cited data collected along an equatorial Pacific (EqPac) transect examined by the Joint Global Ocean Flux Study (JGOFS), an international programme studying fluxes in the ocean. On its north side, the transect extended into the CCFZ. At 9? N, at the southern border of the CCFZ, sediment traps more than 700 metres above the seafloor recorded about 0.1 millimole of carbon per square metre per day, a relatively low flux that translated to about 3 grams per year. This was about 1/7th of the flux of equatorial upwelling in the middle of the Pacific or about 1/30th of the flux reaching the deep-sea floor on the continental margins, for example off California. Interestingly, the flux was only a little higher than that measured north of Hawaii in a supposedly oligotrophic area. As far as Smith knew, this was the only site in all of the CCFZ that had long-term particulate organic flux data to the seafloor.

A consequence of the low POC flux in the CCFZ was that a number of biological rates were also low, among them respiration. Measurements of respiration rate of organic carbon per square metre at the seafloor were roughly comparable to the POC flux, demonstrating again that this was an area of low metabolic activity.

The low POC flux apparently also resulted in a very small body size of animals. At selected CCFZ sites, the mean body size of benthos macrofauna was between 0.07 and 0.4 milligram per individual, very small compared to continental slope and shallow water sites. The small size of animals in the deep sea, particularly in the CCFZ, had consequences for their fragility -- how easily they might be damaged by nodule mining, for example.

Another consequence of the low flux was that the number of animals in any particular size class was quite low compared to such areas as the equatorial Pacific. Data on macrofauna from both the North Atlantic and North Pacific oceans showed a linear relationship between POC flux and biomass or abundance. Moreover, temporal variations in the flux of organic matter at the seafloor were also broadly correlated with changes in the abundance and biomass of animals on the seafloor. Megafauna showed a similar pattern, and similar figures could be constructed for the bacteria and Archaea living on the sediments.

Most of the seabed macrofauna in the CCFZ were deposit feeders -- animals that fed on organic matter sinking to the seafloor, ingesting it along with sediment particles. The vast bulk of animals in the CCFZ in the macrofaunal size class were surface-deposit feeders, focusing their foraging at the sediment/water interface on material recently settled to the seafloor. Another subset of the macrofauna, subsurface-deposit feeders that ingested sediments below the sediment/water interface, were relatively rare compared to other sedimentary environments.

Deposit feeders in the deep sea were particle selective, as demonstrated by a variety of particle-associated tracers, for example chlorophyll *a* or radionucleides such as Th-234. They fed on recently deposited particles – presumably organically rich particles such as phytoplankton detritus -- that had settled to the seafloor within the previous 100 days or so. Because they needed to feed on recently arrived material, any dilution of such food, for example by sediments resuspended from the seafloor during mining, was likely to have a major deleterious impact on their ability to feed and to grow.

Another consequence of lower POC flux, in addition to low respiration rates and biomass, was the fact that bioturbation occurred at a low rate. Radiotracer profiles to examine the rates at which sediments were stirred by animal activity indicated that at 9? N, at the northern end of the EqPac transect, bioturbation rates for Pb-210 were roughly one order of magnitude lower than at 5? N, a short distance to the south, where productivity and flux rates were substantially higher. The low rates at which sediments were mixed had consequences for the rate at which redeposited material might be integrated into the sediment column.

In addition to the basic mixing rates, the penetration depths of particle-associated radiotracers were also low. One important parameter for modelling chemical distribution in sediments and the fate of redeposited material on the seafloor was the depth at which animals were mixing with sediment. Once again, as in abundance and biomass, mixed layer depth was strongly correlated with POC flux. Data correlating POC flux to the Pb-210 depth in sediment showed that, in the CCFZ, mixed layer depths were shallow -- only about 2 centimetres -- consistent with a low energy and biomass regime.

Growth and recolonisation rates of animals in the deep sea in general, and by inference in the CCFZ, were also low. One could only speculate on the rates of recolonisation following a large-scale disturbance in the deep sea. This phenomenon might be studied by placing trays of azoic sediment (sediment without animals) on the seafloor, thereby mimicking the effect of a large-scale disturbance, and then examining the recolonisation rate over time. Data from such an experiment, using a tray 0.5 cm on a side, showed a slow recovery to background community conditions (abundance of animals in the surrounding sediment). The data, applying to macrofauna, were from all around the deep sea, including depths of 1000-2000 m, in areas that had higher energy flux and presumably a higher recolonisation rate than the CCFZ. Even in such productive environments, it took about eight years for the macrofauna to recolonise. The point was not that such a rate should be applicable to a mining disturbance but rather that recolonisation rates in the deep sea were slow following an intense disturbance. The same trays in shallow water might show a recovery to background conditions in a matter of weeks to a few months. Whether or not meiofauna showed the same response as macrofauna, the fact remained that if a deep-sea community were severely disturbed by removing a high percentage of the fauna over a large area, recovery times would be lengthy.

It would be important to factor that conclusion into any design of impact experiments. Even though the DISCOL (Disturbance Recolonization) and JET (Japan Deep-Sea Impact Experiment) projects and others showed that the intensity of disturbance in terms of generated plume was moderate compared to what could be expected from mining, recovery times were long. Differences in communities could be expected eight years after even the moderate level of disturbance produced by DISCOL.

Turning next to the high species diversity in the CCFZ, Smith cited data on polychaete worms – a major component of macrofauna – showing that a collection of 163 individuals had yielded anywhere from about 47 to about 82 different species. Thus, on a local scale, diversity was high compared to many other ecosystems. Implied in that species diversity was a lot of genetic diversity. Another aspect of diversity that was much more controversial and difficult to estimate was how many species inhabited a given region, at each of the collection sites. A post-doctorate scholar of Smith's, Adrian Glover, using controversial techniques, had estimated the number of polychaete species in Area A of DOMES (Deep Ocean Mining Environmental Study) at between 200 and 500. Thus, there might be thousands of macrofaunal species in that single area, although nobody had a good sense of how many species occurred at any of the sites studied in the CCFZ. Without understanding levels of biodiversity, it was difficult to predict the potential for species extinctions.

Low physical energy

The deep sea in most regions was also regarded as having low levels of physical energy. With slight currents producing low amounts of sediment transport, most of the structure was considered to be formed either by animals -- biogenic structures such as worm tubes -- or by manganese nodules. When pairs of time-lapse photographs were taken between 124 and 202 days apart at three sites within the nodule province, the earlier and later photos in each pair looked much alike. Sediment structures had changed little, suggesting that on roughly one-year time scales there was little remobilisation of sediment and that biogenic structure was a primary source of animal habitat.

Photographs from another site in the nodule province, of a large biogenic structure that was probably a worm mound, showed nodules sitting high up on the sediment – evidence viewed to mean that the animals rarely experienced resuspension events. As nodules grew at rates of roughly 1 millimetre per million years and were denser than the sediment, if resuspension events were occurring one would expect the nodules to be buried. Nevertheless, the concept of low energy and high physical stability of the seafloor in the nodule provinces was somewhat controversial at this point, because some current meter and sedimentological data, particularly from the eastern CCFZ, suggested that, at least on geological time scales and possibly even annually, resuspension and sediment transport events might be occurring.

The issue was important because, if the community was stable and never experienced resuspension over long periods -- years, decades or centuries -- then resuspension resulting from mining was likely to have significant ecological impact. On the other hand, if resuspension and redeposition were routine in major areas of the nodule province, the animals in those habitats were likely to be pre-adapted to dealing with some of the disturbances that might result from mining. In summary, most deep-sea biologists viewed the CCFZ as stable but there might be some recent evidence to the contrary in portions of the nodule province.

Geographical variation

Speaking next of the large, continuous nature of the CCFZ habitat, Smith observed that, while many people thought of the deep sea as relatively uniform, there were gradients, both longitudinally and latitudinally. One way to observe such gradients was to look at the abundance of animals on the seafloor. As noted above, the abundance of animals was generally correlated with POC flux in the deep sea, so that macrofaunal abundance in particular could be used to say something about the POC flux regime.

Looking at data on animal abundance at a number of stations in the CCFZ, moving from Echo 1 in the east to DOMES A in the west, he noted a change by roughly a factor of four in regard to macrofauna: 64 animals per square metre in the west and up to 260 animals in the east. This implied differences in a variety of environmental characteristics, particularly POC flux to the seafloor. Moving to the EqPac station at 9° N in the eastern CCFZ also showed a four- to fivefold change in abundance. In addition to those longitudinal changes, moving just four degrees from north to south into the zone influenced by equatorial upwelling demonstrated a sixfold change in abundance from EqPac 9° N to EqPac 5° N. So there clearly were gradients in the abundance of animals as one moved through the CCFZ, and presumably also in a number of environmentally important factors such as POC flux. Other evidence showed that there was not just one continuous fauna from one end of the CCFZ to the other.

High species diversity

Smith next cited data on overlaps in species lists of polychaete fauna at various Domes A and Echo 1 sites, showing that from 5-15 percent of the species at each site were not found at other CCFZ sites. If the fauna were identical and broadly distributed throughout the zone, one could argue that mining in different areas would not cause species extinction, as long as there were some preservation reference areas in other parts of the zone. Nevertheless, levels of atomicity -- the amount of species turnover as one moved from one end of the zone to the other -- were highly controversial and difficult to assess. These areas had been poorly sampled: Domes A was represented by about 47 box-core samples and Echo 1 by something like 2 box cores. Thus, one could argue that some species were simply rare and that sufficient sampling would eventually generate the same species lists at different sites. Such an argument might be valid until more detailed or more exhaustive research had been conducted in the nodule province.

One could also make the opposite argument, that these species lists and identities were based on morphological species -- preserved animals brought into the laboratory and identified under the microscope -- whereas it was becoming increasingly evident from molecular studies that many of the populations identified as a single species based on morphology were actually multiple-species complexes. Molecular genetics based on DNA sequences showed much greater diversity and much more restricted species distribution than biologists had been led to believe from morphology-based taxonomy, so from that perspective the percentage of endemics could be much higher. Until proper studies were conducted to look at the molecular genetics of species ranges, it would not be known whether predictions of the levels of species turnover across the region were conservative or otherwise.

Temporal variability

It was increasingly evident that, on a variety of scales -- seasonal, interannual, sometimes decadal and even multidecadal -- the productivity regime in the North Pacific Ocean including the CCFZ was changing over time. As the amount of organic carbon sinking to the seafloor and the deep sea changed, community structure was also likely to vary. To understand, predict and monitor the effects of mining, those effects would have to be distinguished from natural temporal variability.

Citing data from a number of stations across the central North Pacific, from the slope off California to the North Pacific central gyre, Smith noted that the amount of oxygen respired varied over relatively short time scales, as did POC flux. There was also evidence of longer time scales of variability, including major changes on a decadal scale in the productivity of the North Pacific Ocean. North Pacific salmon catches off Alaska and Washington had shown major shifts about 1976-77 and again in 1985-86, related to long-term climatic changes and primary production of POC flux. Similar changes in productivity on decadal time scales were also likely to be impacting the CCFZ. For example, they affected the lobster fishery in Hawaii, the survivorship of monk seals and many components of the pelagic food web. While salmon offered the most elegant example, it was likely that decadal time-scale variations in the flux of POC to the seafloor in the CCFZ would result in temporal variability in the abundance and potentially the species structure of seafloor ecosystems.

Knowledge limitations

Concluding his discussion of current views about deep-sea biology, Smith cautioned that everything he had talked about was poorly understood. Little was known about deep-sea ecosystems in general and the CCFZ in particular. Even though the CCFZ had been the focus of environmental studies for decades, it was still one of the remotest parts of the seafloor; it was difficult to reach by ship and an expensive place to work in. Consequently, there was only a rudimentary understanding of how the ecosystem functioned and how it might be impacted by mining.

Mining technologies

Turning to projected seabed-mining technologies, Smith noted that they included bucket lines dragged over the seafloor by two ships, devices towed by a ship that picked up nodules and pumped them to the surface vessel, and autonomous or tethered vehicles moving on the seafloor to pick up nodules. From the standpoint of environmental impact, all such systems were likely to do two things: remove the manganese nodules -- the goal of the whole process – and remove habitat of the nodule fauna. In addition, all systems would result in removal of a relatively wide and potentially contiguous layer of 2-3 cm of sediment. As it was difficult to collect nodules without picking up sediment at the same time, surface sediments would be removed in the direct track of the mining apparatus. If nodule resources appeared to be patchy over kilometre scales, there would be much impetus to keep mining tracks relatively contiguous, so many of the resources would be left on the seafloor after mining. A third consequence of major relevance to environmental impacts was the production of tailing discharge: mining would suck up much sediment, creating a plume of resuspended sediment at the seafloor. Further, tailings would be discharged when nodules were processed by the surface vessel; presumably, most of this discharge would occur somewhere in the mid-water, below the oxygen-minimum zone. All of these processes -- the removal of seafloor sediments, the creation of a seafloor plume associated with collection, and discharge of a plume in mid-water or at the surface -- had major potential to impact biological communities.

Expected impacts from mining

According to one estimate of the scale of a single operation, for mining to be economically feasible roughly one square kilometre of seafloor had to be mined each day. Assuming 300 days of operation a year, about 300 km^2 would be mined annually by a single mining operation. If 2.5 cm of sediment were removed during mining, about 6 million m^3 of sediment per year would be resuspended from a single mining operation. Modelling of the deep-sea plume, including the area it would cover, was extremely problematic without knowledge of how it would be released from the mining head, flocculation, behaviour of particles and the settling behaviour of deep-sea sediments. One model estimated that, if the tailings were released at the surface, an instantaneous plume would cover an area of 85 by 20 km.

To give an idea of the scale of potential burial processes from resedimentation, 6 million m^3 of sediment dispersed over a broad area could bury about 6000 km^2 under 1 mm of sediment. According to current thinking, a 1-mm deposition layer might have a significant impact on the deposit-feeding biology of much of the community. Over the 20-year life of a mining operation there would be the potential to bury something like 120,000 km^2 under 1 mm, assuming that the sediment cloud was relatively widely dispersed. These numbers might be thought of as a worst-case scenario rather than a real prediction, but the potential impacts from a dispersed plume of sediment from a full-scale mining operation were large. As test mining was likely to be about one-fifth the scale of actual mining and might go on for something like three to six months, the predicted impacts from test mining had to be scaled down, but there clearly remained a chance that they would be large. Such tests would be useful from an environmental perspective, because until disturbances approaching the scale of a real mining operation were generated, i.e., until near-scale mining operations took place, there could not be a good predictive understanding of mining impacts.

What were some of the impacts that might occur from mining? First, and perhaps most significant, there was a potential for interference with surface-deposit feeding and suspension feeding, through dilution of food materials by lower quality sediment resuspended from the seafloor. Sediments 1-2 cm down in the sediment column had low food value, so that when they were resuspended and mixed with the surface layer of food material, the food resources of deposit feeders would be diluted – potentially a widespread and severe problem in a food-poor environment like the CCFZ. The second impact, intermediate in significance, was entombment and burial of small animals associated with low bioturbation rates. Disappearance rates of seafloor biogenic structures in the CCFZ suggested that these animals might be very sensitive to physical burial. If on the other hand it turned out that major areas of the CCFZ experienced resedimentation events on a more routine basis, entombment and burial might not be such a big issue. A third major impact from nodule mining, of less importance than the others, was the physical removal by the mining device of the nodules, surface sediments and animals. The community in the tracks -- the areas directly mined by the mining head -- would be severely impacted: macrofauna would be wiped out, while some of the meiofauna might go through the mining head and survive, but in general the zone mined would be heavily devastated.

What critical information was needed to predict mining impacts on both the sediment and the nodule biota? One major open question was the dose-response function for the benthic community given a single deposition event. How much sediment redeposition was required to cause a particular degree of impact, as measured in percentage of mortality? The dose-response function was important for extrapolating from small to large disturbances and for predicting the effect of a plume dispersed at the seafloor. Another major unknown was the effects of chronic disturbance. How frequently must modest deposition events -- of less than 1 mm, for example -- occur for their effects to become chronic, in other words non-independent? A one-time deposit of 1 mm of sediment might have a modest effect on the community, but with repeated monthly deposits of 1 mm at a given site, the effects might become non-independent, producing much more mortality. The nature of chronic effects was important in knowing how to manage mining: whether it should be limited to one area for a while and then be moved 10 or 100 km away in order to minimize environmental impacts. A third major gap in knowledge concerned the time scales of community recovery following various intensities of disturbance. Although there had been some clever mining impact studies, it was still not known what the recovery times might be from a major mining-like disturbance in the CCFZ. Some things were known – for example, if nodules were removed, it would take millions of years before they grew back, so that the nodule fauna there would require millions of years to recover, whereas the sediment biota would recover over much shorter periods.

Smith cited other major open issues: What were the typical latitudinal and longitudinal ranges of benthic species in the CCFZ and what were their rates and spatial scales of gene flow? In practical terms, these questions translated to how large an area could be devastated by mining without causing species extinctions. In addition, what were the natural patterns and scales of benthic community variability in space and time?

There was an increasing appreciation that productivity regimes in the open ocean varied on seasonal, interannual (e.g., El Niño) and decadal scales, including specific decadal oscillation, and they were likely to vary with global warming. A recent study showed that changes in temperature of the surface ocean altered the amount of carbon exported from it, so that even on global warming time scales there would be changes. The major challenge was to understand natural patterns of variability in time and space in these systems in order to be able to remove natural variability from any anthropogenic influences due to mining.

SUMMARY OF DISCUSSION

CCFZ variability

A participant observed that the CCFZ seemed to be a transition zone between the equatorial region and the central gyres, with characteristics of both. Oceanic productivity was generally much lower than in coastal regions but there seemed to be a gradient from exceptionally low productivity in the central gyre to areas of intermediate character.

Smith agreed that the CCFZ was an enormous zone with longitudinal and especially latitudinal gradients in POC flux and many other parameters. As one moved from east to west and from south to north, there were dramatic reductions in the rain rate of organic matter and in productivity. The latitudinal gradients were probably quite a bit steeper that the longitudinal ones, although the flux measured in the JGOFS study was similar to that measured north of Hawaii, which was supposed to be an oligotrophic site.

Recolonisation rates

Questions were raised about the idea of studying recolonisation rates by placing trays of azoic sediments onto the seabed in a patch where the native sediment had been removed. One participant thought that might work for the larger animals but might be misleading for smaller ones such as the meiofauna, because they probably came up from underneath rather than from outside, even if the trays were placed in the middle of a large patch.

Smith responded that an experiment in which the top few millimetres of sediment were removed along with all the fauna over a large area of perhaps one kilometre in diameter should give a good idea of recolonisation rates. If the area was recolonised in a week, recovery from a large-scale disturbance might be relatively fast. If it took ten years, recovery might be relatively slow. One thing that had been learned in regard to standardization and the design of monitoring and impact studies was that different components of the ecosystem would not respond in the same way and might need to be monitored with different techniques and time scales.

Tailings discharge

A question was raised about whether mining tailings were likely to be discharged at the surface or in mid-water. Smith replied that, as he understood current thinking, surface discharge should be minimized though some was inevitable. One approach, for purposes of discussion, might be that, since a big plume was being created by mining in the benthic boundary layer, the discharge should take place in the part of the environment already sullied.

Mr. Lenoble observed that for the time being there was no regulation about this problem because most regulations dealt only with exploration. Companies active in this sphere were thinking of ways to reduce surface discharge but there had been little or no testing; they would have time to do that during the 15-year exploration phase. The discharge at the surface would come not only from the sediment but also from the fine particles of manganese hydroxide produced during the transportation and manipulation of the nodules. There would in fact be another discharge, at the bottom during nodule collection, when some separation would take place between nodules and sediment to avoid raising most of the sediment to the surface, thereby reducing surface discharge. The problem at the bottom would be to try to discharge the sediment in such a way as to avoid making a big plume above the seabed and to avoid dispersion of the sediment by having the plume flatten quickly to the bottom.

Another participant commented that the discharge level was more of an environmental than an engineering issue, since a system could be designed either way. It was premature to specify the level, given the lack of environmental knowledge.

Smith agreed that a recommendation as to the location of the discharge would be premature. However, perhaps the Workshop might propose some scenarios for discharge experiments. Otherwise, if there were only one or two cases of test mining, with no recommendations about discharge depth and monitoring, there would be no opportunity to study whether the effects were severe in a particular part of the water column. More was known about the likely effects of surface water discharge, for example in terms of potential iron enrichment causing turbidity, but to really understand the effects in the mid-water, some kind of discharge would have to be tested there. There was a need for guidance regarding discharge experiments during test mining, so that there would be enough understanding to make a suggestion or regulation from an environmental perspective about where discharge should occur.

The Secretary-General said contractors would have to address the discharge issue in their environmental statement at the end of the exploration phase, when applying for exploitation. While it was premature to deal with the topic now given the lack of knowledge, it should be flagged for action close to the end of the exploration phase, when mining systems were to be tested. Some indication should be given as to how it would be dealt with then.

Chronic versus single discharge

A participant cited information from the United Kingdom Ministry of Agriculture that, in the case of dumping dredges and their effects on meiofauna, it seemed better to keep hitting the same area with small doses every so often rather than hitting one area with a huge dose all at once. However, he did not know how that related to mining. This might be another case where animals of different sizes, or perhaps different taxa, reacted differently.

Smith responded that, in contrast, many studies of shallow-water communities showed low levels of chronic disturbance to be more deleterious than one large dose, at least for macrofauna, and particularly deposit feeders and suspension feeders. The different results might be due to the animals' feeding strategies, since deposit feeders' food resources were diluted and those of suspension feeders were damaged by a sediment plume. Experimentation at the seafloor would be needed to understand this issue.

Natural resedimentation events

In connection with the threat from resuspended plumes, a geologist wondered whether studies were being conducted of the effects of naturally occurring instantaneous deposits such as the asphalt from the 1991 eruption of Mount Pinatubo (Philippines). Smith replied that natural events had been used to look at resedimentation impacts, but not in habitats ecologically analogous to areas like the CCFZ. The ecology of the oligotrophic deep sea was so different from that of shallow waters or even the continental slope that it was difficult to extrapolate results.

A biologist suggested that turbidite flows might be the nearest natural event to deep-sea mining. A paper on one such event, at least 1000 years ago on the Madeira Abyssal Plain (MAP) in the northeast Atlantic Ocean,[26] concluded that it had badly affected polychaetes but the diversity of nematodes had been reduced only slightly (see chapter 16 below). This followed a pattern seen in shallow water, that larger animals such as polychaetes were much more affected by such events than nematodes. One reason might have to do with how they fed: nematodes were suspension feeders, not surface feeders. Another explanation might concern scale: a nematode was readily picked up and placed elsewhere, just as a high wind that might blow a man over and break his skull merely moved an insect from one place to another.

Another participant noted that there had been studies of volcanic ash deposition in a shallower environment, foram distributions, turbidite flows, slumping and mass wasting. However, many such events were difficult to date because they had happened so long ago. The authors of the paper on the MAP site were unsure whether the effects they had observed were due to low production or to the historical event. Not only were these events in different environments, they also seemed like a fundamentally different kind of phenomenon because they involved burial or deposition on top, not completely rechurning the sediments. Thus, in terms of both habitat and kind of disturbance, it was hard to compare such natural phenomena with what might be expected from mining.

Economic value of seabed biota

Asked whether the life on the ocean bottom had any economic value aside from its worth as an ecosystem, Smith responded by citing biodiversity and the use of genetic diversity in biotechnology. He mentioned his collaboration with a biotechnology company from San Diego, California, that was interested in prospecting an extreme environment for unusual genes that could be used in products such as cold-water detergents. Its interest in the deep sea was due to the tremendous diversity and extreme biological conditions there, including low temperature and high pressure. The CCFZ contained great evolutionary diversity and considerable genetic resources of potential use in biotechnology. The company wanted him to collect samples wherever he went in the deep ocean, to be screened for unusual enzymes. Samples had been collected in the Antarctic and off the coast of California. A number of products had already been geared up for marketing, including a cold-adapted enzyme for use in cold-water detergents. Other enzymes were for use in pharmaceuticals and in almost any low-temperature application. The huge diversity of animals and probably of bacteria in the deep-sea sediment might have a major economic potential.

No fishes of current economic importance inhabited the deep seabed, due to the low productivity of the environment. Rat-tails were commercially fished in the slope off California at depths of 2000-3000 m, and as some of the same genera and possibly the same species were found in the CCFZ, there might be a potential to fish those. However, the biomass of fish in that region was so low – perhaps a few kilograms per square kilometre -- that they would probably never be commercially fished, and if they were, they would be quickly fished out.

Seabed biology

Responding to questions about animal life at the ocean bottom, Smith said not much was known about life spans. Data from a 7-8-mm-long abyssal clam in the North Atlantic Ocean suggested that it might live 100 years but the error bars on that estimate were so broad that the life span might be only 10 years. Nor was there much information about how far individual animals moved around over the course of their lives or how many other species they interacted with. As to interactions between water-column and benthic biota, animals such as scavenging arthropods that fed at bait on the seafloor could also be caught 1 km above in the water column. However, the intensity of such interactions and exchanges and their importance to the community were not well understood. Food-chain relationships were also poorly understood but there were predators living in the sediment and benthopelagic species using benthic biota as a food source. For example, some arthropods fed on infauna polychaetes and some rat-tails had sediment in their guts. There was a feeling that deep-sea ecology was very sensitive but not enough was known to make firm predictions.

Likening the situation of seabed mining to that on land, a participant remarked that one might have to wait until a new forest grew before learning how long a destroyed forest community would take to recover. In the case of the seabed, it might take a million years to recover the original community if all the manganese nodules were removed.

Smith replied that that was certainly true for the nodule fauna, which were probably the most poorly studied of the seafloor biota. Citing doctoral work on nodule fauna by Mullineaux at Scripps Institution of Oceanography (University of California, San Diego)[27], he said there was preliminary evidence that nodule fauna might be more widely distributed than sediment fauna. The investigator had found what looked like much the same animal communities on nodules about 4000-5000 miles apart in the Central Pacific Ocean and the CCFZ. This matter was worth investigating in more detail.

Another participant thought the size and shape of the nodules made a difference. Nodules in the South Pacific Ocean looked quite different from those in the CCFZ. Bussau[28] had identified nematode species that lived only in the crevices of nodules and not in the sediment. After mining, these animals would have lost their living space.

Scope of environmental research

A participant commented that, whereas most environmental impact research was concerned with such issues as before-and-after assessment, Smith was raising strategic questions such as species range and dose response. As these were not questions to be answered by typical environmental impact assessment approaches, there would be a need for longer-term research programmes to deal with strategic matters. Agreeing, Smith favoured a pooling of resources by contractors with a view to studying the sorts of issues he had mentioned that were difficult to resolve. A distinction should be drawn between baseline monitoring to be carried out at every site and sampling or dose-response studies at a single site whose results could be generalized. Topics such as species range – how broadly species were distributed – required sampling at a number of sites and should be integrated into each baseline study.

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PART II

Results and Standards from Previous Seabed-Mining Environmental Studies

INTRODUCTION

Before considering the standards it might recommend for future environmental studies, the Workshop looked back at how some researchers have already conducted investigations of the deep ocean. After an overview of what has been learned to date about the environmental characteristics of the Indian and Pacific Ocean areas of primary concern to explorers for manganese nodules, it heard specifics of studies undertaken by seven countries, most of them involved in contracts with the International Seabed Authority – China, France, Germany, India, Japan, the Republic of Korea and the Russian Federation.

Dr. Charles Morgan, an environmental planner with the United States firm Planning Solutions, presented a paper outlining priorities for the two types of research under consideration – baseline studies and impact analysis. He contended that the Workshop must address the critical issue of distinguishing between studies that could be completed well in advance of mining tests from those that should be carried out before and during the testing. In particular, as nobody had yet specified a precise site for mining operations, most detailed collection of baseline data should be put off until such sites were determined; otherwise, it was likely to occur at places that would never be mined, given the vast size of the exploration claim areas.

He reviewed some of the information already gathered in the zones of interest, covering the occurrence of potentially commercial deposits, sediment properties, benthic currents, the composition of benthic and demersal animal communities living on and near the seabed, climate, ocean circulation, water chemistry and the pelagic communities of the open ocean.

Regarding priorities, he suggested that, during the current exploration phase, first place be accorded to long-term studies on the resistance and resilience of seafloor communities to nodule-mining disturbances, with attention also given to the geographical ranges and community structures of the animals most likely to be impacted. In addition to special scientific projects on these topics, he suggested that researchers take opportunities to go along on exploration cruises planned by contractors, which would give them a platform for collecting biological and oceanographic data along the entire water column, from surface to seabed. He also listed a number of data-collection activities to accompany mining tests, but suggested that it would be premature to develop standards for such research now, as testing was still several years off and technologies were likely to change in the meantime.

In his oral presentation, Dr. Morgan reiterated his point that much of the contemplated environmental baseline research would be premature at this stage. Besides the fact that the precise mining location was unknown, engineers had not decided how a mining system would operate as it ploughed through the seabed sediments to pick up nodules. This made it impossible to predict the kind of sediment plume it would leave behind, and thus how and over what area the suspended particles would be redeposited – a prime culprit among expected impacts on the benthic ecosystem. Rather than trying to simulate mining and its impacts, he suggested that researchers concentrate on basic data about deep-sea life, concerning which knowledge was especially lacking.

Dr. Michael Wiedicke-Homback, a marine geologist with Bundesanstalt für Geowissenschaften und Rohstoffe (German Federal Institute for Geosciences and Natural Resources), described some of the findings gleaned from German researchers in the Peru Basin of the southern Central Pacific Ocean off the west coast of South America. Much of the data were gathered during the DISCOL (Disturbance and Recolonization) project over the past 10 to 12 years.

Concentrating on geological aspects, his paper described the three areas covered by the studies: (1) large-scale investigations such as bathymetry, topography and examination of sediment distribution, (2) sediment-specific studies of factors such as surface characteristics, composition and bioturbation, and (3) modelling and laboratory tests to predict sediment-plume behaviour during and after mining.

The paper outlined a survey and sampling strategy for a baseline study. Its four phases cover (1) surveying with acoustic methods to produce detailed maps; (2) a definition of seabed structural types, including morphology (basin, slope, ridge, plateau), sediment character (thickness, stratification, erosion) and fine-scale surface features (nodule coverage, geological fault steps); (3) sample gathering and preservation, and (4) laboratory tests and modelling.

In his oral presentation, Dr. Wiedicke described the great variety of topographic forms and sediment-distribution patterns that had been discovered in this area, and pointed out that such differences were likely to show up in the benthic communities as well. For example, a species collected from a slope might not occur elsewhere. In some places, the Quaternary Period sediments in which manganese nodules were found had been eroded away, leaving Tertiary sediments barren of nodules that had a completely different chemical composition and animal community. Isotope measurements at different sediment depths showed glacial depositions much deeper than would be expected, indicating vertical movement of sediment by bioturbation (caused by the activity of burrowing animals).

Reviewing calculations of mining impacts derived from laboratory tests and modelling, he said one group had calculated that the bottom plume produced by the mining vehicle would have only local effects. However, he said the calculations demonstrated the great need for additional parameters before the numbers could be taken seriously. Regarding the effects of tailings (mineral wastes) discarded by processing vessels, he said the calculations favoured release of this material as close to the bottom as possible to avoid extensive spreading, even onto nearby coastlines. Again, he observed that precise information on grain size was needed before reliable modelling was possible.

Dr. Huiayang Zhou, a professor of geochemistry at the Second Institute of Oceanography, Hangzhou, China, spoke of work done by the China Ocean Mineral Resources Research and Development Association (COMRA). He described two aspects of this work: environmental assessment in the Chinese exploration area of the Clarion-Clipperton Fracture Zone (CCFZ) and a mining simulation study conducted in a Chinese lake.

The monitoring programme in the Pacific, operating since 1995, was called NaVaBa, for Natural Variability of Baseline. About 50 scientists had been involved in hydrographic, biological, chemical and sedimentological assessment. Among the discoveries had been an area of mineral assemblages with temperatures above 70 degrees, possibly indicating hydrothermal activity. Interannual variability in temperature and other parameters had been recorded in the deep sea, but it was not known whether this was related to upper-water variations caused by El Niño and La Niña. This research in the Chinese area was continuing in 2001.

The lake tests of mining equipment were known as EISET (Environmental Impact studies and Equipment Tests). Chinese engineers had tested a small manganese nodule collector in a lake 120 metres deep, partly to learn the behaviour of the sediment plume raised by the miner. This was a three-stage programme, comprising baseline monitoring before the test, monitoring during the test and follow-up monitoring to observe recovery of the ecosystem. The observation equipment used was similar to that employed in marine investigations. However, China had no plans to extend this test to the deep sea.

In the discussion, a question arose as to whether China planned to submit its environmental data to the International Seabed Authority. The Secretary-General and the moderator, Craig Smith, mentioned the importance of obtaining data from the various seabed contractors to allow for comparisons, from which everyone would benefit.

Professor M. Ravindran, Director of the National Institute of Ocean Technology, an agency of the Government of India, reviewed the environmental studies conducted at the only exploration site registered by the Seabed Authority in the Indian Ocean, about 2000 kilometres south of India. He also described Indian plans to develop a nodule-collecting vehicle.

In 1997, India had created a disturbance on the deep seabed by pumping up sediment to simulate some of the effects of mining. Known as INDEX (Indian Deep-sea Environmental Experiment), this effort, begun in 1995 with baseline studies, involved more than 55 cruises, mainly on an Indian research vessel and two others leased from the Russian Federation. More than 200 tons of nodule samples had been collected from 1900 locations. Postdisturbance measurements would continue until 2005. Ravindran listed many of the instruments and techniques used to measure various categories of environmental parameters.

The benthic disturbance, continuing for nine days, involved towing a 2-metre-wide mechanism along 26 tracks, with each tow about 4 kilometres long. An estimated 6000 m^3 of sediment had been thrown at least 5 m above the seabed. Photographs of the effects, taken shortly afterward, showed that the tracks and burrows of organisms had disappeared in the upper 20 centimetres of the disturbed sediment but that no redistributed sediment from the plume had been found beyond 100 m from the disturber tracks. In the disturbed area, the density of meiofauna had dropped from 250 to 50. Shear strength (a measure of the amount of weight a substance can bear) had changed only slightly in the muddy surface layer. No changes of consequence had occurred in the chemical composition of the sediment or the pore water it held.

Ravindran's conclusion was that, except for benthic biomass destruction in the tracks, the postdisturbance situation did not seem alarming. He acknowledged, however, that further studies were needed to evaluate long-term consequences, especially recovery rates.

The mining device being developed by India was a vehicle 3 metres wide that would crawl over the surface on plastic tracks. A pick-up device in front would gather the nodules, which would be lifted by a conveyer belt into a crusher. The system was designed to vibrate so that silt would not be carried into the crusher. The crushed nodules would pass into a flexible hose 10 centimetres in diameter, through which they would be pumped up to a vessel at the surface. A second umbilical connection would carry power and communication cables. Though tethered to the surface vessel, the crawler would move about independently on the seabed.

A prototype vehicle had already been tested at 410 m, and a redesigned model would be tested in a hyperbaric chamber before being lowered to a depth of 6000 m in 2002. Once the final specifications were worked out, an actual crawler would be fabricated after 2004. India expected to conduct the nodule mining experiment in 2007-08.

Workshop participants questioned Ravindran about the design elements of India's test miner. He explained that the riser pipe would be flexible, unlike the rigid versions used in other designs, to keep costs down and permit the pipe to be coiled on deck when not in use. The electromechanical cable would be separate to provide redundancy. The hoses would be strong enough so that they could be used to lift the crawler from the bottom if its power failed.

Ravindran described the miner as an environmentally friendly collector, compared to earlier systems developed by others. One participant, however, said it had to be accepted that every mining system would have an unavoidable impact on the environment. The Secretary-General commented that, in contrast to earlier designs that had ignored the environment, a conscious effort was now being made by designers to take environmental consequences into account.

Messrs. Takaaki Matsui and Tomohiko Fukushima, chief scientists of the Deep Ocean Resources Development Co. Ltd. of Japan, outlined deep-sea environmental studies by DORD and the Metal Mining Agency of Japan beginning in 1989, including the Japan Deep-Sea Impact Experiment (JET) in the Central Pacific Ocean. They described the three phases of this study, covering (1) baseline conditions, to understand the natural environment; (2) impact assessment, to understand the effects of mining at a particular site, and (3) impact prediction, concerned with harmful effects that might result from large-scale mining.

Studies of the upper ocean layer (1989-1996) included an experiment in which cold water had been discharged into Toyama Bay off the Japanese coast, to assess the surface dispersion of a mining discharge. Related experiments measured the effects of introducing deep-sea water, with its high nutrient concentrations. The finding was that the abundance and composition of the phytoplankton community changed around concentrations of deep-sea water.

The benthic environmental study (JET) was centred on a seabed disturbance experiment in 1994 simulating the effect of mining. Its aim was to evaluate the magnitude of impact by estimating the redeposition thickness and comparing environmental conditions before and after impact, including comparisons with non-impact areas. Damage to benthic fauna was assessed by comparing the abundance, diversity, community structure and distribution of the fauna before and after impact, and comparing the changes in those parameters with the magnitude of impact.

The Japanese paper detailed many of the procedures used in collecting and analysing data from these experiments. Summing up, it said a significant body of knowledge had been generated, and had been disseminated to the world through international symposia and journals.

Some of the deep-sea research done by French scientists was described by Dr. Myriam Sibuet, Director of the Department of Deep-Sea Environment of the Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea). IFREMER and the Association française pour l’exploration et la recherche des nodules (French Association for Exploration and Research of Nodules, AFERNOD) have signed contracts with the Authority for exploration in parts of the CCFZ.

Dr. Sibuet expressed the view that it was too early to standardise many of the devices and procedures used for deep-sea investigations, because the understanding of this subject was still in its infancy and researchers should be given leeway in selecting the most suitable ways of conducting their studies. For example, cores had to be studied at different depth levels of sediment in order to elucidate temporal changes in the vertical distribution of fauna, but researchers were still searching for the best way to observe such changes. While a de facto international standard existed for box corers, there was no common standard for the trawls used to collect megafauna. Nor could the measurement of active microbial biomass be standardised, because scientists had not yet found the best way to make such measurements.

On this point, the moderator, Craig Smith, agreed that standardization was inappropriate for certain kinds of site-specific investigations into biological and other processes, but he saw the need for taxonomic standards and for agreement on mesh sizes for box-core processing

Describing the Biocean database developed by IFREMER, Sibuet said it was organised taxonomically, enabling users to find information about each species collected by all of the Institute's research cruises over the years. Data initially entered on board the research vessel were later inserted into Biocean for everyone to share. She spoke of the need for an ecologically organised database for impact studies in the nodule areas that would enable researchers to draw comparisons and analyse temporal changes.

She urged an international cooperative effort to organise long-term monitoring in an area by maintaining a ship that would place and service moored sediment traps and current meters. She also stressed the need for an international network of taxonomists that would help to identify animal specimens collected from the seabed. She voiced the intention of IFREMER to organise a multidisciplinary cruise within the next five years that would add to existing geological, biological and environmental information about the French exploration area.

Drs. Woong-Seo Kim and Sang-Mook Lee, senior scientists of the Korea Ocean Research and Development Institute (KORDI), outlined the equipment and procedures their organization had been using between 1991 and 2000. The Institute's programme included physical oceanographic measurements, monitoring of benthic animals, analysis of suspended materials in the water column and meteorological information gathering. In addition to environmental studies, their paper detailed techniques used to estimate the tonnage of manganese nodules, and their metal contents, in several portions of the exploration area allocated to KORDI, including areas relinquished to ISA under the system for reserving certain areas for future use by the Authority or developing countries.

Dr. Kim described methodologies used in biological studies, on such topics as species composition and abundance, biomass estimates and biological productivity, covering both zooplankton and bacteria in the water column and larger animals (macrobenthos) on the seabed. Grazing experiments were performed to examine the effects of suspended sediment, by growing copepods in solutions containing varying amounts of sediment added to the seawater. Samples were also taken for chemical analysis of seawater and the pore water found in sediment.

Dr. Lee, speaking of geological and geophysical research, described devices used for bathymetric surveys and underwater navigation. Like Dr. Wiedecke-Hombach, he stressed the complexity and variety of the deep-sea physical environment.

Commenting on the desirability of standardizing geophysical data collection, he welcomed the idea so long as care was taken to minimise the burden on researchers. He announced that KORDI had postponed further environmental work until after the final relinquishment of certain areas to the Authority in 2002.

Mr. Viatcheslav P. Melnik, major scientist of Yuzhmorgeologia (Russian Federation), described surveys carried out, most recently in 2001, aboard the Russian research vessel of the same name. These were a continuation of work between 1991 and 2000 as part of the Benthic Impact Experiment (BIE) conducted jointly by Russian and United States scientists.

The main aim of all these experiments, he reported, was to create a large disturbance of the upper sediment layer by using a mining-simulator device, and to investigate the ecosystem response to this disturbance immediately and some years afterward. In addition to chemical and physical measurements, the researchers carried out biological studies showing that, while meiofauna seemed relatively unaffected, macrofauna populations in the mining vehicle’s tracks were significantly reduced even seven years after the disturbance.

Mr. Melnik described an undersea apparatus designed by Yuzhmorgeologia, called “Neptun”, bearing photographic and video cameras and lights, and used to survey the sea bottom. Towed by a surface vessel at a speed of 1 to 1.2 knots, it automatically took pictures in a random pattern that were later digitised and placed in a photographic database.

He advocated the development of similar digitised databases holding photo and television profiles as well as images of individual animals. These data, he said, could be readily exchanged between countries and placed in an ISA repository. The animal images could also be used to identify species. One participant urged caution about the latter idea, however, expressing doubt that photographs could produce accurate identifications without the use of actual specimens.

Mr. Melnik, commenting that commercial seabed mining might be as much as 40 or 50 years off, suggested that, in the meantime, experiments should be conducted using a regular dredge to recover manganese nodules, to provide a better simulation of mining. He thought this should be done as an international project, since the effects should be assessed over a large area.

Chapter 4 Priorities for Environmental Impact Analysis of Deep-Seabed Mining

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1. Introduction

1.1. Background

The International Seabed Authority (ISA), in accordance with the United Nations Convention on the Law of the Sea signed on 10 December 1982, has established a mining code. The code regulates and guides deep-seabed exploration for polymetallic nodules containing manganese, nickel, copper, cobalt and possibly other metals, located on the seafloor in regions which are beyond national jurisdiction but subject to the Convention. These regions, termed "the Area", contain nodule deposits that have relatively high abundance and concentrations of these valuable metals, and thus represent the most likely initial targets for economic development.

One of the key responsibilities of the Authority is to ensure that the marine environment of the Area is protected from serious harm. The mining code makes the Authority responsible for developing procedures for establishing environmental baselines that can be used to assess the likely effects on the marine environment of mining activities in the Area. The Regulations of this code[1] make the collection of information for such baseline definition the responsibility of the seabed explorer, termed the "contractor". Contractors are required to use the collected data to establish environmental baselines for use in assessing the likely effects of their exploration and mining activities.

A high priority at this very early stage of development of a seabed mining industry, and the principal task of this Workshop, is the identification of clear and defensible standards to be followed in establishing these environmental baselines. Such standards, based on established scientific principles and the practical constraints of oceanographic operations are needed so that explorers can establish the environmental baselines in their exploration areas using technically sound and reproducible methods.

Key factors that must be integrated into the implementation of such standards and the collection of data are:

(1) The availability and adequacy of existing environmental data,

(2) The contractors' schedules of development and

(3) The lead times required for collection of adequate data.

This paper considers these factors in the context of the major recommendations made in Professor Smith's background paper (chapter 3 above) and the known environmental characteristics of the ocean areas that host the exploration claims of contractors. It uses these factors to suggest priorities and qualitative milestones for data collection.

1.2. Organisation of this paper

This paper is organised as follows:

- ?? Section 2 briefly summarises the anticipated phases of development for a deep-seabed mining industry and the possible links between the contractors' development schedules and the development of environmental standards.

- ?? Section 3 discusses the key environmental variables that must be assessed for adequate baseline characterisation and impact prediction.

- ?? Section 4 suggests a set of priorities for the establishment of standards and acquisition of data concerning these key environmental variables, and the required acquisition times for different types of environmental data.

- ?? Section 5 summarises the available environmental data for the Clarion-Clipperton and Indian Ocean regions of interest.

2. Phases of development of deep-seabed mining operations

No commercial deep-seabed mining operation has been developed to date, so that description of such activity is speculative. However, a variety of international groups have undertaken serious development planning for commercial seabed mining, and several consortia of private and government organisations have conducted initial at-sea testing of scaled-down components of prospective mining systems. Extensive interactions between these developers and the United States Government while completing the Deep Ocean Mining Environmental Study (DOMES) and its associated programmatic environmental impact statement (PEIS)[2] form the basis for this section. A subsequent study of deep-seabed mining[3] and the basic development phases assumed in preparation of the ISA Regulations are consistent with the general aspects of this original description.

2.1. Prospecting and exploration

"Exploration", as defined in ISA Regulation 1.3(b), consists of:

> "... searching for deposits of polymetallic nodules in the Area with exclusive rights, the analysis of such deposits, the testing of collecting systems and equipment, processing facilities and transportation systems, and the carrying out of studies of the environmental, technical, economic, commercial and other appropriate factors that must be taken into account in exploitation".

"Prospecting" is essentially the same set of activities but performed without any exclusive rights to the development of resources in the area.

Various private and public groups have been exploring for commercially viable deep-seabed manganese nodule deposits for more than 35 years. Such work is ongoing and planned for the next several years by various parties that have active exploration contracts with ISA under the provisions of the Regulations. The United States Government, in its rules regulating deep seabed mining[4], has concluded that exploration activities have no potential for significant environmental impact and will require no further environmental assessment beyond that completed for the PEIS.

The United States regulations define exploration activities as including the following:

?? Gravity and magnetometric observations and measurements;

?? Bottom and sub-bottom acoustic profiling or imaging without the use of explosives;

?? Mineral sampling of a limited nature such as that using core, grab or basket samplers;

?? Water and biotic sampling;

?? Meteorological observations and measurements, including the setting of instruments;

?? Hydrographic and oceanographic observations and measurements, including the setting of instruments;

?? Sampling by box core, small diameter core or grab sampler, to determine seabed geological or geotechnical properties;

?? Television and still photographic observation and measurements;

?? Shipboard mineral assaying and analysis; and

?? Positioning systems, including bottom transponders and surface and subsurface buoys filed in Notices to Mariners.

Exploration activities require special consideration in the context of this Workshop. This is *not* because they are expected to cause serious environmental impacts; they are not. Rather it is because they provide the opportunity to obtain valuable environmental data at relatively small expense. The activities listed above have been, and continue to be, carried out for the purposes of mineral-resource assessment. One of the most useful accomplishments that could be achieved from the development of standards in this Workshop is the guidance that these standards could provide to allow these mineral-resource assessment efforts to be expanded in scope to include the data needed to allow significant environmental resource assessment.

Another aspect of exploration activities important for this Workshop is their long history. Since the intrepid Kennecott explorers put down their first dredges in the mid-1960s to look for manganese nodule deposits in the eastern Clarion-Clipperton Fracture Zone (CCFZ), much has changed in the development of oceanographic techniques. On the one hand, these early explorers (which include not only Kennecott but many of the direct predecessors to the organisations that are currently participating as contractors) should expect to derive a significant credit in their work plans for these early efforts, which certainly obtained much useful environmental information. On the other hand, these data are probably less useful for environmental impact analysis than the data collected later using better technology and a higher appreciation for environmental values.

It is not useful in this Workshop to focus on the relative worth of contractor data already obtained. However, a major goal for this Workshop should be to provide the impetus for a comprehensive integration of such data into a useful basis for future impact analysis for all contractors.

2.2. At-sea system testing

The maximum at-sea nodule-recovery rate to date, 30 tons per hour, was achieved in March 1978 by the Ocean Management Inc. (OMI) consortium. During these system tests, OMI recovered a total of 900 metric tons. In the same year, using a different system, the Ocean Mining Associates consortium (OMA) recovered a total of 600 metric tons during an 18-hour test[5]. The United States National Oceanic and Atmospheric Administration (NOAA) monitored these tests as the principal effort of the DOMES II programme. The information collected during these activities provided key inputs to the impact analysis presented by NOAA in its PEIS. In the current 15-year plans of work submitted to ISA by the active contractors, no at-sea test mining is scheduled.

Commercial recovery rates are expected to be more than ten times the maximum rate achieved by OMI, i.e., more than 300 tons per hour. Two to five years of testing of progressively larger systems will probably be required before operation of full-scale prototype systems will be practical. During this time, important environmental impact analysis will have to be completed through monitoring of such tests. Potentially significant environmental impacts predicted through such monitoring could provide the basis for system modification to mitigate or avoid the impacts. Predictions of mining impacts will have to be based on these monitoring results, interpreted in the context of the baseline habitat characterisations established before and during mining tests.

Perhaps the most critical issues related to phasing of the required habitat characterisation are those related to distinguishing the characterisation studies that must be completed well in advance of the mining tests from those that can best be carried out immediately before and during the testing. This critical item must be addressed at this Workshop. Establishing standards for studies that might not be necessary until mining-system tests are conducted many years from now is problematic; it would be better to decide these when specific schedules for testing are submitted by contractors to the Authority.

2.3. Commercial mining

Many strategies for removing manganese nodules from the seafloor and lifting them to the ocean surface have been tested. These range from simple, towed dredges to self-propelled, highly manoeuvrable platforms with hydraulic or airlift pumping systems (e.g. figure 1). Descriptions of the concepts considered to date are presented elsewhere[6]. The expected major throughputs of materials for commercial systems are presented in *Table 1*.

Component	**Daily flux**	**Discharges**	
		Benthic*	**Surface**
Nodules (dry tons)	5,500	250	250
Sediments (dry tons)	54,000	52,000	1,000
Biota (kg)	783	760	23
Bottom water (m^3)	58,000	-	-
Interstitial water (m^3)	42,000	-	-
Total water** (m^3)	105,000	80,000	25,000

* Expected to be discharged within 20 m of seafloor.
**Includes entrained surface water.
Source: modified from NOAA[7].

Table 1 Estimated mining system throughputs.

Each of these systems is likely to produce its own particular set of environmental impacts. Hence, impact assessment will depend very much on the specific designs used. Some consideration of the scale of impacts that would be possible can be derived from table 1, but serious impact analysis cannot be completed until specific development plans are submitted to ISA.

Most important to the Workshop objectives, the specific sites for initial mining operations have not yet been specified by the contractors. Based on the predictions of NOAA scientists[8], a commercial mining system discharging into surface waters would generate a surface plume extending as much as 85 kilometres down-current and 10-20 km cross-current; a benthic boundary-layer plume is predicted to have dimensions of approximately 160 by 40 km. These would be the largest areas potentially affected by initial mining operations and would cover an area (6400 km^2) that is less than 0.5 percent of the areas currently claimed by the contractors (1.5 x 10^6 km^2). During a 20-year mining operation, a contractor would recover from an area between 2500 and 5000 km^2 in extent.

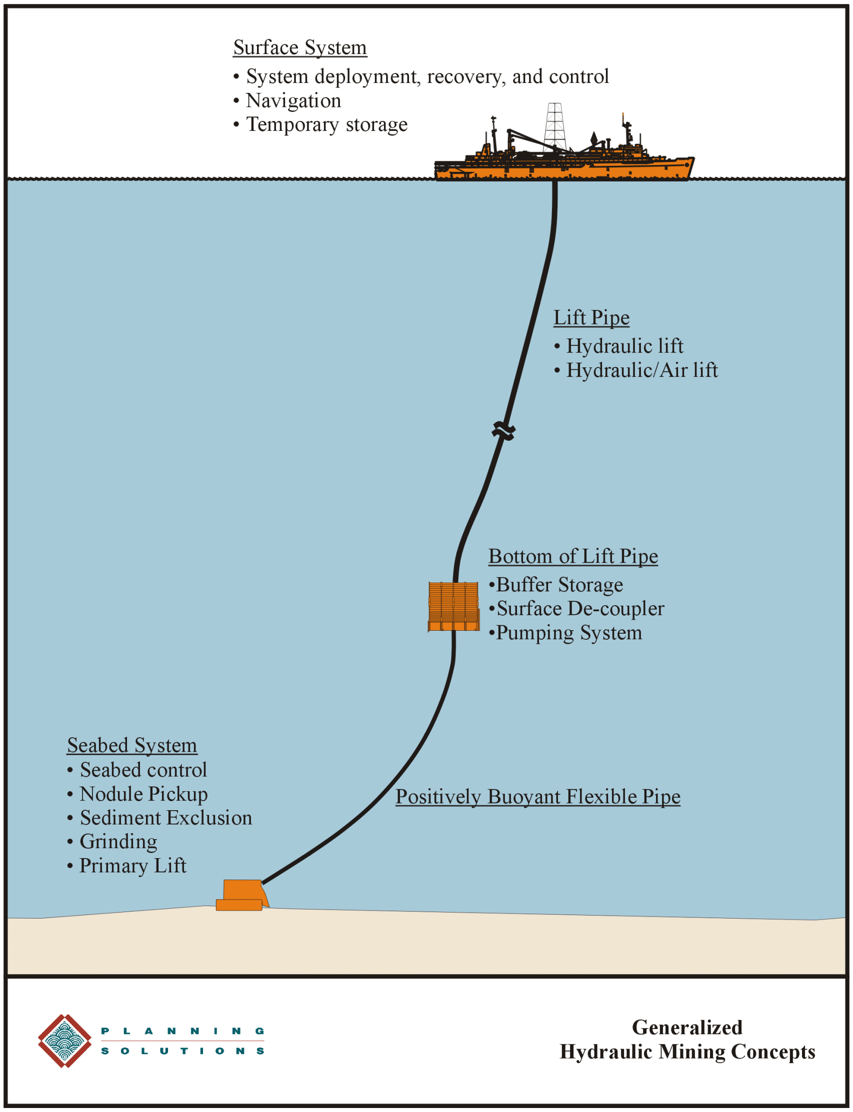

Figure 1 Hydraulic mining system components.

Because the exploration claims cover a very much greater area than would be impacted by the mining operations, any detailed baseline characterisation completed prior to the specification of the actual test and mine-site locations is not likely to be in an area where tests or mining will ever take place. Thus, baseline collection efforts undertaken before the specification of these sites should be considered only if adequate baseline characterisation cannot be established during the time between the specification of the test location and the initiation of commercial mining.

3. Key environmental variables in the claim areas

While it is true that significant acquisition of site-specific environmental data will have to be completed by contractors before commercial development can be initiated, it is also true that significant data have been collected in these areas already. Section 5 below describes the general location of the exploration claim areas and presents a more detailed discussion of the environmental data available for them. The present section focuses on how environmental data standards can help promote the efficient acquisition of some of the most important information needed for successful implementation of an undersea-mining programme.

3.1. Occurrence of potentially commercial deposits

Manganese nodules are common worldwide in both marine and freshwater systems. Conditions which particularly favour high abundance of manganese nodules with relatively high levels of copper, nickel and cobalt include: (1) relatively high inputs of dissolved and organically complexed metals; (2) relatively low levels of other types of sedimentation, such as aluminosilicates and carbonates, and (3) long-term stability of the seabed surface, allowing time for deposit accumulation.

These characteristics are best developed on the seabed under the tropical oceans in areas which have high primary productivity in surface waters, which are far from land sources of sediments and which are deep enough so that carbonate sedimentation is mostly dissolved before it accumulates. It is probably no coincidence that the highest abundances and grades of manganese nodule deposits (as evidenced by the locations of the current international exploration activity) fall in the areas of the world's oceans that are farthest from land.

Because of this remoteness, opportunities for study of these deep-sea environments are rare and the investigations are expensive.

Contractors must carefully optimise their data-collection efforts to make the best possible use of precious at-sea operations. Development of standards for data collection can help improve the quality and decrease the cost of information gathering by minimizing the collection of unusable or irrelevant data and by permitting the easy comparison of different data sets.

3.2. Sediment properties

The sediments from the Indian Ocean site and from the CCFZ consist mostly of clays and siliceous biological casts. Sands and larger sediments are not generally found so far from land, and the commonly formed carbonate biological casts dissolve on the seabed in these deep-water regions faster than they accumulate. The upper centimetre or so of the sea bottom sediments is high in water content and the chemistry of that water is very similar to that of overlying waters. Most of the benthic fauna reside in this zone.

It is important to note that much of the fine-grained material found in these sediments is probably delivered to the seabed in the form of much larger (0.1 to more than 1 millimetre) coagulated particles and faecal pellets from zooplankton and larger animals in the water column. Researchers who have had extensive experience handling material from box cores and other relatively undisturbed sediment samples from the region consistently note the surprisingly coarse-grained feel of the material before it is disaggregated for various analytical testing procedures. Thus, we can expect the in situ behaviour of the material to approximate a bimodal mixture of very fine-grained clays and much coarser aggregations of particles.

This bimodal behaviour makes it difficult to predict the dispersion characteristics of sediments disturbed by mining. The amount of resuspension depends greatly on how extensively the mining system will disaggregate the sediments to their fine-grained end-members during collection of the manganese nodules. It will not be possible to quantify this interaction between the soil and the mining system until field trials are carried out using nodule pick-up components of the mining system. Establishment of standards related to benthic data collection should be directed to determining quantitative relationships that can link the degree of benthic disturbance (e.g. depth of burial, total area affected, distance to undisturbed sediments) to the recovery rates and faunal succession that will occur in the disturbed sediments.

3.3. Benthic currents

The benthic and deep waters of the Indian Ocean may be derived in large part from the Atlantic Ocean, with some contributions from the South Australian and Wharton basins[9]. The currents appear to be generally southerly, with mean speeds of a few centimetres per second and maxima >10 cm/sec. These means and maxima are consistent with the currents in the CCFZ.

Three dynamic regimes are in evidence in the CCFZ: calm periods, intermediate periods and benthic storms (described in section 5.3.1 below).

Local bottom-water advection at the scales of hours to months appears to be controlled by bottom relief. In the central and western parts of the CCFZ this relief, with some exceptions, is made up of elongated hills separated by gentle valleys that are transversely oriented with respect to the major fault zones. Available studies suggest that benthic currents in this region are effective in transporting sediments along the seafloor valleys. These currents are sufficient to suspend and transport significant quantities of the very fine-grained, relatively low-density, uppermost pelagic sediments.

These studies suggest that the seafloor in the CCFZ is subject to episodic periods of erosion and deposition caused by benthic current activity. If future work confirms this and provides more quantitative information about the frequency and extent of bedload transport and resedimentation, it will have important implications for the prediction of impacts due to the suspension and resedimentation of sediments anticipated from mining activities. If benthic communities are normally subjected to significant sedimentation from benthic storms, they will be conditioned to adapt successfully to the resedimentation disturbances that would be caused by mining. Conversely, if they are not normally subject to such periodic disturbances, they may be more susceptible to long-term disruption caused by mining activities.

Furthermore, baseline characterisation for any particular mining claim would have to include some evaluation of the frequency and extent of natural resedimentation episodes near the planned mining area, to distinguish them from the disturbances caused by the mining system. Methods to assess these variables are not well developed but could be critical to impact assessment.

3.4. Benthic and demersal community composition

The benthic and demersal communities in the CCFZ and the Indian Ocean claim area have not yet been adequately characterised. Generally, in both of these deep-seabed areas as well as in other deep ocean basins, the communities are essentially dependent for their nutrition on the organic content of falling detrital material from surface waters. No active hydrothermal vent communities are known in these areas and, obviously, no photosynthesis is possible.

Environmental impacts of mining on the benthic communities are probably the most poorly understood class of impacts of all those that must be considered. Growth rates of individuals and recovery rates of populations following disturbance may be very slow and need to be estimated before reasonable impact assessment can be attempted.

Establishment of an adequate environmental baseline characterisation for the benthic communities in the contractors' exploration areas is probably the most challenging problem that must be faced in the environmental assessment of deep-seabed mining. Certainly one of the highest priorities for this Workshop should be the development of standards that can be used to integrate existing collections and observations into comparable data sets, and to promote uniform collection methods in future investigations

3.5. Climate, ocean circulation and water chemistry

The climate in the Indian Ocean is dominated by the monsoon seasons, including the northeast monsoon (December to April) and southwest monsoon (June to October). Tropical cyclones occur during January-February. Several currents make up the Indian Ocean's current system. The North Equatorial (November-April) and South Equatorial currents, Monsoon Drift, northeast monsoon (in April) and Antarctic Circumpolar currents all affect the flow of currents in the Indian Ocean. In the Indian claim area, these all contribute to a net westward flow of the surface currents year round.[10] General seawater components in the Indian claim area are representative of the low nutrient, oligotrophic tropical environments typical of both the central Indian Ocean and the CCFZ.

The climate in the CCFZ is similarly tropical and subtropical, and is dominated by the northeastern trade winds during much of the year. In the central North Pacific Ocean, the average sea surface temperature is 25 degrees Celsius. The North Equatorial Current dominates surface-water movement in the zone. This is a broad current flowing east to west, extending between 9? and 20? north latitude, and has an average speed of about 10 cm/sec.

Thanks to major progress in recent years in the development of satellite-based remote sensing, acoustic Doppler current profilers (ADCPs) and other technologies, as well as the implementation of large oceanographic programmes such as the World Ocean Circulation Experiment (WOCE), significant advances are being made in the general understanding of the world's climate, oceanic circulation and seawater chemistry. These advances will provide a relatively well-developed regional background for contractors to use in their environmental assessment efforts.

Development of environmental standards in these general areas should focus on the *opportunistic*[11] collection of appropriate data during exploration cruises that can contribute to a long-term baseline record. Standards should assist explorers in the uniform acquisition of data to provide ground truth for oceanographic classifications based on remote sensing and hopefully to expand the inferences that can be confidently made using remote-sensing data.

3.6. Pelagic communities

Within the existing contractor exploration claims, the natural environment includes large expanses of oligotrophic tropical and subtropical ocean. Section 5.6 below describes the general types of bacteria, phytoplankton, zooplankton, micronekton, commercial fishes and marine mammals that have been studied in the CCFZ. These wide-ranging and diverse populations can make characterisation of ecological relationships very difficult.

Furthermore, extensive characterisation of epipelagic (near-surface) communities may not be necessary for adequate impact assessment if no substantial surface or near-surface discharge of mining wastes is contemplated by the contractors. Absent such a discharge, a deep-seabed mining system could cause only relatively small impacts on surface communities, chiefly through the presence of the floating system itself. However, selection of a subsurface discharge would lead to unknown impacts on midwater and/or abyssal pelagic communities, and the methods for environmental characterisation of these communities are not well developed.

Prudent contractors have in the past and will probably continue in the future to pursue opportunistic data and specimen collections from pelagic communities during exploration cruises. Standardisation of methods and integration of available data would be worthwhile to facilitate comparisons between different collection efforts and to identify information gaps that would have to be filled before commercial mining.

3.7. Summary

The above considerations are part of the scoping process of environmental assessment and are directed toward the setting of priorities for the development of environmental standards and collection of environmental data. The next section integrates these considerations and the anticipated phasing of the mining industry outlined in section 2 with the list of recommendations provided by Prof. Craig Smith in his Workshop background paper (chapter 3 above). The objective is to generate a proposed set of priorities for the development of environmental standards and for the acquisition of environmental data.

4. Suggested priorities

As outlined in section 2, the anticipated development scenario for deep-seabed mining includes the ongoing exploration phase, a testing phase for commercial mining systems and ultimately the establishment of commercial mining operations. The first two development phases suggest comparable phases for the establishment of environmental standards and for the acquisition of environmental data (since the impact analysis must be complete before the initiation of commercial mining). During the exploration phase, there are two distinct types of efforts to consider:

1. Data collection efforts associated with opportunistic sampling, to be carried out by the contractors during normal exploration cruises; and

2. Specific scientific investigations that are required for adequate impact assessment and that require long time frames for their completion.

The following priorities are listed according to their relative schedule for implementation.

4.1. Specific scientific investigations with long time frames

4.1.1. Resistance and resilience of seafloor communities to nodule-mining disturbance

This has top priority because of the poor state of existing knowledge and the unknown length of time that will be required to obtain predictive capability.

4.1.2. Geographical ranges and community structure of the dominant macrofaunal and meiofaunal species likely to be impacted

Much of this information can be obtained through standardisation of contractor opportunistic sampling, as noted in subsection 4.2 below, and the integration of existing information. However, an effort is needed to guide the opportunistic sampling efforts and to provide an independent and systematic collection of data at sites not necessarily within contractor search areas.

4.2. Opportunistic efforts during contractor exploration cruises

4.2.1. Geographical ranges and community structure of dominant macrofaunal and meiofaunal species likely to be impacted

This effort will naturally be directed to the areas of most concern, where active exploration is under way. It will be designed and overseen by the work envisaged in subsection 4.1.2 above.

4.2.2. Oceanographic conditions along the entire water column, including current, temperature and turbidity regimes above the seafloor

This should be limited to collections of data that do not impact the basic objectives of the exploration work. The Workshop should recommend methods for efficient collection of such data. More substantial efforts should be initiated only as part of monitoring programmes for mining-component tests.

4.2.3. Observations of marine mammals

Proposed standards for making and documenting such observations should be part of the Workshop product.

4.3. Environmental data collections for mining-system tests

The following activities should be associated directly with mining-system tests. Because such tests are several years into the future, and because the state of the art can be expected to change significantly before they take place, it is premature to develop standards for these data-collection efforts.

?? Adapt the current-measurement programme to the topography and regional hydrodynamic activity in the upper water column and on the seafloor;

?? Measure the currents and particulate-matter concentrations at the depth of the forecasted discharge during the testing of collecting systems and equipment;

?? Measure the particulate distribution to record particulate concentration along the water column;

?? Collect information on water column chemistry, including the water overlying nodules;

?? Determine the basic properties of the sediment;

?? Obtain profiles of microbial biomass;

?? Investigate faunal abundance and species structure associated with nodules;

?? Install time-lapse and baited camera systems;

?? Measure trace-metal concentrations in dominant bentho-, meso- and bathypelagic species;

?? Study community structure of zooplankton and fish near discharge levels and in the benthic boundary layer;

- Investigate the plankton community in the upper 200 m;
- Evaluate bioturbation rates;
- Obtain data on the flux of materials from the upper water column down to the deep sea;
- Determine the frequency, duration and spatial distribution of baseline monitoring.

5. Environmental characterisation of claim areas

Two regions in the deep seabed currently have exploration claims registered with ISA. First, the Government of India has claimed an area in the south central Indian Ocean between 10-17° south latitude and 72-82° east longitude. Second, six States and an intergovernmental group (China, France, India, Japan, Republic of Korea, Russian Federation and an Eastern European group) have claims in the northeastern tropical Pacific Ocean (the CCFZ) between 7-18° N and 157-118° west longitude (see figure 2).

This section summarises the environmental baseline information presented in Morgan, Odunton and Jones.[12] It outlines the environmental information available for the claim areas and focuses on general parameters relevant to environmental impact assessment.

5.1. Occurrence of commercial nodule deposits

Manganese nodules form along gradients of ambient water chemistry in which waters traverse from relatively acidic and low oxygen levels into relatively high levels (see section 3.1 above). Acidic, poorly oxygenated waters can contain significant amounts of dissolved and organically complexed metals. Where these waters pick up oxygen and usually at the same time lose some acidity, many metals will rapidly oxidise and precipitate out. This situation commonly occurs at the water/sediment interface in lakes and oceans, which is where manganese nodules are usually found. Iron and manganese are the most common transition metals in the earth's crust, and thus form the bulk of the precipitated material. Manganese oxides also have special surfaces that are particularly effective in collecting and holding more manganese and other metals, scavenging them preferentially from the bypassing water flow.

Local topography exerts significant control over manganese nodule distribution. The best deposits are found in gently sloping regions that are partially sheltered from major inputs of bedload-derived sediments[13].

5.2. Sediment properties

Manganese nodules are believed to differ morphologically from manganese crusts or pavements primarily in that they form on sediments rather than on hard substrates. Unconsolidated sediments are much more susceptible than hard substrates to disturbance from tectonic activity, benthic currents and biological mixing by burrowing organisms (bioturbation). Extensive examinations of manganese nodules from many environments show that the nodules experience repeated overturning during their growth, resulting in their characteristic onion-like morphology. *(See also section 3.2 above.)*

Sediments from the Indian Ocean site and the CCFZ consist mostly of clays and siliceous biological casts. Sands and larger sediments are not generally found so far from land, and the commonly formed carbonate biological casts dissolve on the seabed in these deep-water regions faster than they accumulate. In the Central Indian Basin, the sediments are primarily siliceous and contain an average of 5.5% by weight of radiolarian tests (shells)[14].

The upper centimetre or so of the sediments is high in water content and the water chemistry is very similar to that of overlying waters. Most of the benthic fauna reside in this zone. Sediment permeability is determined by grain size and shape, sorting, packing and other factors that in turn determine suitability of the sediments as habitat for deep-sea infauna. Biological disturbance of the sediments in turn affects pore-water equilibria.

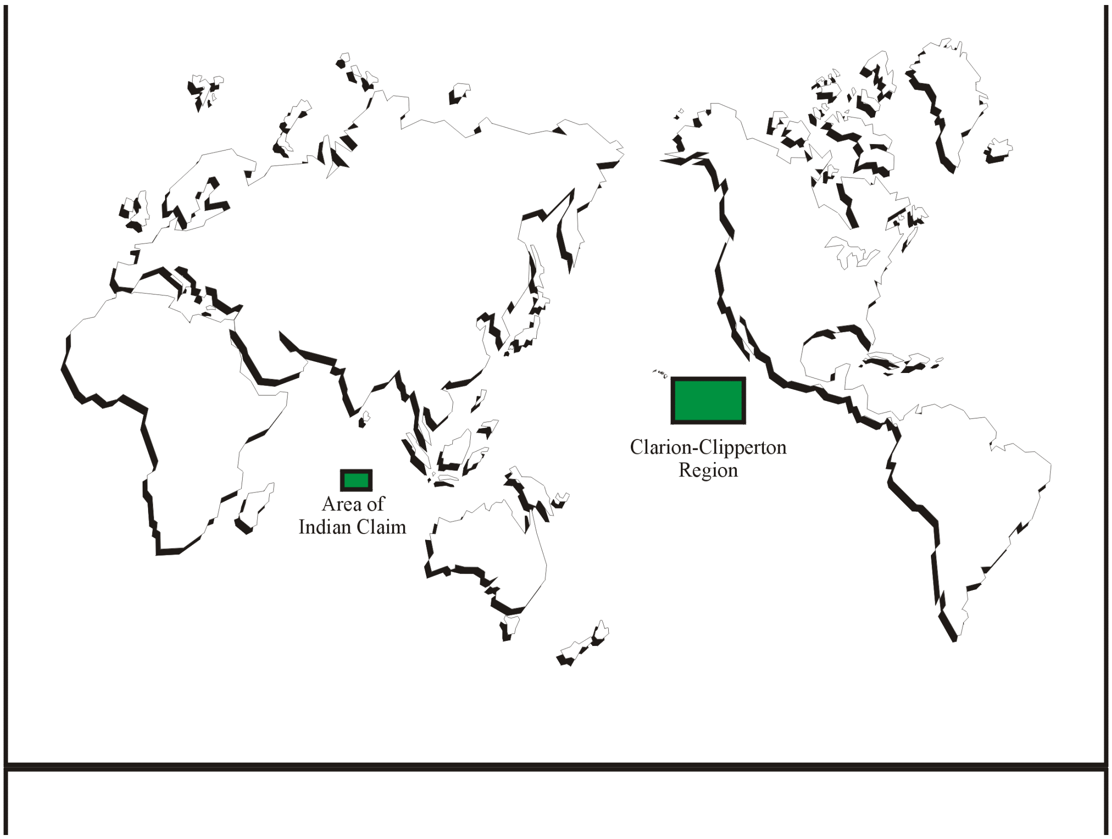

Figure 2 Areas with claims registered by ISA.

Generally, bottom-sediment chemistry is stable. Bacterial activity acts to oxidise the organic material present, and oxygen concentrations decline with sediment depth. Ammonia concentrations in DOMES samples showed significant enrichment over near-bottom water, presumably a result of metabolic activity.

Detailed sampling of the bottom in the CCFZ is reported in several papers[15]. These collections indicate that the sediments consist predominantly of recent and Pleistocene pelagic radiolarian, calcareous-argillaceous and argillaceous ooze with highly variable nodule abundances (from 0 to more than 15 kilograms per square metre). The bulk density of the sediments may vary within the range 1.1-1.62 (mean value 1.19 grams/cm), with moisture contents of 52-85% (mean of about 76%) and porosities of 71-93% (average porosity of about 87%). The diatomaceous-argillaceous ooze pelite fractions (less than 0.01 mm) comprise 50-85% of the sediments and have a dry specific gravity of 0.4-0.9. The argillaceous ooze can consist of more than 90% of pelite and up to 40% or more of subcolloidal fractions of a size less than 0.001 mm.

Sharma and Rao[16] report that the seabed in the Indian claim area primarily consists of biogenic sediments, manganese nodule deposits, massive rocky exposures and associated ferromanganese crust deposits. Siliceous ooze is the primary component of the sediments, with a thin strip of calcareous foraminiferal and coccolithid ooze in the western parts of the claim and some red clays in the southern part.

5.3. Benthic currents

Recent work funded through WOCE has retrieved benthic current data from one current-meter array located in the southwest corner of the area of the Indian claim (20° S, 72° 29.2' E)[17]. Summaries of the data retrieved from the meters at 99 and 1099 m off the seafloor are presented in table 2. The currents appear to be generally southerly, with mean speeds of a few cm/sec and maxima >10 cm/sec. These means and maxima are consistent with the currents in the CCFZ (discussed in subsection 5.3.1 below). Benthic currents on and between abyssal hills in this zone have been documented by a number of authors[18] (*see Figure 3*).

Table 2 Benthic currents in the south central Indian Ocean.

Parameter	Minimum	Mean	Maximum	Std Dev.
Meter at 3,014 m				
Speed (cm/sec)	0.93	2.23	10.30	1.72
Direction (degrees true)	0.30	189.43	359.93	100.76
Eastward component (cm/sec)	-7.94	-0.15	9.43	1.94
Northward component (cm/sec)	-9.54	-0.13	10.26	2.03
Temperature (degrees C)	1.47	1.55	1.64	0.02
Meter at 4,014 m				
Speed (cm/sec)	0.93	2.04	8.01	1.33
Direction (degrees true)	0.07	186.68	359.71	109.05
Eastward component (cm/sec)	-5.58	0.01	7.94	1.72
Northward component (cm/sec)	-6.08	0.19	6.49	1.72
Temperature (degrees C)	1.42	1.44	1.48	0.01
Total water depth 4,113 m. Deployment 14 May 1995 - 26 January 1997. Data from WOCE programme[19].				

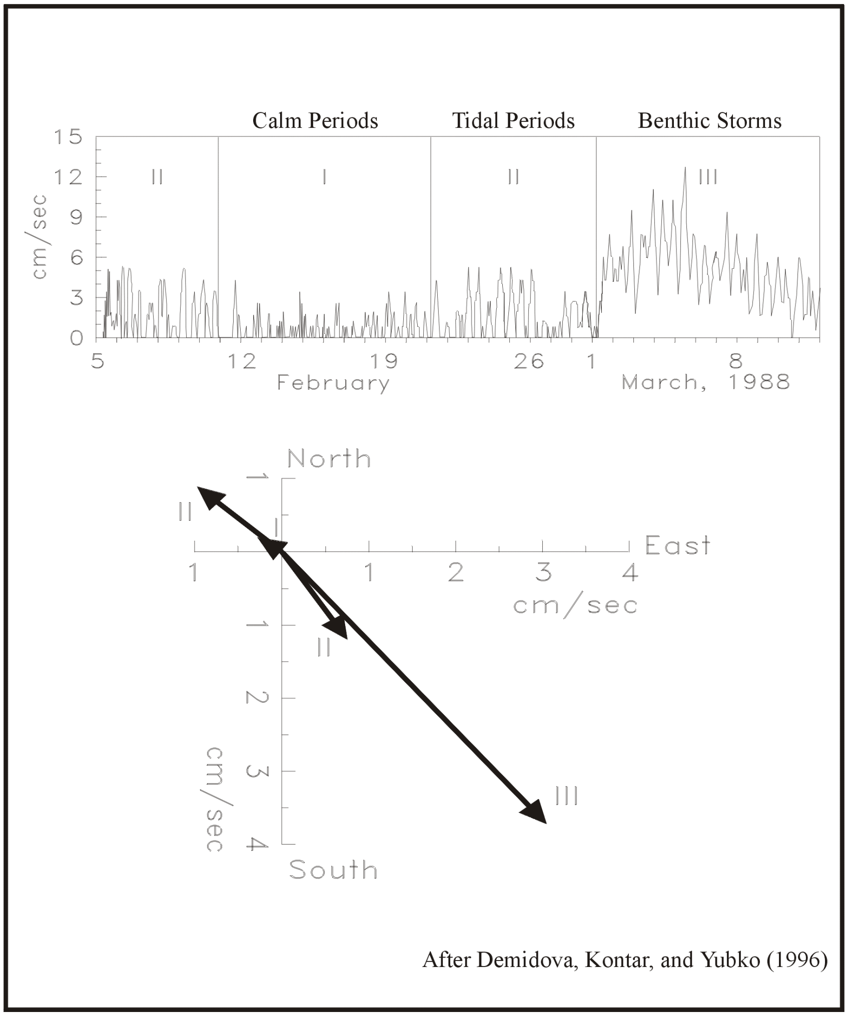

Figure 3 Benthic currents in the CCFZ

5.3.1. Classification of benthic currents

Summary statistics of the benthic current measurements available for the CCFZ are presented in table 3. Mean values of current speed and velocity depend, of course, on the duration of measurement. Hayes found average speeds over periods of 143-197 days to be between 1.5 and 2 cm/sec. High variability in speed and direction was noted in all studies.

Table 3 Benthic currents in the CCFZ.

Location		Water depth (m)	Above seabed (m)	Measured duration (days)	Average direction	Average speed (cm/s)	Maximum speed (cm/s)
N lat.	W lon.						
14° 0.5'	131°00'	4,950	35	13	183	1.5	9
			25	13	163	2.3	10
13° 6.5'	131° 01'	4,980	35	13	200	1.1	9
			25	13	183	2.8	7
13° 31'	132° 57'	4,920	6	13	155	4.3	13.5
8° 27'	150° 49'	5,200	50	143	50	0.35	12
			30	143	59	0.57	10
9° 27'	151° 17'	5,200	4	40	63	3	15
9° 26'	151° 17'	5,190	8	40	46	3.3	15
			4	40	9	2.9	
9° 21'	151° 17'	5,093	4	40	333	1.1	
11° 42'	138° 24'		30	197			14.5
14° 38'	125° 29'	4,508	30	156	331		15
			6	156	324		13
11° 02'	140° 06'	4,906	4.7	123		5.25	12.5
11° 03'	139° 59'	4,873	4.7	200		4.45	11.2
4° 00'	136° 01'	4,469	4.7	195			10.1
15° 13'	125° 58'	4,655	10	11	273	7	
7° 40'	134° 00'	4,705	25	4	56	4.8	8.3
		4,590	19	4	99	5.4	9.6
		4,700	5	4	63	4.5	8.1
1° 02'	149° 50.7'	4,647	1,500	152	87		

Three dynamic regimes are in evidence in the CCFZ:

1. Calm periods, characterised by minimal current speed (0-3 cm/sec), moderate to low variance and low tidal activity. In one experiment[20], this time interval lasted about 11 days, 11-21 February 1988.

2. Intermediate, mostly tidal periods, characterised by the alteration of current speed (0 to 5-6 cm/sec) and velocity, with a corresponding increase in the variance of the data but with the

same minimal values as in the calm periods. This regime was revealed between 4-11 and 21-29 February.

3. Benthic storms, associated initially with a sharp increase in current speed, which can maintain relatively stable speeds to produce 24-hour means of as much as 8 cm/sec[21] and one-hour means of 13-15 cm/sec[22]. The benthic storm measured by Demidova and Kontar[23] lasted about two weeks (the first half of March). Approximately the same periods (several weeks) of increased velocity have also been found in the longer duration observations by Hayes[24].

The general direction of near-bottom currents in the province has been postulated to be dominated by the flow of Antarctic Bottom Water (AABW) to the northeast[25]. This water is introduced to the region through the deep Clarion and Clipperton passages. Flowing along the main fault zones to the northeast, a part of it presumably branches off in the numerous seabed valleys and depressions, potentially influencing local current distributions. However, as shown in table 3, the measured benthic currents available to this study all indicate current directions in direct opposition to the north-northeast direction predicted by indirect methods. At the site of the bottom station BS-3, north-northwest and south-southeast directions dominated the observations. This direction is consistent with the bearing of isobaths at the site. The mean velocity vector for BS-3 is southeast. Analogous results were obtained for the other two stations.

According to several recent studies[26], the submeridional valleys of erosional nature are widely developed in these parts of the province. According to all observations to date, the calm and active regimes discussed above are characterised by opposing current directions. The mean direction at the period of low activity is often north-northwest, consistent with the basic advection of AABW, whereas the flow during benthic storms is often SSE. Hayes[27] describes earlier experiments of longer duration in which this same trend of current reversal during different regimes is evident. Interestingly, this inferred direction of sediment transport along the seabed valleys to the SSE corresponds to the direction of general decrease of ocean depths rather than their increase. (See also Section 3.3. above.)

5.3.2. Benthic currents and sediment transport

The results presented above strongly suggest that benthic currents in the CCFZ are effective in transporting sediments along the seafloor valleys. The benthic storms noted in this and other studies are clearly capable of lifting and transporting fine-grained materials that have been disaggregated by detrital feeders and other mechanisms[28]. These currents are sufficient to suspend and transport significant quantities of the very fine-grained, relatively low density, uppermost pelagic sediments that predominate in this region.

The alternating, intermediate tidal currents are also likely to be effective in transporting sediments. The threshold speed of beginning of erosion depends both on sediment properties in a site under investigation and on benthic current peculiarities there. For instance, there is good evidence[29] that for the same benthic current speed, erosion does not occur if the direction of the current is stable and that it arises immediately with sharp direction change.

The calm periods provide conditions for subsequent accumulation of sediments. During the interspersed periods of low-speed currents (0-1 cm/sec), which can last for several days, even the most fine-grained sediments (up to subcolloidal particles) transported by the currents will redeposit on the seabed. Based on Hayes' estimates of monthly averaged current speed (2 cm/sec), this would result in a net bedload transport of 50 km per month if the high-speed currents affecting the transport were always in the same direction. This transport occurs in quasi-periodic regime, so the nepheloid layer arising during benthic storms and maintained by inertial-tidal alteration and by variability of smaller scales may exist for several years and transfer over hundreds of kilometres[30]. Finally, currents at the velocities observed can also facilitate and generate turbidity flows of a semi-fluid layer of sediments along the inclines, while simultaneously entraining a fraction of the material into the flow[31].

5.3.3. Geological indicators of benthic currents and sediment transport

Extensive sampling and photography of nodule deposits have also been completed in commercial development efforts in this area. This work indicates that benthic currents may be very important to nodule deposit formation and suggests a mechanism that may be central to the process.

Many researchers in recent years have noted the high degree of local variability in the overall abundance, composition and surface morphology of deep-seabed manganese nodules in the CCFZ. This high local variability is attributed to such factors as the local seabed topography, benthic current structure and sediment type[32].

Investigators in the CCFZ have discovered persistent evidence of active bedload transport, both with recent measurements of artificially induced dispersion of benthic sediments[33] and through identification of recent and ancient erosional surfaces using photography, acoustic sub-bottom reflection profiling and direct sampling[34]. Recent Russian and French studies cited above have shown (in the region defined by 133º 40'-136º 40' W and 11-14º N) that these surfaces are arranged in a system of erosional elements morphologically revealed as long, relatively flat valleys (several hundred metres wide by several tens of kilometres long) with depths of several tens of metres and flanked by steep (to 45º) slopes. The valleys generally have southerly downslope directions.

The valleys are filled mostly by Pliocene to Pleistocene siliceous clays, with the depth of recent sedimentation distinctly increasing from north to south[35]. Because the regional bathymetry gets progressively deeper toward the north-northwest, gravity-driven sediment transport is not possible toward the southeast. Thus, the evidence strongly indicates a net southward bedload transport by benthic currents.

5.4. Benthic community composition

This section summarises data for the Indian Ocean claim area and the DOMES data for the CCFZ. Other collections, made in the Clarion-Clipperton region[36] and in the Peru Basin of the South Pacific Ocean[37], show similar taxa in similar relationships. It is beyond the scope of this summary to resolve the differences and similarities among these studies, but such an undertaking would greatly enhance our general understanding of deep-seabed biological communities. (See also section 3.4 above.)

5.4.1. Benthic fauna in the Indian Ocean claim area

Sharma and Rao[38] present a qualitative description of the megafauna observed in the Indian Ocean claim area, summarised in table 4. More recent assessments of infauna densities have been made from examination of box cores [39]. These examinations indicate a dominance of polychaetes and nematodes in the cores, in six macrofaunal and three meiofaunal taxa.

The observed population density ranges from 8-64 organisms/m^2 for the macrofauna and 3-45 organisms/10 cm^2 for the meiofauna. The meiofauna sampled consisted entirely of nematodes in some cores, with associated harpacticoid copepods and larvae in others. With some exceptions, nematodes were concentrated toward the top level in all cores but were found throughout. The harpacticoid copepods were generally confined to the top 5 cm.

The polychaetes dominated the macrofaunal assemblage in the cores, followed by peracarid crustaceans (amphipods and tanaids), bryozoans and rhizopods. Estimated biomass was dominated by the presence of a few crustaceans in some samples. No depth distribution was evident in the cores. These general taxa are the same ones found in the CCFZ (discussed in section 5.4.2 below).

Table 4. Megafauna observed in the Indian claim area.

Phylum	Taxonomic groups
Coelenterata	Actinarians, cnidarians, hexacorallids, madreporites, pennatulids, scleractinarians
Porifera	Hydrazoans, sponges
Annelida	Oligochaetes, polychaetes
Arthropoda	Amphipods, cirripeds, copepods, crustaceans, cumaceans, decapods, isopods, mysidaceans, ostracods, tanaids
Mollusca	Aplacophorans, brachiopods, cephalapods, gastropods, octopods, pelecypods, scaphopods, squid
Echinodermata	Asteroids, brisingids, crinoids, echinoids, holothurians, ophiuroids
Echiurida	Echiurids
Ectoprocta	Bryozoans
Sipunculida	Sipunculids
Platyhelminthes	Flatworms
Rhizopoda	Agglutinating rhizopod protozoans
Hemichordata	Tunicates, ascidaceans
Chordata	Anoumarids, brachiurids, fishes, macrourids, pycnogonids

Data from Sharma and Rao[40].

5.4.2. Benthic fauna in the CCFZ

The benthic fauna in the CCFZ were examined in some detail in the DOMES study[41]. The following summary has been abstracted and modified from this source.

Benthic organisms have been surveyed at three sites in the region, labelled DOMES sites A, B and C (see figure 4). Photography, box cores, free-fall baited traps and bongo-net tows were used to observe and collect specimens. The near-bottom macro-zooplankton community includes primarily crustaceans (copepods, ostracods, amphipods and decapods) and exhibits very low concentrations: fewer than five individuals were caught per sample in net tows. This indicates highly dispersed populations near the bottom compared with upper waters. Bottom scavengers trapped in the area consisted of two families of fishes (rat-tails and liparids) and amphipod crustaceans. Amphipods collected during DOMES were found in large numbers (about 50,000 individuals in the 73 samples obtained) and were represented by 10 species. Photographic surveys generally show only the larger organisms (termed megafauna) and are not representative of the true abundance of the benthos.

In these surveys more than 90 percent of the macrofauna were sea stars, brittle stars, sea anemones, sea cucumbers or sponges. Box cores were analysed for the infauna, which generally comprise the numerical majority of the benthos. The relatively large organisms in this collection (average wet weight of 1.6 milligrams) are found in average densities of from 92 to 152 individuals/m^2. Most of the infauna consists of small (less than 1 mm) organisms that live in the upper 1 cm of sediments. Forty percent of the macrobenthos collected were polychaete worms (underestimated due to sampling problems), 19% tanaids and 11% isopods. Sponges, bryozoans, gastropods, sea cucumbers, sea urchins, bivalves, sea anemones, brittle stars, brachiopods and miscellaneous non-polychaete worms comprised most of the remaining organisms (see table 5). Some of the organisms collected apparently live on the surface of the manganese nodules, including foraminiferans, bryozoans, coelenterates and serpulid worms. The faunal characteristics of the three DOMES sites (including the weight of the large epifauna) varied in terms of average biomass, average density of macrofauna and meiofauna, and the percentage of suspension feeders.

In the mid-l960s, marine ecologists were surprised to discover the very high diversity of the fauna in the deep sea. The 80 box-core samples from the DOMES sites illustrate this high diversity, with 2,422 individuals of 381 macrofaunal species. Nearly three-fourths of the species were represented by four individuals or less; 131 species were represented by only one individual, with an average density of less than one individual per 20 m^2. The diversity of this habitat is so high that even with 80 samples, the number-of-species versus number-of-samples curve has not levelled off. In other words, if more samples were taken one would expect to find more species. A familiar land analogy of this diversity is not readily available, but one can imagine a 20-m^2 field with over 2000 stalks of grass representing more than 350 species.

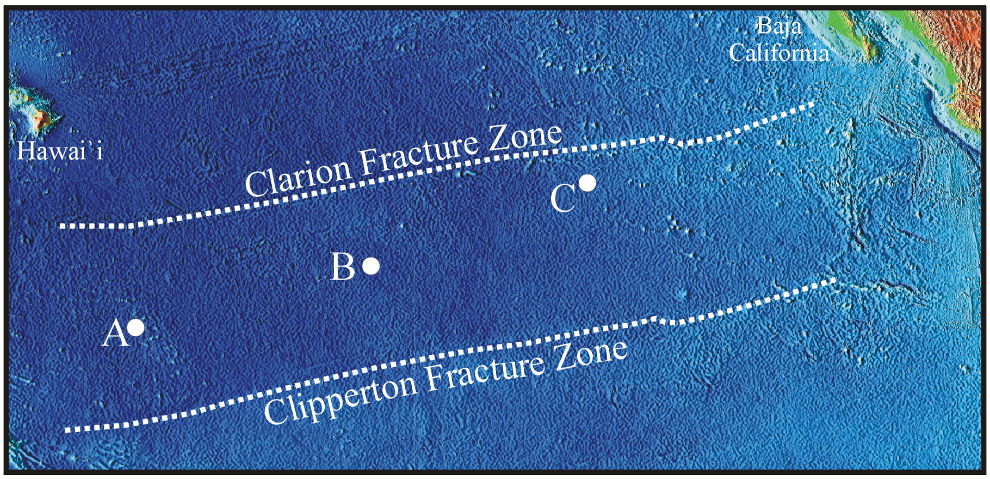

Figure 4 DOMES sites in the CCFZ

5.5. Meteorology and water-column characteristics

The Indian claim area and the CCFZ represent the most remote sites on the planet from land. As discussed above, the formation of commercial grade manganese nodules appears to require minimal inputs of terrigenous sedimentation and very deep water, below the Calcite (or Carbonate) Compensation Depth (CCD). This section describes the key features of the ocean and air which overlie these deposits and which would be directly relevant to environmental impact assessment.

5.5.1. Central Indian Ocean

This subsection outlines the general aspects of climate, ocean circulation and water chemistry that influence activities in the Indian claim area. These data are much less complete than the corresponding information outlined in section 5.5.2 below for the CCFZ. However, data from the Indian Ocean component of WOCE, begun in 1994, are expected to be widely available soon and will greatly help to augment our general understanding of the central Indian Ocean environment.

	DOMES A		DOMES B		DOMES C		Total	
	No.	%	No.	%	No.	%	No.	%
Macrofaunal and megafaunal taxa								
Polychaeta	189	38.6	239	46.4	542	38.2	970	40.1
Tanaidacea	121	24.7	77	15.0	274	19.3	472	19.5
Isopoda	57	11.6	30	5.8	197	13.9	284	11.7
Bivalvia	40	8.2	73	14.2	90	6.4	203	8.4
Gastropoda	13	2.7	25	4.9	23	1.6	61	2.5
Ectoprocta	25	5.1	8	1.6	97	6.8	130	5.4
Porifera	4	0.8	16	3.1	55	3.9	74	3.1
Hydrozoa	3	0.6	2	0.4	3	0.2	8	0.3
Stephanoscyphus	1	0.2	10	1.9	2	0.1	13	0.5
Actiniaria	3	0.6	-	-	15	1.1	18	0.7
Brachiopoda	10	2.0	9	1.7	31	2.2	50	2.1
Hemichordata	-	-	1	0.2	1	0.1	2	0.1
Sipunculoidea	3	0.6	4	0.8	14	1.0	22	0.9
Echiuroidea	-	-	-	-	3	0.2	3	0.1
Ophiuroidea	9	1.8	-	-	10	0.7	19	0.8
Echinoidea	-	-	3	0.6	1	0.1	4	0.2
Crinoidea	1	0.2	-	-	7	0.5	8	0.3
Holothuroidea	1	0.2	-	-	2	0.1	3	0.1
Aplacophora	2	0.4	2	0.4	2	0.1	6	0.2
Polyplacophora	1	0.2	-	-	5	0.4	6	0.2
Monoplacophora	1	0.2	-	-	-	-	1	-
Scaphopoda	1	0.2	-	-	1	0.1	2	0.1
Oligochaeta	-	-	-	-	8	0.6	8	0.3
Pycnogonida	-	-	-	-	3	0.2	3	0.1
Cumacea	-	-	4	0.8	3	0.2	7	0.3
Amphipoda	2	0.4	5	1.0	14	1.0	21	0.9
Cirripedia	-	-	-	-	3	0.2	3	0.1
Ascidacea	3	1	7	1.4	7	0.5	17	0.7
Unknown	-	-	-	-	4	0.3	4	0.2
Total	490	99.9	515	100.2	1417	100.0	2422	99.9
Total per core	22		25		37			
Meiofaunal taxa								
Nematoda	1116	87.3	1486	87	709	69.1	3311	82.5
Ostracoda	77	6	82	4.8	226	22.0	385	9.6
Copepoda	84	6.6	138	8.1	81	7.9	303	7.5
Acarina	-	-	2	0.1	8	0.8	10	0.2
Turbellaria	2	0.2	-	-	1	0.1	3	0.1
Kinorhyncha	-	-	1	0.1	1	0.1	2	-
Total	1279	100.1	1709	100.1	1026	100	4014	
Total per core	58		85		27			99.9

Table 5 CCFZ benthic fauna.

5.5.1.1. Climate

The climate is dominated by the monsoon seasons, including the northeast monsoon (December to April) and southwest monsoon (June to October). Tropical cyclones occur during January and February. Major international research is currently underway through WOCE to characterise and understand the El Niño/Southern Oscillation phenomena that have been documented in the area.

5.5.1.2. Ocean circulation

The WOCE cruise "18N" recorded ADCPs along a north-south transect during March and April 1995. These show predominately southerly currents. (See also section 3.5. above.)

Climatological surface heat-flux data suggest that a large heat exchange takes place between the atmosphere and the Indian Ocean. Because this ocean extends northward only to low latitudes, no cold-water masses are formed at its surface. Therefore, if the net heat gain is to be transported to the south by meridional mass overturning, cold water must be drawn from the south at depth, be transported by upwelling to the surface and then flow southward. Hydrographic analysis[42] implies that there is a strong overturning cell with a large net northward flow below 2000 m near 18º S. If this cell exists, it would imply an average upwelling rate at the 2000-m level several times larger than that of the Pacific Ocean. However, the summary benthic current data from almost two years of deployment, summarised in section 5.3 above, suggest a net southerly trend for the deep currents.

5.5.1.3. Sea water characteristics

General seawater components are presented in table 6. They are representative of the low nutrient, oligotrophic tropical environments typical of both the central Indian Ocean and the CCFZ.

5.5.2. Clarion-Clipperton Fracture Zone

This section outlines the general aspects of climate, ocean circulation and water chemistry that influence activities in the CCFZ.

5.5.2.1. Climate

Ocean temperatures vary widely, geographically and with depth. Based on temperature, the water column can be divided into three layers: (1) the mixed layer, (2) the thermocline and (3) the deep layer. The mixed layer, extending downward from the surface, is directly influenced by winds and waves. In the central North Pacific Ocean, the average sea-surface temperature is 25°C. At the thermocline, which begins at the bottom of the mixed layer, there is a rapid decrease in temperature with increasing depth. The temperature change through the thermocline can be as much as 12°C[43]. In the deep layer, the temperature continues to decline at a steady but slower rate. At depths of 1000 m and more, the temperature levels to a few degrees Celsius[44]. In the DOMES study area, a strong permanent thermocline was found to separate surface and intermediate waters. Mixed layer depths varied between 36 m (summer) and 55 m (winter), while the thermocline extended to 150 m in summer and to 130 m in winter[45].

Table 6 Major variables in the water column at the Indian claim site

Depth (m)	Temp. C°	Salinity (g/kg)	Dissolved oxygen (ml/l)	Phosphate (µm)	Nitrate (µm)	Silicate (µm)
0	23.0-30.0	33.5-35.5	4.3-5.0	0.1-0.3	0.4-1.0	2.0-6.0
100	18.0-24.0	34.8-35.4	2.0-5.0	0.1-1.0	0.5-15	3.0-15
200	13.0-19.0	34.6-35.6	1.0-5.0	0.3-1.6	1.0-25	3.0-22
300	10.0-17.0	34.7-35.7	2.0-5.0	0.3-2.0	4.0-30	3.0-35
400	10.0-13.0	34.8-35.4	2.0-5.5	0.6-2.0	5.0-30	5.0-40
500	8.0-11.0	34.7-35.0	2.0-5.5	0.8-2.2	10-30	5.0-45
600	7.5-10.0	34.6-34.9	1.5-5.5	1.0-2.6	15-35	5.0-55
800	6.0-6.5	34.5-34.8	1.5-4.5	1.5-2.8	25-40	30-75
1000	5.0-5.5	34.6-34.8	1.5-3.0	2.4-2.6	30-40	60-95
1200	4.0-5.0	34.6-34.7	2.0-2.5	2.4-2.8	30-40	70-110
1500	3.0-4.0	34.7	2.5-3.0	2.6	35	80-115
2000	2.2-2.4	34.7-34.75	3.2-3.4	2.4-2.6	30-35	90-125
2500	1.7-1.8	34.74	3.4-3.8	2.2-2.5	30-35	100-120
3000	1.4-1.5	34.74	3.8-4.0	2.4	30-35	115-135
4000	1.05	34.73	3.90	2.36	34	120-150
5000	0.95	34.70	4.14	-	-	-

Temperatures at the base of the thermocline averaged 12-13°C. Below this depth, temperatures decreased more slowly to about 4.5°C at 1000 m[46].

Surface temperatures typically reveal parallel isothermal structures between November and April, with a latitudinal temperature gradient of about 0.6-0.8°C per degree of latitude[47]. These parallel isotherms break down in the summer. Minimum and maximum temperatures generally occur in March and September, respectively. The annual range in surface temperature at latitude 12° N was only 1.7°C, but at 26° N it increased to 5.3°C. Below the mixed layer, the average temperature gradient is about 15°, 6° and 5°C per 100 m at latitudes 10°, 20° and 30° N, respectively. Seasonal and diurnal thermoclines may be superimposed on the permanent thermocline.

5.5.2.2. Ocean circulation

As speculated for many years and confirmed in the DOMES programme[48] and later in the TOPEX/Poseidon remote-sensing programme, the North Equatorial Current dominates surface-water movement in the study area. The North Equatorial Current is a broad flow east to west extending between 9° and 20° N, and has an average speed of about 10 cm/sec. The surface-water mass in this area, called the North Pacific Subtropical Water, is between 50 and 200 m thick. Beneath the North Pacific Subtropical Water lies a 1000-m layer of colder water called the North Pacific Intermediate Water. This layer is characterised by a salinity minimum. The water originates at high latitudes in the Pacific Ocean and sinks beneath the North Pacific Subtropical Water in a broad area north of approximately 45° N.

The nearly homogeneous North Pacific Deep Water is found in a zone approximately 3600 m thick beneath the North Pacific Intermediate Water. North Pacific Deep Water originates in the North Pacific Basin and flows very slowly southward. Antarctic Bottom Water is found close to the seafloor in a zone several hundred metres thick. AABW originates in the Antarctic Ocean and moves slowly northward.

The wind-generated open ocean wave climate is typified by four general wave types: Northeast Trade Wind waves, South Pacific and North Pacific swells, and hurricane-generated waves. Simultaneous arrival of waves from more than one source is common. Trade-wind waves may occur throughout the year but they dominate from April to November, when they are present 90-95% of the time as compared to 55-60% of the time from December through March. Waves generated by these winds typically have periods of 5-8 sec with heights of 1-4 m. They usually approach from the northeast, east or southeast. South Pacific swells resulting from storms in the Southern Hemisphere occur between April and October. They produce swells (the southern swell) from a southern quadrant with long periods (14-22 sec) and low amplitudes (approximately 1 m).

5.5.2.3. Water chemistry

Water chemistry and primary productivity studies in the region show that the Northern Equatorial Current carries a distinct but diffuse plume of nutrients and fine-grained materials westward from terrigenous and upwelled sources off the North American continent. Due to the normal increase of solar energy inputs to surface waters with decreasing north latitude, primary productivity generally follows an increasing trend toward the equator. However, because of the nutrient influx from the west in the area of interest, the gradient here is dominated by a trend of decreasing primary productivity to the west.

Seawater density varies inversely with temperature, directly with salinity and, to a minor degree, directly with pressure. Seawater density controls oceanic stratification. According to DOMES data, the sea-surface density in this region is about 1.022 g/cm^3. At depths of 1000 m and more, it is about 1.0275 g/cm^3. These small changes are significant, so density is usually expressed by the quantity sigma-*t* (s_t), a dimensionless unit calculated by subtracting 1.0 from the density and multiplying by 1000. In the above case, s_t varies from 22.0 to 27.5. The rapid increase in density that coincides closely with the thermocline and the halocline (the zone of rapid salinity increase) is called the pycnocline.

The pycnocline/halocline/thermocline is an important midwater layer because it retards vertical diffusion and sinking. Thus, as animals and plants in the mixed layer die and sink, they tend to accumulate and decay in this zone. This concentrated decomposition depletes available dissolved oxygen, creating an oxygen minimum.

DOMES project data (figure 5) reveal typical oceanic salinity and temperature profiles with little seasonality[49]. The average mixed layer salinity was 34.3 g/kg of seawater. Below this are found two minima and maxima within the upper 1000 m. A maximum range of about 2 g/kg through the water column was typical.

In the ocean, pH is maximal at the surface due to the combined effects of carbon dioxide uptake and oxygen evolution in the photosynthetic process. With increasing depth, photosynthesis decreases while decomposition and respiration increase, consuming oxygen and depressing pH. A pH minimum generally coincides with the oxygen minimum. DOMES results for dissolved oxygen are typical of oceanic conditions in the contract areas, showing essentially saturated concentrations of dissolved oxygen within the mixed layer and slight supersaturation [400-500 microns] just below the mixed layer, resulting from a thin layer of enhanced photosynthetic activity where phytoplankton biomass accumulates.

Below the thermocline, oxygen concentrations rapidly decrease to a minimum. Between 300 and 500 m, concentrations as low as 1 µm have been measured. Below the minimum, concentrations increased to about 350 µm near the bottom (5000 m)[50].

Marine plants, or algae, require certain elements for their growth, as do their terrestrial counterparts. Some of these elements, particularly nitrogen, phosphorus and silicon, are required in relatively large amounts and are termed macronutrients. Most of these elements are abundantly available in seawater; however, in tropical and subtropical surface waters iron, nitrogen and, to a lesser extent, phosphorus, can be present in concentrations limiting to algal growth. Ambient nutrient concentrations reflect a dynamic balance among the forces of water-mass advection, diffusive mixing and biological cycling.

Nitrate concentrations in the DOMES study area were low in the mixed layer (typically about 1-2 µm), reflecting active uptake by phytoplankton[51]. In the thermocline, nitrate concentrations increased with depth to about 35 µm. Occasionally a nitrate maximum was detected near the base of the thermocline. Anderson[52], in a summary of the DOMES nutrient chemistry investigations, reported a resistant nitrate maximum (approximately 45 µm) at the interface between the oxygen-minimum layer and the "upper deep water" at depths of about 800-1000 m. Below this layer, concentrations gradually decreased to about 41 µm and about 36 µm at 4000 m. Within 20 m of the bottom, there was a further, abrupt drop to less than 30 µm[53].

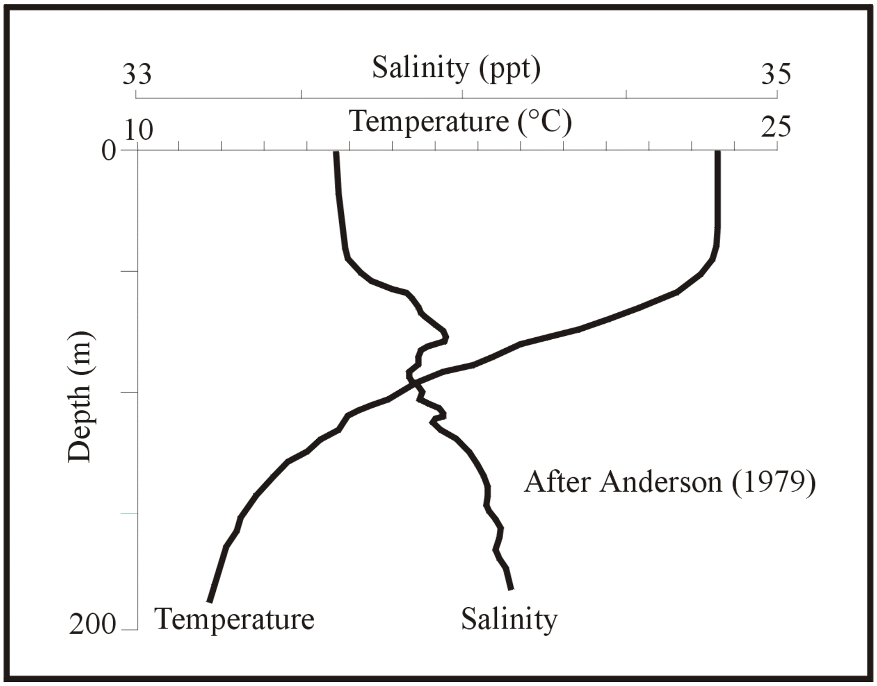

Figure 5. Typical salinity and temperature profiles in the CCFZ

Concentrations of the other forms of fixed nitrogen, nitrite and ammonia, are much lower than those of nitrate. Both are essentially undetectable in the mixed layer. Ammonia concentrations peaked near the top of the thermocline; the average maximum concentration was 0.31 µm. Nitrite concentrations peaked near the middle of the thermocline; the average maximum concentration was 0.4 µm. Below the thermocline, ammonia was undetectable; nitrate concentrations were typically an order of magnitude less than in the maximum[54].

Diatoms and silicoflagellates require large quantities of dissolved silicon to form their valves. Typical silicate concentrations in the DOMES survey were about 25 µm in the mixed layer, increasing to about 35 µm at 400 m and, unlike either nitrogen or phosphorus, increasing very substantially at greater depths. A concentration maximum was observed at about 3000 m[55].

Phosphorus occurs in three principal forms in seawater: dissolved inorganic phosphorus, dissolved organic phosphorus and particulate phosphorus. In the oceanic environment, phytoplankton directly assimilates dissolved inorganic phosphorus for use in the energy cycle of the cell. Organic forms, particulate and dissolved, result from growth, decomposition, and various excretions and secretions of living cells. Phosphorus in tropical and subtropical surface waters, like nitrogen, is present in relatively low concentrations, and dissolved inorganic and organic phosphorus forms are assimilated as rapidly as they become available. Roels et al.[56] comprehensively reviewed information on phosphorus concentrations in the eastern tropical Pacific. Westward from California along the North Equatorial Current, equivalent nutrient levels of phosphate occur at increasing depths along and perpendicular to the axis of the current. The nutrient maximum is larger and shallower in the east. The phosphate maximum generally coincides with the oxygen minimum, implicating regeneration of biological material as the nutrient source. Phosphate concentrations in the area generally decline from the maximum of 3-3.5 µm at 300-1200 m to a level of 2.25-2.5 µm at the bottom. Typical concentrations in the DOMES data were about 0.32 µm in the mixed layer, increasing to a maximum of about 3.0 µm between 800-1000 m and decreasing slowly to about two-thirds of the maximum at the bottom[57].

Trace compounds, or micronutrients, include metals and organic substances such as vitamins and their precursors that are necessary for algal growth. Values from a station to the north of the DOMES area (32^{o} 41' N, 145^{o} 00' W)[58] show maxima in manganese concentrations at the surface (0.62 nanogram-atom per kilogram) and in the oxygen minimum (0.71 nanogram-atom per kilogram). Copper and nickel concentrations increased with depth.

Suspended particulate matter (SPM) includes living and non-living, organic and inorganic particles. The non-living portion is called detritus. However, even inorganic detritus has bacteria and other microorganisms associated with it, and the term "organic aggregate" is sometimes applied. SPM is an important component of the planktonic food web because it is present in sizes commonly ingested by zooplankton. DOMES results[59] showed mixed layer concentrations of SPM of about 47 microns per litre and maxima (to 110 µg/l) just above the thermocline. Concentrations below 200 m were uniform at about 10 µg/l with a slight increase (to about 12 µg/l) within 400 m of the bottom. The inorganic fraction of the SPM increased near the bottom, suggesting sediment resuspension by bottom currents.

5.6. Pelagic biota

Within the existing contractor exploration claims, the environment includes expanses of oligotrophic subtropical ocean. Data were not available for the Indian Ocean claim area in particular, but the environment is similar and can be expected to have the same and similar types of biological resources as those found in the CCFZ.

5.6.1. Bacteria

Bacteria are found throughout the water column as well as in the sediments. These microbial decomposers are concentrated at the sea surface, in the oxygen-minimum zone and in the sediments. They are associated, as organic aggregates, with all detritus, and their remineralisation of organic matter provides a major source of nutrients for use by algae. Sorokin[60] found that bacterial aggregates constituted 20-40% of oceanic particles, with little depth variability other than a slight concentration at the bottom of the thermocline. The size of the aggregates (larger than some small phytoplankton) makes them easily available as substrate for fine filter feeders, but also for coarse filter feeders and even selective feeders such as larval fish. He estimates that "bacterioplankton" are as important as algae as a primary food substrate.

5.6.2. Phytoplankton

El Sayed and Taguchi[61] examined water samples from the DOMES area and identified 163 types of diatoms, 122 dinoflagellates, 48 coccolithophorids and 15 other types. The coccolithophorid *Gephyrocapsa huxleyi* was the dominant species of phytoplankton at the depth of the chlorophyll maximum. In subtropical surface waters, nutrient concentrations are low and phytoplankton populations, measured by either cell counts or chlorophyll *a* concentrations, are sparse. Daily primary productivity is low, 100-200 mg of carbon per m^2.

A subsurface maximum is seen in chlorophyll *a* concentrations below the mixed layer. Concentrations of about 0.06 mg/m^3 are found in the mixed layer but are three to four times those at 70-80 m. Typically, production is limited by the low availability of nutrients in near-surface waters and by the decreasing availability of light at greater depths. Surface light at these latitudes is generally so intense that a thin layer at the surface experiences photoinhibition. The highest values of gross primary production are found at about 40 m, while the most efficient productivity (maximum production per unit of chlorophyll) is usually found below 50 m. The photic zone, above the depth at which 1% of the surface-light intensity remains, generally descends to about 90 m in these clear, oligotrophic waters. The concentration of chlorophyll *a* and SPM creates a discontinuity in light attenuation at the top of the pycnocline.

5.6.3. Zooplankton and micronekton

Hirota[62] sampled zooplankton and micronekton in the DOMES area. Microzooplankton and nanozooplankton were sampled from waters to a depth of 200 m. Macrozooplankton were sampled to 1100 m and micronekton were collected with a midwater trawl.

Micronekton biomass ranged from 280-580 g/100 m^2 (median 358 g/100 m^2), with greater than half accounted for by fish, particularly myctophids (lantern fish). Macrozooplankton concentrations were highest (10 g/1000 m^3) in the upper 150 m, lowest at about 200 m in the oxygen minimum, and intermediate between 200 and 900 m. Maximum concentrations of neuston (surface-dwelling macrozooplankton and fish larvae) were 50-100 mg/m^3. Most taxa of micronekton showed density maxima within the upper 100 m of the water column.

Among the filter-feeding macrozooplankton (mostly herbivores), the most important are the calanoid copepods and larvaceans. The somewhat larger omnivores, mainly medium-sized copepods and adult euphausiids, are more important in terms of energy flux through the community because of their greater vertical range and diel migrations. Carnivorous macrozooplankton include larger copepods, larval fish and chaetognaths, with the latter the most abundant.

5.6.4. Nekton

Non-commercial nekton common in the DOMES area included some squids, lancet fishes, flying fishes, lantern fish, rat-tail fish, pelagic shrimp and euphausiids.

Commercial fish species, including tunas, tuna-like species and billfishes, are found all across the Pacific Ocean at tropical and subtropical latitudes. The following species, due to their commercial importance, are of primary interest: yellowfin tuna (*Thunnus albacares*), big-eye tuna (*T. obesus*), skipjack tuna (*Katsuwonus pelamis*), albacore tuna (*Thunnus* *alalunga*), blue marlin (*Makaira nigricans*), striped marlin (*Tetrapterus audax*), shortbill sportfish (*Tetrapterus angustirostris*), ono or wahoo (*Acanthocybium solandri*) and mahimahi (*Coryphaena hippurus*).

Most billfishes and tuna-like species are top-level predators like the tunas, although they occur in the same open-ocean habitat. The billfishes and tuna-like species are solitary rather than schooling fish. Most species are regarded as being as highly migratory as the tunas. Like the tunas, their latitudinal range is seasonal, with movement to higher latitudes in warm seasons and to lower latitudes in cold seasons.

Tunas (and some billfishes) are distributed vertically to great depths. The depths of greatest concentrations are stratified with some overlap among species. Striped marlins are taken mostly at 150-290 m, yellowfin tuna at 150-300 m and big-eye tuna at 290-380 m[63]. Skipjack tuna usually occur in surface schools associated with flocks of seabirds. Although small yellowfin tuna tend to school at the surface, either as mixed schools with skipjack or as discrete schools of their own kind, larger yellowfins are deep swimming.

Although the distribution of tuna larvae is less extensive than that of the adults, skipjack tuna and yellowfin tuna larvae are most abundant around Hawaii in the summer (as are blue marlin, mahimahi and wahoo larvae), and big-eye tuna larvae are distributed as far north as 25° N in the Central Pacific Ocean. The distribution of billfish larvae somewhat resembles that of big-eye tuna in the Central Pacific[64]. Spearfish larvae are found across a broad area of the subtropical North Pacific. Tuna larvae are distributed vertically to depths of 130 m or more but most are confined to the upper 50 or 60 m column[65].

Larval fish collected in the DOMES area included members of commercially important pelagic species but were primarily representatives of midwater and near-surface species of no commercial significance. Larvae of commercially important species were more concentrated in the upper 200 m and especially in the neuston. In the 200-1000 m range, few larval fish were found[66].

5.6.5. Marine mammals

Several marine mammals have been sighted in the CCFZ. A number of species of dolphins have been spotted in the northeastern Pacific Ocean and may be present in the contract areas, though most species are most often seen closer to land. The Pacific bottle-nosed dolphin (*Tursiops truncatus*) occupies a variety of habitats, especially in the seaward edges of banks surrounding islands. Individuals grow to a size of 4 m and more. The spotted dolphin (*Stenella attenuata*) is very common in Hawaii but is found nearly always at least 3 km from shore and may be present in the zone. The spinner dolphin (*Stenella longirostris*) is also found throughout in the eastern tropical Pacific. Schools tend to remain in well-defined home ranges. These dolphins eat primarily mesopelagic fishes and epipelagic/mesopelagic squid. The rough-toothed dolphin (*Steno bredanensis*) is common and is likely to inhabit the CCFZ.

All of the large baleen whales move from polar or temperate regions in spring and summer toward the equator in fall and winter; however, neither the migratory routes nor the seasonal distribution of blue whales are well mapped. Blue whales (*Balaenoptera musculus*) are distributed south from the southern Chukchi Sea to waters off Panama. Leatherwood et al.[67] report that substantial numbers have been spotted at 1300-2800 km off Central America at latitudes between 7^{o} and 9^{o} N in February, March and June. These authors also report that blue whales have been reported far offshore from northern California in May.

The fin whale (*Balaenoptera physalus*) summers in northern waters of the Bering Sea and south as far as central Baja California. Leatherwood et al.[68] report that in winter their distribution extends at least from the Big Sur area off central California south to Cabo San Lucas, Baja California. The authors further state that much of the population is believed to winter far offshore and thus these whales are probably present in the CCFZ at least during the summer.

Determination of the range of the sei whale (*Balaenoptera borealis*) is hampered by historical lumping of this species with the Bryde's whale in whaling logs. It is primarily a pelagic temperate latitude species; however, the winter range extends to at least off Baja California, and Leatherwood et al.[69] report recent sightings in the eastern tropical Pacific Ocean. The sperm whale (*Physeter macrocephalus* or *P. catodon*) is found throughout the eastern North Pacific, but south of latitude 40^{o} N during the winter[70].

PRESENTATION ON PRIORITIES FOR IMPACT ANALYSIS OF DEEP-SEABED MINING

Dr. Morgan began his presentation by stating that he worked not as a scientist but as an environmental impact specialist. Environmental impact analysis was like engineering in that it employed science, but it was certainly not science.

Exploration of the deep seabed had been under way since the mid-1960s and was taking place now. Mining-system tests had just begun in the late 1970s and early 1980s but were not taking place now. To his knowledge, not one of the active contractors had scheduled such a test; not one was listed specifically in any of the 15-year plans of work and there certainly would be none in the next 5 years. Moreover, little was known about commercial mining of the deep seabed. Several speculative mechanisms for doing the work had been discussed. Yet, only meagre ideas had been advanced about how the crucial bottom interaction would take place: what, if any, mobility the mining vehicle would have, how fast it would move, how it would interface with the ocean surface, what would be done with the discharge materials collected at the mining ship. None of this was known and anyone who said otherwise had kept the secret well over the years.

As exploration was an active endeavour, there was a real need to for guidance on environmental standards so as to optimise exploration time and take advantage of the significant amounts of information already collected, in order to generate the most useful picture of the environment obtainable from the vast array of data collected since the mid-1960s. The changes in oceanographic techniques over that 35-year period had increased the difficulty of putting the information together into a coherent database – one of the most important approaches to optimising the data related to ocean mining.

A fundamental fact to bear in mind was that it was not known where mining would take place. One of the key duties of an environmental impact analyst was to extract specific information from engineers, planners and lawyers so that the analysis could be done. However, such information could not be extracted in this case because it was not available. Even if everything on the list of monitoring guidelines was done at a selected site, the fact that commercial mining would take place in a few square kilometres within an exploration area covering hundreds of thousands of square kilometres in two different ocean basins meant that the odds of hitting a future mine site were very low. Thus, great care must be taken, when collecting environmental data, to ensure that they could be generalised and that they would still be useful in 5, 10 or 20 years.

Simulations of seabed mining were extremely problematic. At least 20 years had been spent on different methods of stirring up sediments and then trying to infer the implications for an undefined mining system that would collect nodules sometime in the future. Good engineering and scientific work had been done in the Deep Ocean Mining Environmental Study (DOMES), the Benthic Impact Experiment (BIE), the Disturbance Recolonisation (DISCOL) project and the Japan Deep-Sea Impact Experiment (JET). Yet, although a lot of money had been spent on simulations, those directly involved would be the first to admit that they had no quantitative picture of how the mining system would operate. Simulations should be put aside until there was a real system defined by a real mining interest.

One key variable concerned the location of deposits and the implications for environmental impacts. Manganese nodule deposits were found in areas of light sedimentation, where little particulate organic carbon made it to the seafloor. They occurred in places that had heretofore held little interest to humans, primarily because they were as far away as one could go from where people lived. This fundamental limitation should help to focus the development of environmental standards. Many fundamental problems existed and would remain until there was sufficient interest in generating the investment required to get information from these extremely remote environments.

One fact about sediment properties largely killed any prospect of developing quantitative mining simulations, in his view. When box corers were brought up from the bottom, the mud they contained felt granular, because they were an accumulation of faecal pellets from zooplankton and bigger animals, along with chemical precipitations that were much larger. Therefore, when the sediments were disturbed, they behaved in an almost bimodal way: sediments that were finely sheared behaved as fine clays and could create a nepheloid zone that extended far from the disturbance, while sediments that were only moved and not really sheared would fall down as fast as sand particles. This posed a fundamentally intractable problem for any simulation of how mining might affect the seafloor. Until it was known exactly how a mining device would shear the sediments and to what degree, there was no hope of predicting how big the impact area would be or how far from the mining device sediments would settle.

Morgan next commented on the paucity of knowledge about sediment stability in the deep ocean. On the one hand, photographs of a site taken before and after a 200-day interval looked the same – the sediment had not moved. However, some Russians, including Demidova at the 1998 Sanya Workshop[71], had hypothesised that significant redistributions of sediments took place in these environments. Although the time scale was unknown, there was a fair amount of geological evidence for this. In what these researchers called "benthic storms", currents approached the speeds necessary to start redistributing sediments. This did not mean that massive benthic storms were common, for there would probably be much more evidence for them if they existed. However, the hypothesis could not be directly contravened at this time, illustrating the fact that not enough work had been done on the sensitivity of this environment to sediment redistribution.

Knowledge was especially lacking about benthic communities -- their species makeup, their distribution, their sensitivity to sedimentation, their rates of succession and recovery. In fact, none of the other key environmental factors approached this level of abysmal ignorance. Not even the time frames of impacts were known – that is, whether the effects would last for decades or centuries. When working for an ocean-mining consortium, Morgan's central problem had been how to perform an impact analysis when he had no idea about some basic ecological relationships. For this reason, he urged the Workshop to focus on benthic life studies.

DOMES and subsequent programmes had collected millions of bits of information in many scientific disciplines covering the huge Clarion-Clipperton Fracture Zone. That zone extended from close to the North American continent all the way out almost to the middle of the Pacific Basin, from about 7 degrees north latitude all the way up to 20º N. Within that area were all kinds of gradients: for example, productivity dropped off from south to north and the input of sediments from the mainland resulted in a decrease of primary productivity from east to west. The Indian Ocean basin was another huge area subject to natural forces that had not been well defined. Environmental baseline data were meaningful only in relation to an activity. Since environmental assessment was fundamentally linked to a disturbance of nature, until it was known when and where that disturbance would occur, care must be taken in allocating precious resources to obtain information.

In closing, Morgan discussed how to take advantage of contractors' plans for exploratory voyages over the next few years by using such trips as an opportunity to collect environmental data. The contractors would agree, as long as their fundamental objectives, mineral and mining assessment, were not compromised. They would not want to see environmental data collected to the exclusion of mineral-resource assessment. A case must be made that the data sought were crucial now, and the only area he thought worthy of ship time was fundamental problems relating to the benthic biota. A worthwhile objective of the Workshop would be to optimise the collection effort on exploration cruises while adhering to the principle of non-interference with their fundamental goal. Although such opportunistic data collection was valuable, the fact remained that most of the data collection, particularly in relation to the water column, would have to be repeated when it was known where and how mining would take place.

DISCUSSION ON PRIORITIES FOR IMPACT ANALYSIS OF DEEP-SEABED MINING

Benthic community studies

One participant, noting that the jurisdiction of the International Seabed Authority (ISA) was limited to mineral resources, said he understood that its interest in the benthic community concerned environmental problems affecting that community. Was it suggested that the ISA should also consider the community as a resource that could be licensed like minerals?

Dr. Morgan replied that he did not regard the genetic resources of the seabed as falling within the Authority's purview. What he meant was that benthic biota were the only productive subject of environmental assessment at this time. It was not too soon to start studying the time frames for the effects of seabed disturbances. If information could be obtained within a few years about the magnitude of recolonisation rates and species distribution, planning could take place accordingly. There was a great risk that information required for designing mining systems and devising mining plans would be acquired too late. The issue might be addressed in two ways: through basic scientific studies supported partially and recommended strongly by the Authority, and through opportunistic collection that the contractors could do now. He endorsed suggestions for voucher collections and centralisation of taxonomy as a way of optimising the work of under-budgeted pioneer seabed investors, so that in ten years they could be proud of their contributions to the advancement of understanding.

Benthic currents

When a participant expressed surprise at the high speeds cited for benthic currents, Morgan responded that he did not view 10cm/sec as extreme. He had seen spikes up to 10-15 centimetres per second, whereas the averages were certainly much lower.

Professor Craig R. Smith, with Morgan's concurrence, remarked that he was not comfortable with the term "benthic storm". As the rates of 9-10 cm/sec came from 30 metres above the bottom, the flow was probably not resuspending the sediment. Moreover, there were no transmissometry records and thus no data on resuspended sediment. Talk of a benthic storm was using the term liberally for a period of higher flow velocity. Whether sediment was being resuspended and transported was an open issue, on which harder data were required.

Another participant spoke of cliffs up to 40 m high on the seabed, some of them overhanging and collapsing from time to time. Such periodic movements implied the existence of slopes extending for some distance.

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Chapter 5 Parameters And Standards for Assessing Sedimentary and Manganese Nodule Facies in a Potential Mining Area in the Peru Basin

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This paper focuses on geoscientific results of research undertaken in the Peru Basin. The Peru Basin, in the southern Central Pacific Ocean, is a potential future mining area for manganese nodules. Several interdisciplinary cruises with the German RV *Sonne* were conducted in the area during the past 10-12 years, covering biology, sedimentology, geochemistry, soil mechanics and other disciplines. The objectives of these projects included a proper description of the current environmental situation at the seafloor and a definition of potential impact-sensitive parameters, well in advance of any deep-sea mining activity. The results presented here stem from two survey areas: (1) the Disturbance Recolonisation (DISCOL) project area at about 88 degrees 30 minutes west longitude / 7° south latitude and (2) an area about 230 kilometres further west (Sediperu area).

In this article, I will present a selection of those parameters, which turned out to show an often-unexpected variability and, thus, are important for defining the baseline situation. I will concentrate on the geological aspects; results on benthic biology are covered by a contribution of Gerd Schriever (chapter 15 below). Details of the results presented here are covered in a special volume of *Deep-Sea Research II* [1].

1. Large-Scale Parameters

1.1. Bathymetry

Bathymetric mapping in the survey areas of the Peru Basin exhibited abyssal hill topography with water depth often between 4000 and 4400 metres. However, some hills were higher and one huge seamount towered about 2 km above the general seafloor level. A general topographic pattern became obvious: north-south aligned, elongated 200-

300 m deep basins alternating with ridges. These structural features are from a few km to 10 km wide, and can be followed for tens of kilometres. Some show relatively steep slopes, which appear controlled by block faulting of the underlying basaltic basement[2]. Additionally, small volcanic cones, 25 m high and a few hundred m wide, are scattered in the area.

Conclusion: A bathymetric map with complete coverage of the area under investigation is essential, because the topographic variation is greater than previously expected. Slope inclination places limits on potential mining and is an important parameter for different environmental settings.

1.2. Sediment echo sounding

Use of a parametric 4-kilohertz sediment echo-sounder system made it possible to distinguish different sediment sequences and, where the sediment cover was thin, to define the thickness of the entire sediment cover above the volcanic basement. Besides an overall increase of sediment thickness towards the north, the Quaternary sequence was found to vary greatly: e.g. thinning of the sequence towards some of the larger volcanic cones but thicker-than-usual deposits “behind” some hills, erosional windows within the Quaternary cover (exposure of Tertiary strata at some ridges), indications of downslope sediment transport at some steep ridge flanks (slumping)[3].

Conclusion: Sediment echo sounding reveals variability in the thickness of the youngest sediment sequence. It shows (ongoing) natural sediment redistribution or indications of a higher-than-expected dynamic in this environment. Thus, neighbouring locations may differ in their long-term “inherited” history. This variability of the substrate is an important parameter likely to influence the character of the benthic communities.

1.3. Sea-floor reflectivity (side-scan sonar imaging)

Side-scan sonar profiling showed that the seafloor often displayed a high acoustic reflectivity (relatively hard surface layer) that is occasionally interrupted by irregular zones (50-400 m wide) of low reflectivity (soft surface). This low reflectivity occurred at ridge crests and elevated plateaus. It marks surface areas where the otherwise common manganese nodule coverage at the seafloor surface was lacking[4]. Furthermore, small (25 m high and 100-300 m wide) volcanic cones were detected that were barely covered with soft sediment. This detail was completely unexpected on oceanic crust thought to be 16-18 million years old.

Conclusion: Side-scan sonar surveying contributes to an understanding of small topographic features (steps, escarpments, faults, potential obstacles) and makes it possible to characterise the seafloor surface (soft bottom, hard-rock outcrops, nodule coverage). The extent and density of manganese nodule coverage is also an important parameter for benthic communities. Note again the small-scale variability at scales of 50-100 m in some areas.

1.4. Calcite Compensation Depth

Measuring the content of carbonate in numerous surface sediment samples allowed us to define the Calcite Compensation Depth (CCD) for the areas investigated. (CCD defines the shallowest water depth at which sediments at the seafloor are found to be free of carbonate.) CCD was found to differ between the DISCOL area (water depth 4100 m) and the Sediperu area (water depth 4250 m) by about 150 m over a lateral distance of 230 km[5]. The significance of CCD for baseline studies in the Peru Basin is manifold: it marks a fundamental change in the geochemical composition of the sediment as a substrate for faunal communities, carbonate components change the density and geotechnical properties of the surface sediment, and growth rate and coverage of manganese nodules were found to be related to CCD (see section 2.1 below) – again an important substrate parameter for benthic communities.

Conclusion: CCD varies considerably on a lateral scale and, therefore, has to be defined for each survey area (locally). It provides a prime parameter for assessing general water-depth related trends for substrate characteristics and nodule abundance.

2. Parameters Determined from Sediment Samples

2.1. Sediment-surface characteristics

The most important variation in the character of the sediment surface in the Peru Basin was caused by the presence or absence of manganese nodules. As pointed out above (section 1.3), acoustic methods can help to distinguish between nodule-covered and nodule-free areas. High abundance (kilograms/m^2) of manganese nodules was found to occur in water depths at or close to the CCD; in the DISCOL area this was between 3950 m and 4250 m[6]. Highest abundances were sampled at 4150 m and only slightly lower values were found at 4000 m. However, at the shallower depth a very tight "cobblestone" cover of small nodules (about 5 cm diameter) was observed, while at the deeper location few but very large nodules (about 15 centimetres in diameter) were scattered over the sediment surface. The "cobblestone" cover resembles a hard ground situation, providing a substrate for sessile organisms. This depth-related trend combined with varying bathymetry results in a highly (but systematically) variable environment on a local scale.

Conclusion: The observation of depth-related trends in manganese nodule character and distribution provides a key to understanding a complex pattern of marked environmental differences in the sediment surface ("hard ground" vs. soft sediment).

2.2. Sediment composition, sedimentation rate, stratigraphy

Considerable variation of sediment composition in the Peru Basin was observed in the topmost 30 cm. The main components, such as carbonate, clay minerals and biogenic opal, differ laterally and vertically, often by factors of several tens of percent. Influencing the composition, in addition to water depth (carbonate dissolution), are sedimentation rate (less than 0.1 - 2.3 cm/thousand years) and stratigraphy: thus, in areas of locally high deposition (e.g. current-induced, behind obstacles) the topmost sediment section may be of uniform composition due to its young age. Other sites of low sedimentation showed a downcore increase in carbonate of up to 20 percent in the upper 10 cm of the sequence (last glacial carbonate maximum)[7]. We also encountered sites where carbonate ooze of Tertiary age was exposed at the seafloor[8].

Conclusion: Sediment composition is one parameter for defining the substrate of benthic communities. Knowledge of its variations in the upper 30 cm of the sediment is also important for assessing the consequences of mining activity (e.g., the character of the resuspended sediment plume) and the mechanical properties of the sediment. Sediment age and sedimentation rates provide an extremely helpful framework for understanding observed variations in sediment composition and its systematics (downcore zonation).

2.3. Thickness of semi-liquid layer

In the Peru Basin, the semi-liquid layer -- the intensively bioturbated, homogenised upper sediment layer -- is considerably thicker than that in the Clarion-Clipperton Fracture Zone (CCFZ). Thickness varies mainly between 8 and 12 cm (up to 20 cm including the transition zone). As the semi-liquid layer is dark brown (oxic, rich in Fe/Mn oxides[9]) and mainly underlain by a suboxic, light-olive coloured sequence, a quick and easy method to define its thickness is colour measurement of the sediment[10]. Other methods that we applied include measurement of water content/porosity, bulk density and shear strength[11]. Methods may differ by 2 cm in defining the lower boundary of the semi-liquid layer; this is also due to a transition zone below. Shear-strength defined thickness of the semi-liquid top shows a slight increase in thickness with increasing water depth.

Furthermore, there appears to be a relationship between the thickness of the semi-liquid layer and the size of manganese nodules: sites with a thick semi-liquid layer tend to have smaller nodules (and a fairly slow growth rate)[12].

Conclusion: The semi-liquid layer in the Peru Basin is considerably thicker than in the CCFZ (due to its higher sedimentation rate). Its thickness is a key parameter for assessing the near-bottom impact of future nodule mining (extent of the resuspension plume).

2.4. Bioturbation

Besides the intensive biological activity responsible for the homogeneity of the semi-liquid top layer, cores taken in the Peru Basin display deeper reaching bioturbation, which generates a mottled appearance of the sediments. Mottling results from mixing of olive-coloured sediment with dark brown sediment from above (or infill of surface sediment in burrows). Thus, the downcore colour record, with its often greater than 10 cm "transition zone" below the semi-liquid layer, provides a first measure to assess how deep this zone of bioturbation may reach. Analysis of excess Pb-210 indicates that, in the Peru Basin, near-recent sediment (age: <200 years) is mixed downcore with older sediment to a depth of between 15 cm and >45 cm (often down to 30-45 cm)[13]

Conclusion: Traces of biological activity are found downcore, often to a depth of 30-45 cm, indicating that some organisms can burrow well beyond the semi-liquid layer, to which biological studies are occasionally restricted.

2.5. Organic carbon content

Organic carbon contents in the Peru Basin are relatively low, ranging from 0.3-0.8%. Above the CCD, there appears to be a relationship between water depth and organic carbon content: with increasing dissolution of carbonate the content of organic carbon increases; however, once the CCD is reached, no obvious trend can be reported[14].

Conclusion: Organic carbon content describes the nutrient level of a substrate that is needed to characterise benthic communities. It is also important for assessing oxygen consumption due to the decay of organic matter and the related transition from an oxic to a suboxic environment in the near-surface sediments.

2.6. Other sediment parameters

Additional sediment parameters have been defined for the Peru Basin that are not presented in this paper, e.g. physical properties and pore-water composition. Details are given in several articles of the special volume of *Deep-Sea Research II*[15].

3. Modelling and Laboratory Tests

3.1. Miner-produced resuspended sediment plume

Based on laboratory work on Peru Basin sediment samples and literature on other deep-sea environmental projects in conjunction with technical details of a manganese nodule mining system, Oebius et al.[16] have tried to assess the impact that a “miner” would have on the seafloor environment. (“Miner” refers to the self-propelled vehicle at the seafloor that collects the manganese nodules.) I touch only on those results that provide a general view of the impact, in the absence of mining test runs in situ.

The results rest on the following assumptions: A mining system with a self-propelled bottom vehicle will be used, about 6 m wide and about 3 m high (“German mining system”); this miner will use water jets to separate nodules from surface sediments; the bottom vehicle will move at velocities of about 1 m/second.

The most interesting findings were that only about 20% of the sediment affected by mining will be resuspended, while most of it will form large chunks, will be remoulded and will quickly resettle behind the miner.

For these boundary conditions, a solid mass flow of 85 kg/s was calculated for the resuspended material. This would induce a suspension cloud of about 54 m^3/s with a solid mass of 1.6 grams/litre.

Conclusion: The results are considered a first approach; additional parameters for a realistic impact assessment are needed. In particular, a determination of sediment grain size must take account of how nodules are collected. In situ tests using a specific mining procedure will help to define a more realistic model of sediment resuspension than that based on laboratory-defined grain-size composition.

3.2. Near-bottom sediment transport modelling

Jankowski & Zielke[17] have calculated near-bottom sediment transport in the Peru Basin based on the following assumptions: a sediment discharge of 10 kg/s for a duration of one day, resuspended in six days, and bottom current velocity mostly <10 cm/s. Their results include the following:

?? The plume residence time is about 1.5-6 days.

?? Plume extent is approximately 15 km before background particle concentration of suspended sediment is reached again.

?? About 0.5 mm of sediment cover will settle 1-2 km alongside the miner track; with continuous discharge, sediment cover near the track may reach up to 30 millimetres thick. (Flocculation effects have not been considered and may accelerate redeposition of sediment.)

Conclusion: These results suggest a predominantly local impact of near-bottom resuspended sediment. However, the modelling is not sufficiently supported by mining-specific field data, which are urgently needed.

3.3. Modelling long-term propagation of tailings (for DISCOL area)

Rolinski & Sündermann[18] used a global scale Lagrangian transport model to calculate the dispersion of tailings released from a mining vessel in the Peru Basin. To arrive at realistic current velocities, a global geostrophic circulation model was used.

Their results rest on the following assumptions: Currents are determined according to the large-scale geostrophic ocean model; bottom-current velocity is mostly 3-5 cm/s.

The authors used two grain-size distribution curves, one determined by grain-size analysis in the laboratory, and the second, coarser one, from Oebius and co-authors[19]. Significant results are:

For grain-size distribution A (mainly 1-70 microns):

?? Resettlement of 90% of tailings will occur within 3-10 years for a release depth 3000 m below the sea surface, resuspended 500 m below the surface.

?? Assuming El Niño conditions, transport will be directed predominantly eastward and deposition will occur near the coast; assuming La Niña conditions, a predominant transport direction is less apparent, but will be westward for releases at great water depths.

For grain-size distribution B (mainly 5-300 µm):

?? Deposition will be nearly instantaneous (99% within <1 month) and will be completed within 100 km from the source

Conclusion: Proper modelling greatly depends on the grain-size distribution of the material released. Therefore, it is important to define the grain size in practical tests, using seawater. Sediment material will not necessarily completely disintegrate during the mining operation and clay minerals in natural environments may coagulate, resulting in much faster settling of agglutinated aggregates. In order to restrict dispersion, the release of tailings at great water depths is recommended.

4. Survey and Sampling Strategy for a Baseline Study

Based on the above results, a generic survey and sampling strategy is suggested for baseline studies which takes account of observed trends from our Peru Basin investigations and tries to minimise efforts to cover natural variability:

I. Survey with acoustic methods

a) Acquire bathymetry of a survey area (a full-coverage bathymetric map is needed) with sufficient resolution (approximately 10-m contour lines).

b) Map sediment distribution and thickness using a high resolution sediment echo-sounder system (profiles along and across are required). (Bathymetric swath mapping and sediment echo-sounding systems can normally be run in parallel.)

c) Deploy a (deep-towed) side-scan sonar system to define small topographic features and acoustic reflectivity of the surface (e.g. coverage with nodules, etc.).

d) Check and classify side-scan results using photo-sledge runs.

II. Define facies types

Based on the results from the initial surveys, several facies types should be defined, based on differences in morphology (basin, slope, steep escarpment, ridge, plateau), sediment character (thickness of sequence, stratification, acoustic transparency, reworked sediment, erosion, etc.) and fine-scale surface features (nodule coverage, fault steps, etc.). This approach also appears reasonable in the CCFZ, where a variety of sedimentary facies zones have been reported[20].

III. Characterise sediment-facies types by seafloor sampling

a) Sample different facies types adequately (taking account of their distribution), using a box corer and multicorer.

b) Take two or three cores at each site to cover fine-scale variability.

c) Preserve samples onboard the vessel / analyse various parameters (e.g., immediately dry samples for organic carbon determination; sample pore water in cold-room conditions, using a glove box and an inert gas atmosphere).

IV. Laboratory test and modelling using the above parameters

5. Instruments and Methods used in the Peru Basin

The following is a list of the major instruments and methods used for the investigations:

?? Conductivity-temperature-depth (CTD) instrument (Seabird) with rosette water sampler (Niskin bottles)
?? Hydrosweep swath-mapping system
?? Parasound sediment echo sounder (4 kHz)
?? Deep-towed side-scan sonar (operating frequency 59 kHz)
?? Deep-towed photo/video sledge (3 m distance to seafloor, real-time video transmission, glass fibre cable)
?? Surface sampling:
  o Box corer (Reineck-type) (50 by 50 by 50 cm)
  o Multicorer (40x10cm, excellent quality)
  o Maxicorer (50x30 cm, good quality)
?? Long corers:
  o Piston corer (Kullenberg-type), diameter: 9, resp. 11 cm, length up to 20 m
  o Gravity corer: 5-10 m length
?? Core-logger (Geotek) (density, primary wave [*P* wave] velocity, magnetic susceptibility)
?? Geochemical composition of sediments by X-ray fluorescence (XRF) / X-ray diffraction (XRD)
?? Carbonate content via volumetrically determined CO_2 (also using pressure sensor) from reaction with HCl
?? Organic carbon with Leco furnace
?? Pore-water sampling (cold room, under inert gas [O_2-free], inert storing bottles) (O_2, NO_3, NH_4, SO_4, H_2S, PO_4, SiO_2, Fe, Co, Ni, Zn, Cu, Pb, Ti, Cd, Mo, V, As)
  o Dissolved nutrient-type ions measured photometrically
  o Heavy metals determined voltametrically

- o O_2 by Winkler titration and Clarke-type microelectrode

For more details on methods, especially those used for analyses in shore-based laboratories, see the more specialised articles cited in the references below.

SUMMARY OF PRESENTATION AND DISCUSSION ON PARAMETERS AND STANDARDS FOR ASSESSING SEDIMENTARY AND MANGANESE NODULE FACIES IN THE PERU BASIN

Introducing his paper, Dr. Wiedicke began by expressing the view that Charles Morgan had overstated his point about benthic community studies (see chapter 4). Even accepting the idea that those communities deserved top priority, their relationship with the substrate could not be neglected.

He cited three approaches to measuring the important parameters, all relevant to baseline environmental studies and impact assessment: (1) large-scale investigations such as bathymetry, fine-scale topography (recorded with a different system) and examination of sediment distribution; (2) sediment-specific studies on factors such as surface characteristics, and (3) research using modelling and laboratory tests. Much more information -- covering biology, sedimentology, geochemistry, soil mechanics and flow modelling – could be found in a special new volume of *Deep-Sea Research II*.[21]

Large-scale parameters

Regarding the Peru Basin of the Pacific Ocean, off the west coast of South America, he said its topography, controlled by the underlying rocks, was characterized by a pattern of grabens and ridges, with basins, slopes and even seamounts. Researchers mapping seafloor depths had found a previously unknown seamount about 3 kilometres high. Compiling a good bathymetric map was a top priority, because many environmental parameters were controlled by water depth.

Another finding concerned the inclination of the seabed slope. Mining-design experts thought the slope would present a problem for mining operations, at least at present, though this might change with technological development. There was also a need to know the sediment facies type, which was affected by downslope transport of materials and the removal in some areas of the semi-liquid layer covering the nodules. These differences were also likely to show up in the benthic communities; for example, a species collected from a slope might not be found elsewhere.

Regarding the distribution of sediments, he cited echo-sounder profiles from the Peru Basin and the Sediperu area to the west, showing a north-south gradient in terms of sedimentation rates. At one location, researchers had extracted a core that was entirely from the Quaternary Period, about 2 million years old, in a sediment layer 20 metres or thicker. According to all that was known of the Peru Basin, this was the source of the remobilised manganese that eventually showed up in the nodules on top. About 20 km further south, a core showed Quaternary sediments only four m thick. Such differences explained the variation in nodule coverage. The occurrence of manganese nodules in the Peru Basin depended greatly on Quaternary sediments. If that sequence was available, nodules could be expected; if not, there would be a problem finding them.

Some indication of downslope slumping of sediments had been detected in places. Such information was important because, if the area were to be sampled without knowing that it was a naturally disturbed environment, the results might wrongly be attributed to a mining operation.

Some Tertiary Period sediments exposed at the seafloor were characterised by calcareous ooze lacking organic carbon, resulting in a completely different animal community. Their presence proved that a large amount of sediment redistribution had occurred, because otherwise the Tertiary sediment would not be found barren of younger sediments.

Side-scan sonar had been deployed in the western area to map the seafloor surface. This system recorded the hardness of the sediment, as measured by the acoustic reflectivity of the sediment surface. The results showed neighbouring areas with sharp boundaries between high and low reflectivity on a small scale of 50-100 m, which would be hard to detect without a proper preliminary survey. The difference in reflectivity was due to the fact that some areas completely covered with manganese nodules were close to areas that had hardly any nodules on top.

The sonar was a deep-towed system, operating about 50 m above the seafloor at a frequency of 35 kilohertz. Used in conjunction with mapping procedures such as bathymetry and sediment echo sounding, it defined sedimentological facies types. This approach was usable as well in the Clarion-Clipperton Fracture Zone (CCFZ). By summarizing the characteristics of the sediment sequence, it revealed fields that had almost no sediment coverage and others with varying thickness of young sequences, associated with different nodule types and coverage and, most likely, different benthic communities.

Sediment and nodule characteristics

Comparisons between potential mining regions of the Peru Basin and the Sediperu area showed considerable differences in terms of surface-water productivity, as measured by phosphorus oxide, opal and barium levels, with consequent differences in the characteristics of each area. Another important parameter having a lot to do with the growth of manganese nodules was Carbonate (or Calcite) Compensation Depth (CCD), i.e., the water depth below which no carbonate was present. CCD was 150 m deeper in the Sediperu area, for example.

Wiedicke cited a comparison between two samples from the Peru Basin, one from a lesser depth having many nodules about 4 centimetres in diameter and another from a greater depth with fewer but larger nodules. Such differences were closely related to CCD, which was thus a significant factor both for the biota and for any mining operation. The overall pattern in the Peru Basin showed a semi-liquid brown layer overlying a suboxic yellowish to brown layer. The manganese nodules grew and lay atop the brown layer. Manganese in the sediment was removed and remobilised in the suboxic layer, moved upwards with the pore-water flux and redeposited in the surface layer.

One of the most important parameters to define was the thickness of the brown top layer, which was the target for mining as well as the area where most of the animal life was concentrated. A box-core sample used for illustration indicated a mixing, due to bioturbation, of dark sediment on top and lighter-coloured sediment beneath. The density profile, from top to bottom, showed an initial increase followed by a decrease, reflecting the carbonate content, which increased to a certain depth and then decreased. From studies of the Pacific Ocean it was known that carbonate production during glacial periods was much higher than today, so the carbonate maximum in the sediment column, in this case at a depth of 10 cm, was considered to represent the glacial period of about 17,000 years ago. Opal content and *P* wave velocity also dropped at first and then rose significantly.

Another useful way to define the top layer was to look at its shear strength. A typical core sample had a semi-liquid top layer with hardly any shear strength; a transition zone and a bottom layer with much higher shear strength. A top layer defined in terms of mechanical strength was not necessarily the same as one defined on geochemical terms. Some observers saw a trend according to which the thickness of the top layer increased with water depth, but Wiedicke was not convinced of that because the observation was based on samples from one area and the same water depth, whereas other areas had not been sampled. In his view, the data reflected local variations rather than a trend. The low in *P* wave velocity was much better defined in shallower than in deeper water -- an effect of sediment composition, as there was much more carbonate at higher levels.

Bioturbation rates had been studied by measuring Pb-210. With a half-life of about 22 years, this isotope disappeared after about 200 years. Core samples showed a decrease of Pb-210 from top to bottom. However, in one representative sample the radiation signal was detected below 30 cm even though the bulk of glacial sediment from 17,000 years ago was at a depth of about 10-15 cm. Such data were explained as a mixing of more or less recent sediment into deeper levels, due to bioturbation. Another sample from the Disturbance Recolonisation (DISCOL) project area showed this effect down to more than 40 cm.

According to one theory, the thickness of the top layer was related to the effectiveness of remobilisation of the manganese below, with consequences for surface characteristics. Dense coverage of small nodules occurred because they were so small they did not reach down to the current level of manganese oxide precipitation; they grew slowly because their only source was manganese precipitation out of the water column. This produced a secondary high of manganese at a certain depth, in an area where the top layer was thicker. In places having a relatively thin layer, with more efficient manganese remobilisation, there were large nodules that reached down to the level where the manganese was being precipitated, thereby dramatically enhancing nodule growth. The growth rate of manganese nodules in the Peru Basin, at least for the large ones, was about 20 millimetres per million years, or several orders of magnitude higher than in the CCFZ.

Modelling and testing

Wiedicke described calculations of mining impacts that might result from the use of a self-propelled mining and collector system about three metres high and six metres wide, moving at the speed of one metre per second and employing water jets to dislodge manganese nodules from the sediment surface. Using data gathered in the Peru Basin concerning the thickness of the top layer and information from other groups that not all of the fine sediment would be redistributed and resuspended, one group in Berlin[22] had calculated that a maximum of only 20 percent of the sediment would be resuspended; most would quickly be remoulded into chunks of sediment deposited behind the miner. This was regarded as a first approach that demonstrated the great need for additional parameters before the numbers could be taken seriously.

Another group had calculated near-bottom sediment transport assuming sediment discharge of 10 kilograms/second, between 1 and 6 days duration, and bottom-current velocity less than 10 cm/s. They had come up with a plume-residence time in the order of 1.5 to 6 days, a maximum distance of 15 km from the track before background concentration was reached and sediment coverage of about 0.5 mm in the 1-2 km zone alongside the track. For continuous discharge, they had modelled sediment coverage as thick as 30 mm close to the track of the miner. They had not calculated flocculation effects. According to this model, the plume would have a predominantly local impact. These calculations concerned the bottom plume produced by the miner, not the tailings from above.

Still another group had looked at the long-term propagation of tailings discharged from a processing ship at the surface. They had used a well-established geostrophic ocean model that was fairly evolved for this purpose, although it did not take account of tidal movement. A bottom-current velocity of between three and five centimetres per second was assumed. The model had utilised two different grain-size distribution patterns: one as defined in laboratory tests and the other resulting from practical experiments in which the material was not completely dispersed in the water column. The differences in result were striking. Under the worst case scenario, resettlement of 90% percent of the tailings would take three to ten years, depending on release depth: three years at 3000 m below the surface and ten years at 500 m below. Resettlement of 95% would take 5 to 14 years. Transport under El Niño conditions would be predominantly eastward, with deposition on the coast; under La Niña conditions, the transport would not take any particular direction. With the other grain-size distribution, there would be nearly instantaneous deposition of 99% of the material within less than one month, to a distance of barely 100 km from the source. He understood that tailings release as close as possible to the bottom was recommended. As the model depended greatly on the reliability of information about the properties of the released material, precise information on grain size was needed before reliable modelling was possible.

Wiedicke listed the basic instruments (other than laboratory devices) deployed to measure the parameters he had identified: a conductivity-temperature-depth (CTD) test device, complete coverage with a swath mapping system to produce a good bathymetric map, a sediment echo-sounder system, a deep-towed side-scan sonar operating at a frequency of 59 kHz, a deep-towed photo sledge system with real-time video transmission to the ship via a glass-fibre cable, long corers, box corers, multicorers and maxicorers. While biologists depended on box corers to pick up material, multicorers and maxicorers also captured the bottom water above the sediment, without creating much resuspension of material transported from the surface. The maxicorer, a specially developed instrument that did similar sampling on a larger scale, had been used to investigate sediment strength and soil properties. Pore-water sampling had to be done under cold-room conditions in gas and the samples had to be stored in special bottles; most of the analysis had to be done onboard ship if the samples were to be useful.

He offered his understanding, admittedly incomplete, of what a sampling strategy should look like:

?? The area should be properly surveyed with mapping systems – a sediment echo-sounder system in parallel with bathymetric mapping.

?? Sediment-surface properties should be investigated with a side-scan sonar system (though the deep-towed system his group had used was quite time consuming and might be made obsolete by fast-evolving future systems such as a swath mapping system that could also map reflectivity).

?? Data from these sources should be used to define facies types and distribution, as a means of understanding fine-scale variations.

- ?? Classification of facies types should be verified by looking at their surface with a video system.

- ?? Samples should be gathered and tested onboard for various properties.

- ?? Finally, laboratory testing and modelling should be conducted.

In conclusion, he suggested that the large-scale and sediment parameters he had described be used also as an environmental framework for defining the benthic communities.

SUMMARY OF DISCUSSION

Sonar mapping anomalies

A participant from the Korea Ocean Research and Development Institute (KORDI) said his organisation, using a 12 kHz side-scan sonar system on a manganese nodule field, had found a substantially higher backscattering strength than Wiedicke had reported. This was a standard frequency used in Hydrosweep and many other deep-water systems. As KORDI had generally found a greater abundance of nodules, his people had thought at first that this might be due to reflection from the nodules themselves. Another possible explanation, however, was that, because the wavelength at 12 kHz was much bigger than the nodule, the effect might be due to the physical property of the substrate 10 or 20 metres below the nodules; thus, besides a reflection directly from the nodules, it was also coming from the upper substrate.

Wiedecke-Hombach replied that similar observations had been recorded in the Pacific Ocean with other kinds of side-scan sonar systems; strange features had been found that could not be observed on the surface. The effect had been ascribed to interference of the signal wavelength and its penetration into the uppermost sediment layer. A side-scan sonar system should be geared to the particular target; with small nodules, higher frequencies might have to be used so that nodule distribution would not be confused with sediment properties.

Use of geological data for environmental baseline studies

One participant wondered how the geological studies recommended by Wiedecke-Hombach might fit in with the programme of environmental baseline studies. Since geologists would have to collect such data before any test mining, one approach might be to wait for the results before designing a baseline-sampling programme.

Wiedecke-Hombach agreed that it might be valid to use the survey results in that way. However, as geologists tended to concentrate their sampling on certain areas and topographic types, they could miss other types. In addition to water-depth measurements and a bathymetric map, environmental studies needed to consider the topography of the sampling site. Even at the same water depth, a slope, a basin or the top of a hill were different environments. A hilltop tended to have less sedimentation because currents removed much of the sediment. In some areas, the Tertiary sequence was exposed at the surface, meaning that 2 million years of sediment were missing or had never been deposited. While overall deposition did not change on a small scale, something might occur to remove it, producing a lot of small-scale variability that also affected benthic communities.

He was asked whether explorers might regard such data as proprietary and be unwilling to give away information about nodule resources or the technology they were using. He replied that potential investors were supposed to inform the Authority about the distribution of manganese nodules before they could resister a claim area, half of which was to be set aside for others' use.

A member of the Legal and Technical Commission also expressed the view that environmental information would not be considered proprietary. While he did not know the thinking of contractors, proprietary data would typically relate to the economics of the deposits, such as nodule abundance and metal grades, keys for assessing resources and reserves.

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Chapter 6 Data Standards Utilised in the Environmental Studies of the China Ocean Mineral Resources Research and Development Association (COMRA)

Dr. Huiayang Zhou, Professor of Geochemistry, Second Institute of Oceanography, State Oceanic Administration, Hangzhou, China

SUMMARY OF PRESENTATION

Dr. Huiayang Zhou described and illustrated some of the activities relating to deep-sea environmental impact studies conducted by the China Ocean Mineral Resources Research and Development Association (COMRA).

China, he noted, had two separate pioneer investor areas in the western part of the Clarion-Clipperton Fracture Zone (CCFZ). The purpose of its environmental studies was to predict the potential impact from future deep-seabed mining. COMRA had developed a model system for potential use in deep-sea mining, consisting mainly of a collector on the seafloor and a pipe from the mining ship at the sea surface.

He cited the two places in the ocean that would be most affected by environmental impacts: the upper ocean layer, where tailings might be discharged, and the deep seabed, where the manganese nodules would be mined or collected.

For integrated coastal management, environmental impact assessments were being successfully carried out in nearly every country, using good plans and procedures, he observed. However, China thought that such systems were not suitable for deep-sea environmental studies, for many reasons. As so little was known about the deep sea, the first need was to explore the deep-sea ecosystem and its spatial and temporal variability. Since 1995, China had had a programme called Natural Variability of Baseline (NaVaBa). COMRA, set up in 1990, had done baseline-collection activities while Chinese scientists were engaged in manganese nodule exploration. This environmental study was conducted systematically and had clear objectives.

About 50 scientists were involved in the NaVaBa project. It consisted of two programmes, one for the hydrographic baseline and the other for the biological, chemical and sedimentological baseline. Different research groups used a research ship to make baseline measurements in the two Chinese pioneer areas. Data collection took place along transects, generally from north to south, with some from east to west. Two parts of the pioneer areas, about 80 square kilometres, had been selected for intensive work and comparisons of spatial variability.

The research vessel generally used in the Chinese programme displaced about 5600 tons, though other ships were sometimes used as well. Water was sampled at different depths in the water column with a device that used 12 bottles, making it possible to collect at least 12 layers of samples at one time. An acoustic Doppler current profiler (ADCP) was used to measure currents, and a conductivity-temperature-depth (CTD) device measured temperature and salinity. Oxygen sensors and/or pH sensors were also used at times. The biochemical parameters tested included primary production and chlorophyll *a*. Plankton nets were used to collect plankton from different layers, and a bongo net was employed to measure fish eggs and larvae.

A deep tow with a camera and video was used to measure megafauna on the seafloor. Some work had also been done on fauna attached to manganese nodules. This research generated knowledge about spatial variability. Benthic nets were used to collect megafauna, although specimens were hard to collect because they were destroyed by the manganese nodules in the nets. Box corers were used to sample macrofauna, and for sedimentary and geochemical work. A sieve was used to process the biological samples. A multicorer was used to collect undisturbed surface sediment for meiofauna processing. The ship also had a chemical laboratory that included a cleaning lab for work on heavy metals and processing of pore-water samples.

The seabed meiofauna in the western part of the Chinese pioneer area was generally concentrated in the surface layer (0-1 centimetre) of the sediment. There was some spatial variability, which might be related to the patchiness of distribution of the meiofauna. Zhou displayed data from two sample areas about a mile apart that displayed differences in bioturbation, sediment erosion and chemical composition. In addition, mineral assemblages had been found with temperatures above 70 degrees, possibly indicating hydrothermal activity.

Current-meter chains had been deployed, generally for one year. Differences had been observed between the western and eastern areas. The current rate was generally below 8 cm/second but occasionally there had been records of about 15 cm/s.

Unexplained variability of temperature had been observed about 15 metres above the seafloor. At the time measurements were made, El Niño and La Niña events in the area were taken into account. Investigations were generally conducted in the same season to investigate interannual variability. In 1998, the mixed layer had become thicker, meaning that the thermocline layer was deepening. Other parameters in the oligotrophic zone – such as pH, nutrients and biochemical variables including chlorophyll *a* from different depths -- had also behaved similarly because of the disturbance caused by the El Niño event.

Generally, the thermocline layer in this area increased and became thinner from west to east. During El Niño, the layer deepened, and in the mixed layer, the nutrients and some biochemical parameters were depleted. Variability had also been recorded in the deep sea, but it was not known whether this was a response to the events in the upper ocean.

Discussing a strategy for solving some of the problems of the deep-sea ecosystem, he said COMRA would like to know whether mining would have no obvious impacts or serious impacts on the ecosystem. The question could be studied by setting up models covering different aspects of hydrographical, biological and chemical systems and sedimentology. Sensitive parameters should be selected; not all parameters should be measured. The weight of each parameter should be determined for calculations or predictions in the model.

The key problem, of course, was natural variability. COMRA already had some data for the past few years, and work in the Chinese pioneer area had continued in 2001 to observe the changes.

EISET programme

Finally, Zhou described COMRA's EISET programme (Environmental impact studies and equipment tests), in which Chinese engineers had tested a small manganese nodule collector in a lake 120 m deep and had conducted environmental impact studies. They thought it valuable to do such environmental impact studies with the potential miner, even though the tests occurred in a lake and not in the ocean. One of the purposes of the programme was to learn the behaviour of the plume. Monitoring was being done from a ship, employing cores, nets, water samplers, sediment traps and sediment samplers, ADCP, a deep-water video camera and pore-water samplers.

The programme had been divided into three stages. The first stage was baseline collection before the testing of the miner. The second stage was monitoring while the equipment test was in progress, and the third stage incorporated monitoring to see the recovery or recolonisation of the ecosystem. Baseline collection had been completed a month ago, using water samplers, CTDs, nets, ADCP, sediment traps at six levels and other equipment similar to that used in marine investigations.

SUMMARY OF DISCUSSION

Deep-sea fauna

Asked whether China was studying the potential economic or medical benefits of seafloor fauna, Dr. Zhou said he still did not know the economic value of this ecosystem but he thought that people should try to understand everything involved with harvesting manganese nodules. To another question, he replied that he did not know whether the International Seabed Authority might be able to concern itself with the economic benefit of the fauna.

Equipment studies

Asked how relevant the experiment on the lake was for deep-seabed mining, he answered that the experiment measured grain size and other characteristics of the sediment, as well as some biological parameters. While aware of the differences between a lake and the deep ocean, COMRA thought its experiment afforded a good opportunity to learn about the behaviour of benthic plumes. Although there were differences, especially because of the different currents, the measurements and results would be compared with those from deep-sea experiments, such as the Disturbance and Recolonisation project (DISCOL) and the Benthic Impact Experiment (BIE).

He replied in the negative when asked whether China had any plans to extend its equipment test to the deep sea.

Deep-sea environmental studies

Dr. Zhou was asked whether he thought COMRA had collected enough environmental data from its exploration area in the Pacific Ocean to meet the requirements for baseline studies, given the huge natural variability shown in its data from 1997-99. He responded that, in an effort to understand the ecosystem, COMRA had used data from the 1950s and 1960s for comparison purposes and would continue to work on the NaVaBa project for the next three years. Only sensitive and significant parameters would be measured in the current study. Asked about the differences in data between the 1960s and the 1990s, he said some older data might be less valuable, in view of technological developments in marine surveying. However, Chinese scientists knew the extent to which the older data could be used even in the future.

A questioner asked about possible relationships between the effects of El Niño and La Niña on the surface water and the variations observed on the seabed. Zhou responded that Chinese scientists did not know whether the deep-sea variability originated from the obvious variability in the upper ocean. Logically, there should be some effects from the upper ocean, but he could not say to what degree, in what way or with what time delay, nor did he know the role played by other impact sources such as the polar ocean.

Asked whether COMRA planned to submit its data to the Authority for a systematic comparison with other data sets, Zhou said he did not know whether the Secretary-General or the Legal and Technical Commission would ask for it.

The Secretary-General commented that the Authority hoped to get as much information as it could from all sources, including data on environmental aspects that the pioneer investors were required to submit in their reports. Of course, the Authority did not want everything they collected because it would be too much to have, but it hoped to receive at least the basic information so that it could compare the results of one pioneer's environmental efforts with those of others. As most of the pioneers were in the CCFZ, everyone would benefit by being able to compare the different parts of that zone and derive an overall picture, which he hoped would happen at some point. Such an exchange of information would be important in enabling the pioneers to see whether what they had done compared with what others had done and whether their findings could be reconciled with the findings of others. Similarly, the Authority was trying to collect data on the Indian Ocean from India and other sources.

In addition to the environmental information submitted by the pioneers in their annual reports, he hoped that, on occasions like the present Workshop, when scientists were assembled, others would also make available their data, their findings and their evaluation of the environment, so that everyone could draw comparisons. One of the important purposes of the Workshop was to gather scientists together for an exchange in which they could learn from each other what people were doing and what observations they had made. Out of that exchange could emerge some kind of synthesis of what was going on overall.

The moderator, Professor Craig Smith, commented that combining different data sets could give a sense of whether what looked like El Niño variability was broad in scale, occurring at a number of sites in both the upper water column and at the seafloor. A temporal coherence in the responses of the benthos and the upper water column would suggest a large-scale climatic event as opposed to local variability.

Chapter 7 Data Standards Utilised in the Environmental Studies of the Department of Ocean Development, India

Professor M. Ravindran, Director, National Institute of Ocean Technology, Department of Ocean Development, Chennai, India

SUMMARY OF PRESENTATION

Professor M. Ravindran presented an overview of the environmental studies conducted by the Government of India in the last five years as the only explorer at the Central Indian Ocean Basin site. These studies were still going on and would continue in a long-term programme, he said.

Three major groups in India were involved in the environment programme: the National Institute of Oceanography (NIO) – the premier institution for this topic in India, which had been working on survey, exploration and environmental impact assessment (EIA) studies; the National Institute of Ocean Technology, only eight years old, engaged in technology development for mining of manganese nodules; and other scientific and industrial research institutions concerned with metallurgy.

EIA studies had started in 1995, with most of the work done by NIO. The Institute had done an EIA to establish the baseline conditions of the Indian Ocean Basin area. It had created a disturbance by pumping up the sediment and assessing the impact immediately and a few years later, and had provided input to the design of an environmentally friendly mining system.

This work had been named the Indian Deep-sea Environmental Experiment (INDEX). The first phase had been completed in the first two years, 1995-97. The disturbance had occurred at the end of 1997, using the Russian Research Vessel *Yuzhmorgeologiya*. Currently NIO was collecting environmental data using the Russian RV *Sidorenko* on long-term hire. That vessel was currently at the site doing post-disturbance measurements three or four years after the event, and it would continue doing so for another two years.

India's site lay between 10 and 16 degrees south latitude and 72 and 80° east longitude, about 2000 kilometres south of India. More than 200 tons of nodules had been collected from nodule sampling locations located at almost every 2-minute interval. Nodule abundance in the area went up to more than 17 kilograms per square metre.

Much effort and many ships had been employed, using more than 55 cruises and 2200 ship days. The main ships currently in use were the *Sidorenko* and the Oceanographic Research Vessel *Sagar Kanya*. ORV *Sagar Kanya* belonged to the Department of Ocean Development (DOD) and was the department's pioneering contribution to the EIA studies and the exploration for polymetallic nodules.

Equipment

Professor Ravindran next discussed the instrumentation used and the parameters measured, remarking that the choice of data standards would require a realistic look at the instruments and the variations in measurements. He began by listing the equipment used for position fixing, hydrosweep, deep-towed sonar surveys, deep-sea photo and television cameras, mooring systems with current meters and sediment traps, conductivity-temperature-depth (CTD) profiling and water sampling.

For position fixing, NIO had used a Magnavox Global Positioning System (GPS) receiver, with which the depth and reliability of the position reading averaged plus or minus 40-50 m. The hydrosweep provided coverage of 200 percent of the depth and gave 59 depth points per ping. The survey of the pioneer area had been completed in 1992-93.

Deep-towed sonar surveys used frequencies of 150 and 14 kilohertz for position fixing of depth. The photographic and TV cameras were from the "Neptun" system on the Russian vessel. The focal length was about 21.6 millimetres, within 5 m of the seabed. The still camera had a capacity of 3000 frames per sink.

Mooring systems had been positioned all over the area. They bore current meters with an accuracy of ±0.03 m/second, a transmissometer for light measurement accurate to ±1% and sediment traps programmed to open for five days, with measurements in grams. CTD had been measured using the SeaCat, made by Sea-Bird Electonics (SBE). Box corers and mulitcorers were used for sediment studies.

Five areas had been selected, each 10 by 10 miles. Later, two of these areas having identical characteristics had been singled out as test and reference sites. High-resolution bathymetric maps had been created for these areas. Comparisons had been made between the test and reference sites so that two sites of identical character could be chosen. The criteria used to select the sites had been geological setting, separation by an optimum distance so that the reference area would not be disturbed by the test, bottom topography favourable for the bottom-crawling mechanism and low nodule abundance so that the disturber would not be clogged.

Nodule abundance in the five study areas averaged about 2 kg/m². The seabed was flat, with 1° slopes and only a 20-m variation in elevation within each 100-m² area.

Data had been collected over an area of 4 million km², about 5500 m deep, divided by lines 1500 km apart. Nodule samples had been taken from 1900 locations every 12.5 km, using five to seven free-fall grabs at each station. Measurements and sampling had included chemical analysis, single- and multibeam echosounding, magnetic and gravity data, sediment cores, box cores and bottom photography.

Parameters

Ravindran listed the categories of parameters analysed in the project, as follows:

?? *Geological*, including bathymetry, sediment thickness, distribution of nodules/rocks etc., nodule size, morphology, elemental composition, and geochemical parameters of sediment and pore waters;

?? *Biological*, such as the biomass of the benthic environment and microbiological investigations;

?? *Physical*, including current circulation patterns in the water column and water mass (temperature, salinity) structures; and

?? *Chemical*, including hydrochemical parameters and metals.

Equipment and methods

He listed the following instruments and methodologies used:

?? ***Geological studies:***

- ✍ Bathymetry: narrow-beam echosounding at 12 kHz, a sub-bottom profiler at 3.5-5 kHz, deep-tow sonar up to a few hundred metres, seafloor photographs.

- ✍ Mineralogy of bottom sediment: wet sieving followed by pipette analysis of texture.

- ✍ Geotechnical analysis of sediment: water content by the weight-loss method, with samples dried for 24 hours at 105° C.; shear-strength apparatus using vane shear testers; wet bulk density, specific gravity, porosity.

- ✍ Geochemistry.

- ✍ Pore-water chemistry: nitrite, silica.

- ✍ Soil analysis.

- ✍ Particle fluxes: time-series sediment traps, with samples sieved to separate finer and coarser particles; major component analysis by $CaCO_3$ weight-loss method or calcium extraction, organic matter by CHN analysis.

?? ***Biological studies:***

- ✍ Phytoplankton, zooplankton, primary productivity: by C-14 measurement.

- ✍ Benthos: fauna dyed with rose bengal after wet-sieving samples through 1-mm, 300- and 45-micron sieves to measure abundance and identify mega-, macro-, meio-, and microfaunal components; total bacterial counts for microbial analysis; biochemical analysis.

?? ***Physical studies:***

- ✍ Meteorological observations: weather station on board.

- ✍ Water column: standard CTD, expendable bathythermographs (XBTs) and expendable CTD probes (XCTDs).

✍ Benthic currents: current meters on mooring lines.

✍ Light transmission: transmissometers attached to mooring systems.

?? *Chemistry:* Dissolved oxygen, alkalinity, nutrients (nitrate, nitrite and silicate), dissolved trace metals and suspended solids.

(For details on methods and equipment, see appendix B at the end of this volume.)

Results

Displaying a contour map generated from a hydrosweep of the area, Ravindran said the researchers had accidentally discovered a possible fracture zone, as well as some seamounts at 76° E and 12.5° S that peaked at about 1000 m above the bottom.

From other results, scientists had generated graphs and profiles of salinity, pH, dissolved oxygen (DO), PO_4 and NO_3. Vertical sections of temperature and salinity had also been produced as part of the baseline studies, along with sections of oxygen, nitrate, pH and phosphate.

For the benthic disturbance and impact studies, the area selected was about 3000 m long and 200 m wide, with 26 tracks. The disturbance had continued for nine days, for an effective time of 2850 minutes. It was estimated that approximately 6000 m^3 of sediment had been pumped up by at least 5 m, over a distance of about 88.3 km. Each tow had run approximately 4 km.

Pre-disturbance profiles had shown living organisms at the test site. Post-disturbance images displayed distinct features of the disturber tracks in some areas around the site, with the sediment disturbed and thrown to the side. A thin layer of sediment had covered the undisturbed areas. After five days, no sediment had been collected in the traps above 20 m from the seafloor. At 7 m, there had been some plume suspension, but beyond 100 m from the track, nothing had been found in the sediment traps. These were important results from the sediment trap and photographic observations. Before the disturbance, the tracks and burrows of organisms could be seen, but they had disappeared in the top 20 centimetres. Most of the disturbance had been restricted to the upper 20 cm of the sediment in the tracks. The range and average of sediment particles pre- and post-disturbance had not changed much.

With regard to the geotechnical properties of the sediment before and after the disturbance, a characteristic had emerged that was important to the engineers who designed the mechanical systems: there had been a variation of shear strength, but the difference was slight. Looking at individual layers, shear strength in the top 5 cm had fallen by 2 to 3 kilopascals -- an average value, though with enormous variations. Below 5 cm, shear strength had improved slightly, due to compaction at that level. Since the shear-strength calculations were based on disturbed measurements made at the ocean surface, they showed a lot of variability. For that reason, India had opted for an in situ measurement of soil strength. It had already developed an instrument and had tested it at depths of 50 and 100 m, in the hope of extending it to 6000 m. That work was proceeding and would be completed within a year. The meter was just a capsule that would be lowered to the seabed and tested in situ, so that this sort of variability did not occur. Given the enormous demands for manoeuvrability of the crawler, this measurement had to be more reliable for the task of putting an engineering system on the seabed. India had attached a lot of importance to this problem and would be going ahead with in situ measurements.

The disturbance had produced a loss of meiobenthos in the track area. Thus, it would be important to find out when the density would return to its original value after recolonisation. Those studies were going on and would continue for the next two years.

Samples had been taken north and south of the disturbance tracks, which ran southwest to northeast. In the disturbance area, there had been a drop in the density of individuals from 250 to 50. South of the disturbance, there had been a slight increase, possibly because some individuals had migrated.

Ravindran showed a graph of current velocities recorded continuously over the six months between 1 November and 28 April, using moored current meters located at 50, 4 and 80 m above the bottom. The measurements showed that, at levels close to the bottom, the currents were very slow except for one or two readings.

Chemical-composition tests of sediment-trap and disturbance samples, done as part of the baseline studies, had shown no changes of consequence. Light transmission before and after disturbance showed almost no variation, which meant that sediment was not ruining the transmissivity of light in the area. Chemicals and dissolved metals in the sediment pore water also showed little variation.

Reviewing the milestones in the Indian Ocean studies, he said compilation of baseline data had been completed in March 1997, the selection of test and reference areas had been done in February 1997, and the benthic disturbance test, on which reports had been submitted, had been performed in May-September 1997. India was currently monitoring the impact and would continue this work until March/April 2005. Funds had already been allocated for this long-term programme.

Except for benthic biomass destruction in the tracks, the rest of the information did not seem alarming, subject to confirmation by long-term measurements. Data from two or three years after the disturbance were being analysed. A cruise had started in May and the ship was currently at the site doing measurements. As the data collection was extensive, analysis and interpretation took time. More information would be provided in the years to come.

India had worked with the Russian Ministry of Natural Resources in its EIA studies, during which samples had been collected from 23,000 stations and some 10,000 locations. The EIA study, at a depth of 5500-6000 m over a period of five to seven years, was an enormous task. Thus, in deciding on the data standards and the parameters to be measured, the scientific work force that would be required to do the measurements and analyses should be taken into account. A realistic number of parameters and a realistic spatial and temporal distribution of the measurement programme should be defined for the future EIA guidelines.

Test system for mining

How to model the disturbance and the redeposition of tailings was an important problem, Ravindran observed. Obviously, modelling of the disturbance was technology specific, dependent on the type of nodule collector and collecting or transport system to be used. In this regard, efforts should be made to build environmentally friendly nodule collectors.

Working toward that end, India had developed a crawler jointly with Germany. This crawler, 3 m wide, had a rubber track with an involute profile. As the track moved, it compacted the soft sediment. It had been designed to minimise the plume rising to the surface, like the disturber in the Benthic Impact Experiment (BIE). This was a more environmentally friendly crawler than the others had been. It had a special manoeuvring mechanism permitting each of its belts to move independently over topography varying by a metre.

India had tested the manoeuvrability of the crawler in water at 410 m, and had then added a manipulator and a dredging cutter connected to a high-pressure pump. A concentration meter measured the concentration of the slurry, which was pumped through a flexible riser to the ship at the top. Based on this experience, a crawler had been designed for the deep sea, with a pump slightly heavier than the conventional one used at the test depth. At 500 m, the soil conditions were not very different, except that there was no fine water-mixed layer. The clay at 500 m had poor shear strength, close to that of deep-sea mud. Happily, the crawler had been able to pump the slurry at about 1.17 specific gravity, reaching a flow rate of about 14 tons/hr through a flexible riser with a diameter of about 80 mm.

For operation at 6000 m, the specifications had been slightly improved. The tracks of the environmentally friendly nodule collector would be made from a special plastic, rather than rubber, to afford better compaction. A flexible riser was being developed in order to make the system cheap, instead of the rigid riser that everyone else was using. Only one pump was to be used to raise the slurry to the ship -- a multi-cylinder piston device capable of pumping solids up to 20% by volume. Such pumps were available, operating at 120 bars. The concept was to have multiple crawlers pumping to the receiving vessel. The crawler weighed not more than 8-9 tons, a reduced weight so that the multiple crawlers could be launched easily and would not be clogged.

The conveyor, with its compact track belt, carried a density meter, hydraulic pump, sensor head, electric motor and other devices. Based on the test results, lightweight motors had been chosen for everything so that the entire weight for the 6000-m experiment would be less than 10 tons.

The collector had a conveyor belt running in front of the crawler, with a pick-up device consisting of one rigid grating and another grating that moved against the first. The pick-up grating rotated about a fixed point, remaining flat throughout, so that the pick-up device would not plough into the sediment. In addition, the system vibrated so that the silt would not be carried into the crusher and would not become part of the tailings. The conveyor belt lifted nodules to the crusher at the top. The size of the nodules to be collected was limited to 80 mm and they would be crushed to less than 30 mm, the maximum size that would leave the crusher. The crusher moved from side to side and delivered into the pump.

As fewer parameters would be transmitted during the test in situ, a simpler umbilical could be used. Special hose joints had been devised so that the crawler could be lifted by the hose if the umbilical failed. As these joints would be strong enough to raise the crawler, it was less likely to be lost at sea. There was a contingency plan for handling the system.

The existing crawler had mobility in all directions, with its rear chassis limited to one point about which the entire axle could move. Each wheel on the tracks was connected to a bearing that could move independently of the wheel in front -- a nice arrangement for uneven topography.

For the deep-sea mining test, an in situ geotechnical test would first be done at 6000 m to design specifications for the varying requirements and weight combinations of the crawler. As the *Sagar Kanya*, a government-owned ship, did not have a dynamic positioning system, mining time would be limited, because if the weather turned bad there would be a large wind change. Therefore, the crawler could not be kept down for more than eight hours, and launching and retrieving took a lot of time. Indian researchers wanted to mount a dynamic positioning system on the ships, so that they could work under more comfortable conditions and do more tests per cruise.

The system was ready, except that it had to be encapsulated for the 6000-m test. Before they were put down into the sea, the main components would be tested in a hyperbaric chamber capable of testing at 6000 m. The entire system had been tested at 50 m to prove that it worked.

The first in situ test would be completed in 2002. Then, in 2002-04, the collector-crusher qualifications would be worked out, and finally the crawler would be fabricated after 2004. India expected to conduct the nodule mining experiment in 2007-08.

SUMMARY OF DISCUSSION

Sediment conditions

Asked about sediment conditions in the Indian Ocean, Dr. Ravindran said the top 5 cm was liquid. Measurements of bearing strength in that layer were unreliable, highlighting the need for more reliable data. The nodules were not in that layer but were subsurface. A lot of variability had been reported in the bearing/shear strength, with readings from 0-7 kPa. He strongly recommended further in situ measurements.

Small variations were important for the mechanical design of the crawler, he observed. With shear strength below 2 kPa, the crawler might be lost. However, the crawler had been designed with a slip-control system to sense the resistance by measuring shear strength, so that if it was about to slip its speed would automatically be reduced and it would not get stuck.

A participant, drawing a comparison with the Clarion-Clipperton Fracture Zone (CCFZ) in the North Pacific Ocean, recalled that in the French area, the so-called semiliquid layer was only 1 cm deep, but the subsoil was also soft, with shear strength between 4-5 kPa. In the Peru Basin to the south, the semi-liquid layer had been reported to be 8-12 cm thick (chapter 5 above, section 2.3).

Nodule collector design

Asked what advantage was gained by placing all the machinery on top of the crawler, Ravindran replied that most prior work had used a hydraulic lifting system with submersible pumps at intermediate stages. The major problem with that approach was that the lateral force exerted on the riser pipe required a rigid riser and pumps that were much more complicated and expensive. How was this rigid pipeline to be stored on the deck? How much time would be needed for installation and recovery? All these factors made such a mining system more expensive. India was looking at a riser that could be rolled up and kept on the deck. In addition, the lateral load of the current would not cause excessive movement of the compliant riser. Moreover, because of its specially designed buoyancy distribution, the crawler could move independently of the ship. Therefore, India thought that, from the point of view of affordability when mining became commercially viable, lower levels of output were preferable. That was the goal of the engineering design.

To a question about the risers that would link the crawler with the surface vessel, Ravindran said there would be two of them. The first was the umbilical carrying the electromechanical optical cable, which supported the entire weight of the crawler. It supplied up to 100 kilowatts of power at 3000 volts, and also carried control signals at 220 V on six or seven fibre-optic channels, at least two of them passing through a slip ring so that the sensors could be monitored continuously as the crawler descended. Experience had demonstrated the need to have one umbilical for power and data, and another to transfer the slurry and provide redundancy. The hoses were being designed with enough strength so that the crawler could be lifted in case something happened to the umbilical power. One crawler had already been lost when the weather had become so bad that the umbilical had to be cut because its mechanical armour was rubbing against the ship, harming the dynamic positioning system. Once its thin outer layer of armour was damaged, the riser had lost the mechanical strength to lift the crawler. Divers had to be sent down to connect a rope from the winch to the chassis of the crawler so that it could be lifted. The researchers did not want to repeat that experience.

A canvas hose was being used for the riser but the engineers would like to change it to Kevlar. The liner was specially chosen to withstand the abrasion of the slurry. Discussions were under way to obtain stronger hoses, about 100-250 mm in diameter, from a German firm.

A questioner wondered whether a crawler weighing less than 10 tons attached to a hose about 10 cm in diameter might be lifted off the seafloor by undersea currents. Ravindran replied that the ship would stay in position during mining and would not have to drag the 6000-m riser, because the crawler could move as much as a kilometre by itself while remaining tethered. Currents were at a maximum at the surface – about 1 knot or so – but at lower levels the flow dropped to a few centimetres. Given the riser's diameter of about 100 mm, and the combination of buoyancy and weight distribution, the equipment would not be pushed around too much.

Another participant, citing the tradeoffs that India faced between engineering and environmental aspects, asked Ravindran to explain the thinking that lay behind the choice it had made. He responded that India had not decided anything. Despite the fear that a sediment plume from the mining system would remain suspended for months or years, measurements showed that that was not so. Further, the top 20 cm of the benthos in the track had been disturbed, but it remained to be seen when conditions would return to their original level. The first set of information after the immediate post-disturbance scenario showed that the effects were restricted to 100 m from the track and about 5 m above the seabed. His conclusion was that the situation was not very alarming. India would take its decision when all the data were together and it could discuss with other people about their experiences and consult with the Authority as well.

Biological impact

Asked whether there were plans to look at the species density of macrobenthos samples, Ravindran replied that a specialist on microbiology and marine biology would conduct taxonomic research as part of the study. Ten papers had already been published and more were in the pipeline.

Asked about sediment profiles before and after the disturbance, and particularly whether the indirect impact from resedimentation had been taken into account, Ravindran said that some of the initial results were contradictory. For example, in some areas the benthic density had increased, though on average there had been a reduction within the track area. Some variability was inevitable, given the fact that the positioning system had an accuracy of ±30-40 m and the observations were at a depth of 6000 m.

The limited measurements and analysis done so far concerned the situation immediately after the disturbance, not one or two years later. Measurements of data from the reference site would come subsequently and should throw more light on the indirect impact in the long term. The immediate impact concerned such matters as when the sediment settled, how much benthic mass in the track had been lost and how much transmissivity had declined. Other aspects, such as soil strength, were not much affected. With the use of an environmentally friendly collector and crawler, the impact would be less.

The moderator, Professor Craig Smith, said it was important to understand the cause of the significant change reported in the benthic fauna. The track area was a 200-m wide swath over which the 2-m wide disturber had been dragged for 26 tows. There had been some combination of direct removal of sediment and resedimentation within the track area. The impact within the track was probably less than would occur from a mining head directly passing over a spot, because not as much sediment had been removed. The big treads on the Indian device would probably cause essentially complete mortality of the macrofauna, though perhaps not of the nematodes. However, in terms of a sediment plume, the impact would be minimised.

Ravindran responded that the impact would depend on the technology of the crawler.

Water chemistry

A questioner, noting that no changes had been recorded in water chemistry after the disturbance, asked whether this might have been due to currents having replaced the sediment plume by clean water. He wondered what had happened to the silica, which occurred at high levels in pore water, after 20 cm of sediment was put into the water column. Since the data showed no change, it was possible that the silica had moved away.

Ravindran replied that current velocities had been measured at only a few centimetres per second within 5-10 m of the seafloor. The few thousand tons of soil kicked up by the disturber must still have been present, since there had been no large currents moving it away totally. It was difficult to apply mass-balance equations in the open ocean, where there were no controlled laboratory conditions permitting accurate measurement of the chemical properties of the water. The Workshop should discuss what standards and instruments to use in measuring water quality.

Environmental friendliness

A participant said he had difficulty with the expression "environmentally friendly collector". While he appreciated that India was thinking about the environment and making efforts to minimise the impact from the collector, it had to be accepted that every mining system would have an impact on the environment that could not be avoided.

Ravindran agreed but added that the type of collectors used so far by various groups had been less environmentally friendly than the Indian one

The Secretary-General recalled a video presented by a United States consortium at the 1999 workshop on technology showing a first attempt to design a collector. That device had totally ignored the environmental aspect and was quite damaging to the environment, as was apparent from the description of the equipment. It was interesting that almost every other presenter currently designing collectors was clearly aware of the environmental aspect. Environmentally friendly or not, it was important to see this conscious effort to take into account the impact a mining device would have.

Chapter 8 Data Standards Utilised in the Environmental Studies of the Deep Ocean Resources Development Company Ltd. (Japan)

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1. Overview: The Japanese Approach

Deep-sea mineral resources are expected to support the activity of our future industries. At the same time, however, biological communities in the same area are thought to be a valuable resource for future generations. Therefore, it is necessary to consider not only mining development but also ways of protecting these communities, characterised by their specialised niches, fragility and rarity.

The Metal Mining Agency of Japan (MMAJ) and the Deep Ocean Resources Development Co., Ltd. (DORD) initiated their environmental study on manganese nodule development in 1989. The goals of this study were to obtain environmental baseline information and to evaluate the magnitude of impacts that might be caused by commercial mining. The study focussed on two marine ecosystems, upper layer and benthic.

The upper layer and benthic environment studies each consisted of three phases, as follows:

Baseline study:

?? To understand the natural environmental conditions.

Impact assessment study:

?? To understand the effects of mining, impact experiments were conducted.

?? For the upper layer environmental study, cold-water discharge and nutrient enrichment experiments were done. For the benthic environmental study, a deep-sea impact experiment was conducted.

Impact prediction:

?? Based on the results of the baseline and impact assessment studies, the harmful effects caused by a larger scale of mining activities will be predicted.

2. Upper layer environmental study

2.1. Schedule of the study

Table 1 shows the investigation schedule for the upper layer ecosystem. The survey was conducted from 1989 to 1996. Because the benthic disturbance experiment for the environmental impact assessment in the bottom layer was carried out in 1994, the upper layer investigation was not conducted in that year. Examination of the technique and the conceptual design of a numerical model were performed from 1989 to 1990, and sampling in the study area began in 1991, the third year of the study. Sampling by water collection was the subject from 1991 to 1993, and net sampling was carried out in 1995 and 1996. The numerical model to assess the surface dispersion of deep-sea mining discharge was under development from 1989 to 1991. This model was developed to simulate a situation in which cold water pumped up from the seafloor during mining would be discharged at the surface. The location of the model-development experiment was Toyama Bay, on the Japanese coast. In addition, to understand the impact of deep-sea water discharge at the surface on the growth of phytoplankton, enrichment experiments were carried out in 1991 and 1992. A cultivation experiment was conducted onboard.

Investigation item	Fiscal Year							
	1989	1990	1991	1992	1993	1994	1995	1996
Examination of the technique	→	→						
Baseline study								
Physical			→	→	→		→	→
Water quality (chemical)			→	→	→			
Plankton (Water collecting)								
Plankton (Net sampling)			→	→	→		→	→
Impact assessment								
Model development	→	→	→					
Enrichment experiment			→	→				
Benthic disturbance experiment						☆		

Table 1 Time schedule of the upper layer investigation.

2.2. Parameters for impact assessment

Figure 1 shows the baseline-survey components for the upper layer. The baseline study was roughly classified into three categories: physical, chemical and biological environment. These three categories are explained below.

2.2.1. Chemical environment

The upper layer investigation was conducted in order to predict and evaluate the influence on an upper layer ecosystem when deep-sea water is discharged to the ocean surface. Unlike surface water, since deep-sea water is high in nutrition and low in temperature, it is thought to greatly influence breeding, growth, survival rate, etc. of microorganisms including phytoplankton. Moreover, since phytoplankton are the primary producers of the ocean, if the balance of phytoplankton communities is changed, other organisms would be influenced. The analysis concentrated on NO_2, NO_3, PO_4 and SiO_2, which have direct impacts on the chemical substances in seawater.

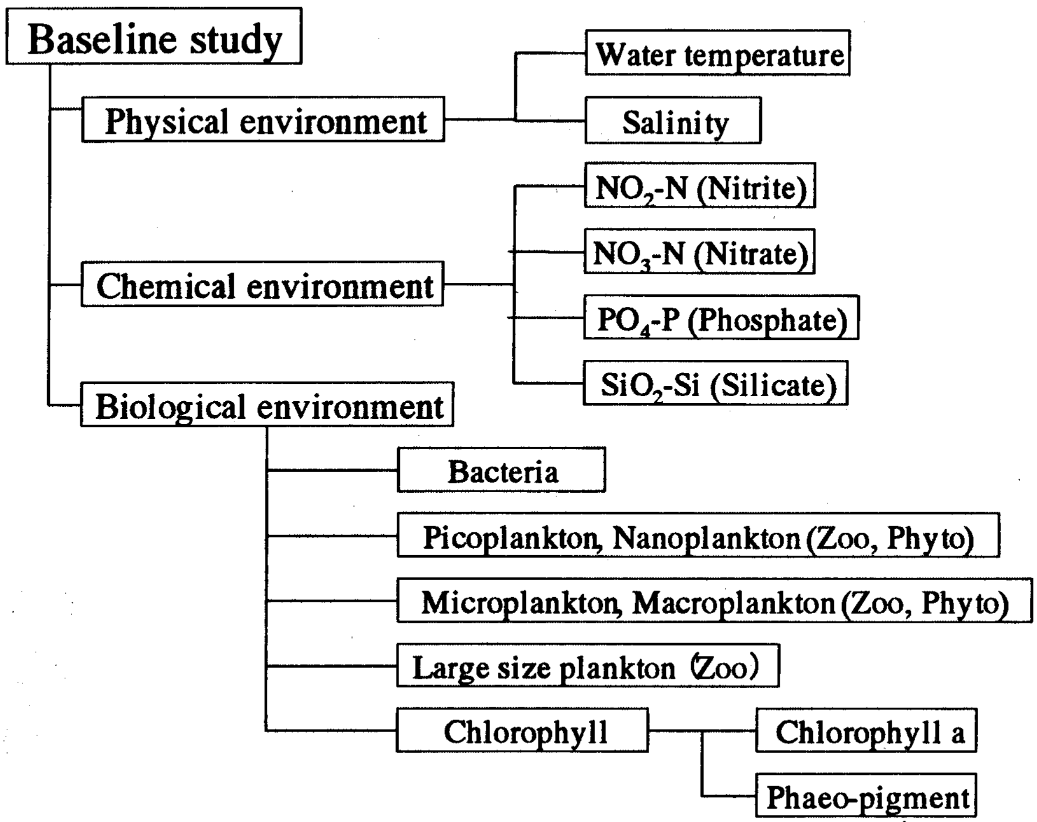

Figure 1 Survey components of the upper layer baseline survey.

2.2.2. Physical environment

Water temperature and salinity are the most popular items of observation in oceanography. Moreover, these can be investigated rather easily by the use of CTD (conductivity-temperature-depth) meters.

2.2.3. Biological environment

Microorganisms, which constitute the fundamental portion of an ecosystem, were the biological focus of this study. For the composition of this fauna, bacteria, phytoplankton and zooplankton were observed. Among these, since phytoplankton and zooplankton differ greatly in size, they were classified into picoplankton, nanoplankton, microplankton, macroplankton and five sizes of large animal plankton. Chlorophyll *a* and phaeopigment were also incorporated into the investigation as parameters for understanding primary production.

2.3. Survey strategy

2.3.1. Line-transect survey

The upper layer investigation occurred at 11 stations located in a straight line, as shown in figure 2. The survey area was near 9 degrees north latitude, 146° west longitude on the southeastern side of the Intertropical Convergence Zone (ITCZ). The latitude of 9° N in the Central Pacific Ocean lies at the boundary of the North Equatorial Current and the Equatorial Counter Current. In this area, mixing occurs at the surface, with upwelling from lower layers. With this in mind, an effort was made to follow a north-south survey line centring on Japan's western mining area, so as to understand the complicated environment of the study area.

As an example of an observation result, figure 3 shows the spatial distribution of water temperature.

The surface-water temperature decreased from north to south, and thermoclines were well developed in the central area. At the central sampling stations, the mixed layers were shallow and low water temperatures appeared below them. Ogura[1] reported that surveys carried out along the 155° W meridian[2] indicated a region bounded by the North Equatorial and Equatorial Counter currents where water masses of relatively low temperatures had been observed near the surface. Similarly, Nishibori et al.[3] carried out fixed line observations along the meridian of 175° east longitude, and results showed that there were two water masses with relatively low temperatures in the surface areas near the equator.

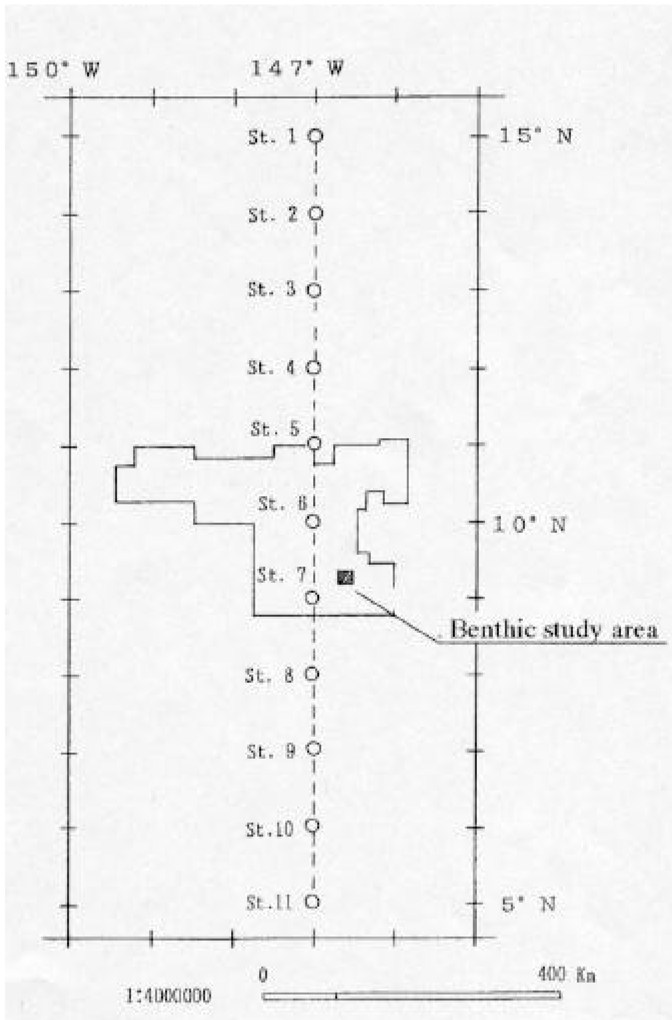

Figure 2. Map of the investigation area showing the sampling stations for the upper layer.

2.3.2. Vertical observation and sampling

Generally, it is said that the photic layer in the ocean is shallower than 200 metres, which is the distribution layer of the photosynthetic phytoplankton. Moreover, the pycnocline, which is also shallower than 200 m, is also important to ecosystems and other existing fields. For this reason, vertical water sampling and CTD observations were conducted from 0-200 m depths. Water samples were collected from seven layers at 0, 20, 50, 75, 100, 140 and 200 m, using rosette samplers equipped with 12 1.7-litre Niskin bottles. Figure 4 shows the 1992 vertical profiles of chlorophyll *a*. The subsurface peak in chlorophyll *a* concentration occurred between 75 and 140 m at all stations. For all stations, chlorophyll *a* concentration decreased to zero near 200 m.

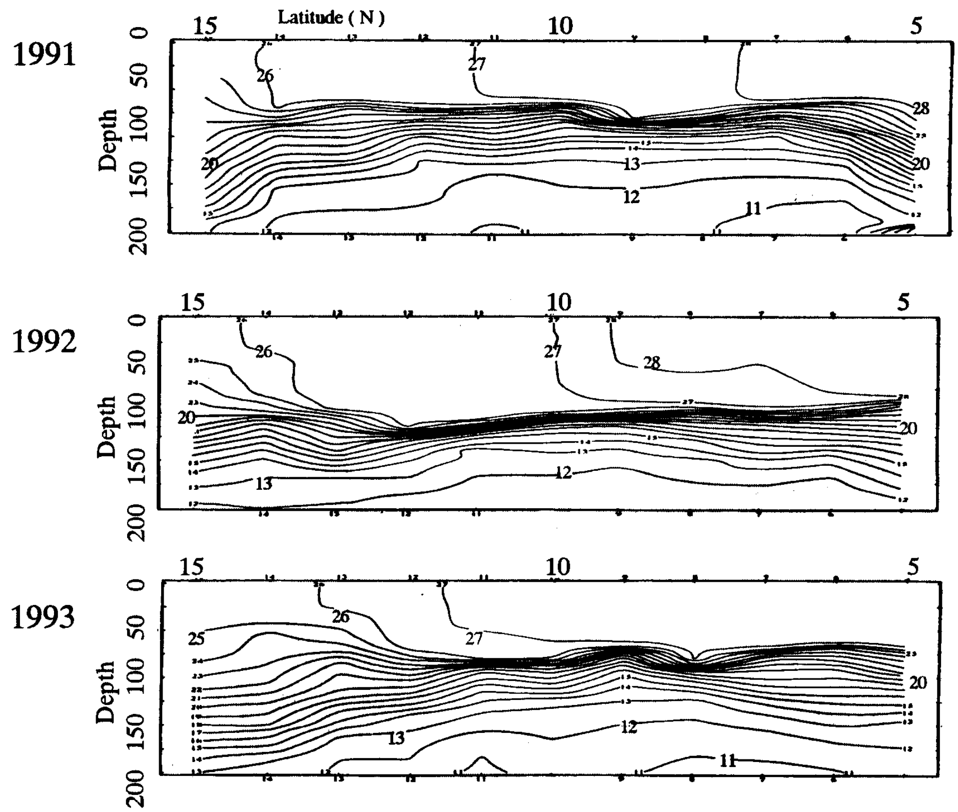

Figure 3 *Spatial distribution of water temperature along 146° W (5-15° N)[4].*

2.4. Sample processing and size categories

2.4.1. Identification

Fluorescence and optical microscopy were alternatively used depending upon the size of the cells, so that a wide range of size classes could be observed. Samples for fluorescence and optical microscopy were fixed with glutaraldehyde with a final concentration of 1 percent. From the preserved sample, an appropriate portion was subsampled and double-dyed with DAPI and FITC, and the cells were filtered on a 0.2-3 micron nucleopore filter. These filters were then stored frozen until the laboratory analysis after the cruise. In the laboratory, the organisms were identified and counted along with size measurements on a fluorescent microscope (Olympus IMT-2). For the optical microscopy, 1 litre of water samples, preserved in neutral formalin (final concentration of 5%), was used, and the organisms were identified and counted, and their size measured. Identification was performed to species level, where possible. However, data analysis was performed at the level of taxonomic class.

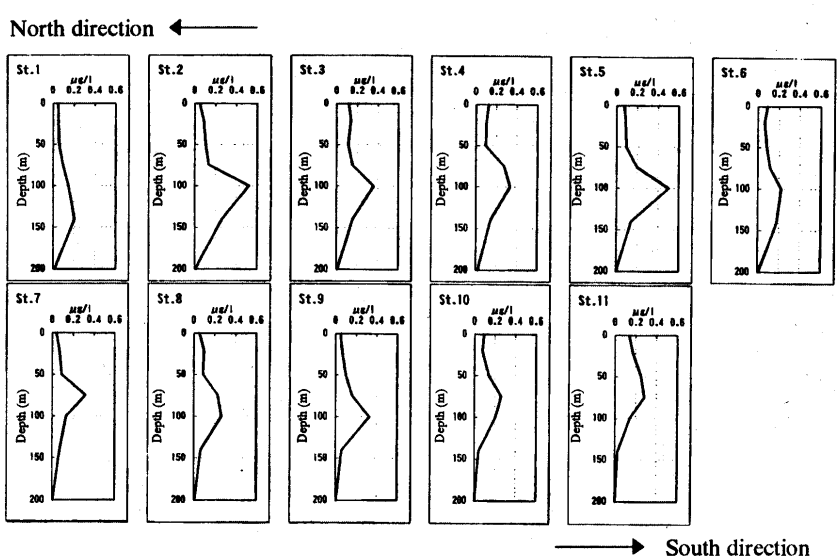

Figure 4 *Vertical profiles of chlorophyll a (micrograms/l) in 1992*[5].

2.4.2. Size categories

Chlorophyll *a* was measured fluorometrically (Turner 112 fluorometer) on deck after one litre of the water sample was passed through a series of filters of different mesh sizes (10, 3, 1 and 0.2-µm nucleopore filters). The plankton were analysed in five size categories: bacteria, picoplankton (0.2-2 µm), nanoplankton (2-20 µm), macroplankton (20-200 µm) and large plankton (200 µm or more).

2.4.3. Estimation of carbon biomass

Carbon biomass was estimated using conventional conversion formulas. Each species of phytoplankton and zooplankton was reduced to a geometric simplex, such as volume, to calculate the carbon biomass. Carbon biomass at the community level was calculated using appropriate formulas.

2.5. Impact assessment

2.5.1. Water discharge experiment (numerical model approach)

Research was carried out to develop the assessment method for the marine environment and to establish a three-dimensional hydrodynamic prediction model using the monitoring data at the ocean-mining test site.

In Toyama Bay (Japanese coast), where cool water is drawn up from the deep sea and discharged into the surface layer, a field survey was carried out to gather the data required for the cool seawater dispersion simulation. Also, the bends of the thermistor-chain system (figure 5) were estimated based on the measurement results.

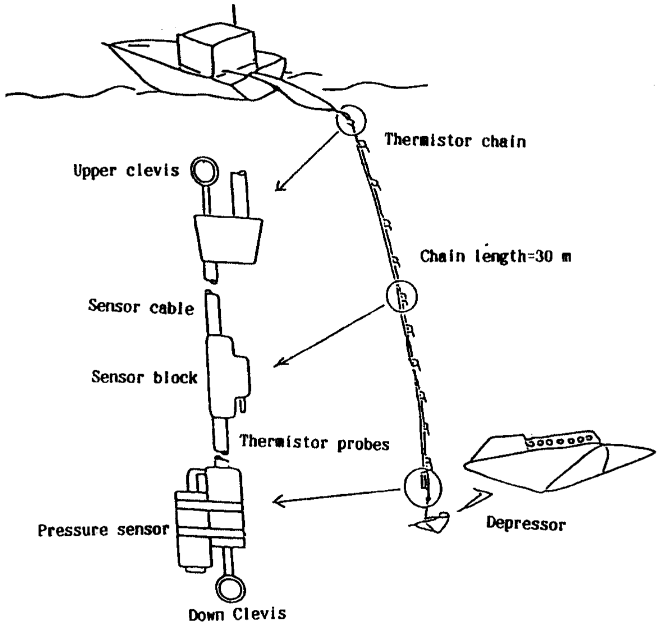

Figure 5 *Schematic illustration of thermistor-chain system.*

The numerical model to assess the surface dispersion of deep-sea mining discharge was completed in 1991. A sample result of the simulated numerical model is shown in figure 6. Surface temperatures near a discharge point after 12 hours show a decrease of 1.4° Celsius compared to ambient water.

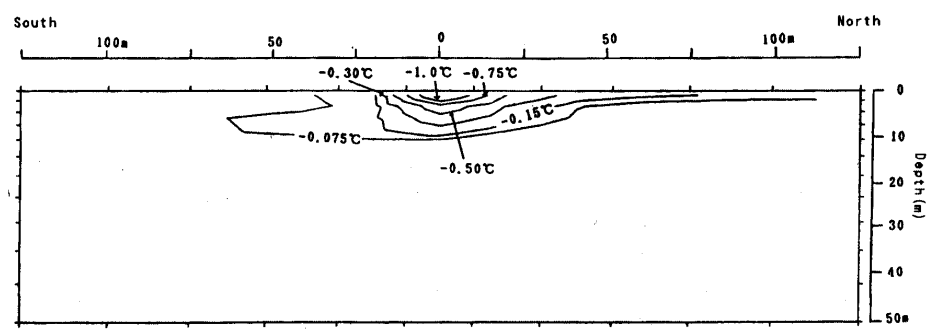

Figure 6 *North-south vertical profile of temperature difference from ambient water, after 12 hours.*

A cool water zone stretches broadly downstream from the discharge point and a temperature-difference zone of less than 0.5° C is distributed within an area extending several tens of metres beyond the discharge point. Cool water discharged at the surface layer is carried by the northward current but at a lower depth.

2.5.2. Enrichment experiment

As part of the environmental impact research for manganese nodule mining, experiments were carried out to determine the impact of the mining effluent on phytoplankton. These experiments was conducted to determine the effects of introducing deep-sea water, which contains high nutrient concentrations, on dominant pico- and nanoplankton.

Results of the experiments showed that the addition of deep water could cause an increase in chlorophyll *a* and changes in the composition of these communities. In experiments where the concentration of bottom water was low, cell-number maxima were attained in a shorter period. In contrast, in experiments with high concentrations of bottom water, it took more days to reach the maximum and the values were higher than those in other experiments with lower concentration (figure 7). However, at higher concentrations (50% surface seawater and 50% bottom water), microflagellates increased with decreasing nitrate and nitrite concentrations, and Bacillariophyceae showed an increase at lower concentrations. In all the experiments the daily growth rate of bacillariophyceans increased with increasing initial concentrations, though cyanobacteria and microflagellates showed no significant correlation with bottom-water concentrations.

These results suggest that the concentrations of nitrate and nitrite can influence succession of phytoplankton communities.

3. Benthic Environmental Study

The field study of the benthic environment, which included both baseline and impact assessment research (the latter labelled JET: Japan Deep-Sea Impact Experiment), was performed in the western part of the exclusive Japanese claim area in the Central Pacific Ocean (figure 8). The purpose of JET was to evaluate the effect of artificial rapid sediment deposition (=disturbance), which was supposed to occur during commercial mining. This experiment consisted of four field studies, as follows:

JET 1: the field study conducted before the disturbance;
JET 2: the field study conducted immediately after the disturbance;

JET 3: the field study conducted one year after the disturbance;
JET 4: the field study conducted two years after the disturbance.

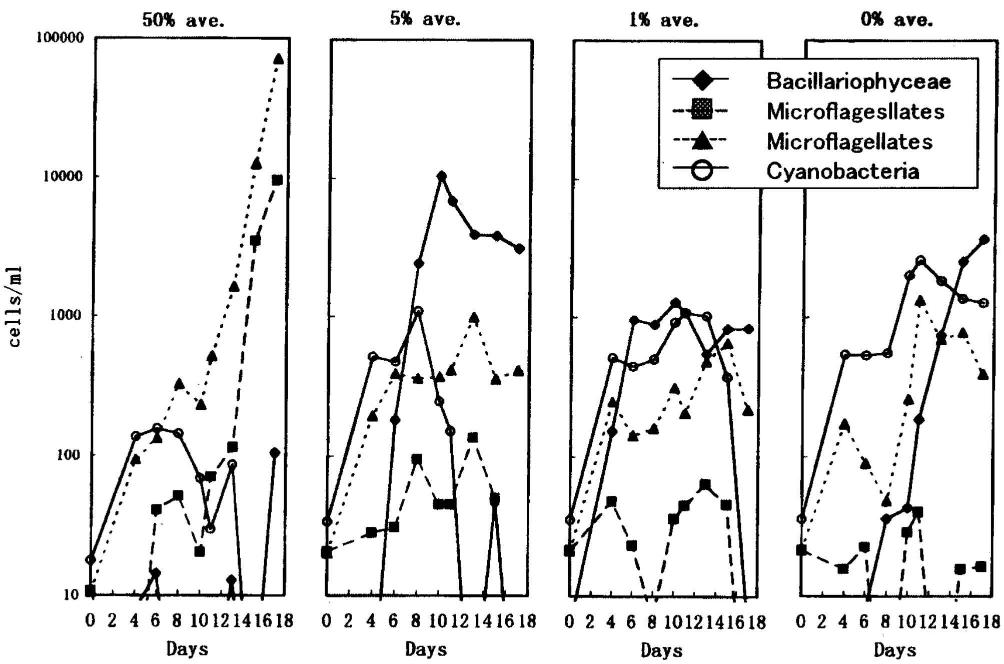

Figure 7 Density of phytoplankton in deep-sea water enrichment experiments[6].

3.1. Parameters

Chemical, physical, geological and biological environmental characteristics were studied in both the baseline study and JET (table 2).

For the chemical environment, the concentrations of opal, calcium carbonate, organic carbon, total nitrogen and radioisotopes (Th-234 and Pb-210) in the sediment were measured. The data sets obtained were used to understand the natural environmental condition and to evaluate the effect of the artificial rapid deposition event on the benthic community. From the data sets for calcium carbonate, organic carbon and total nitrogen, an applicable indicator for the magnitude of sediment deposition has been derived[7]. The results of the radioisotope analysis were also expected to address the recovery process[8].

Deep-sea currents, one of the physical environmental factors, were measured to develop the 3-D numerical model of sediment dispersion[9]. During the artificial rapid deposition event, the sedimentation rate, which was the other physical environmental factor, was measured to estimate the quantities of sediment deposition. To understand the environmental background of the experiment site, the sedimentation rate was also measured for a year before the disturbance.

For the geological parameters, grain size and shear and penetration strength were measured. From the grain-size data, the settling velocity was estimated and used for the parameters of the simulation model. Other data sets would contribute to the future design of the mining collector.

The abundance of sedimentary bacteria, meiobenthos, macrobenthos and megabenthos were studied to evaluate the effect of the artificial rapid deposition. Different responses to the disturbance were observed within those faunal groups (table 3).
These results strongly demonstrate that the study of these biological factors was quite important.

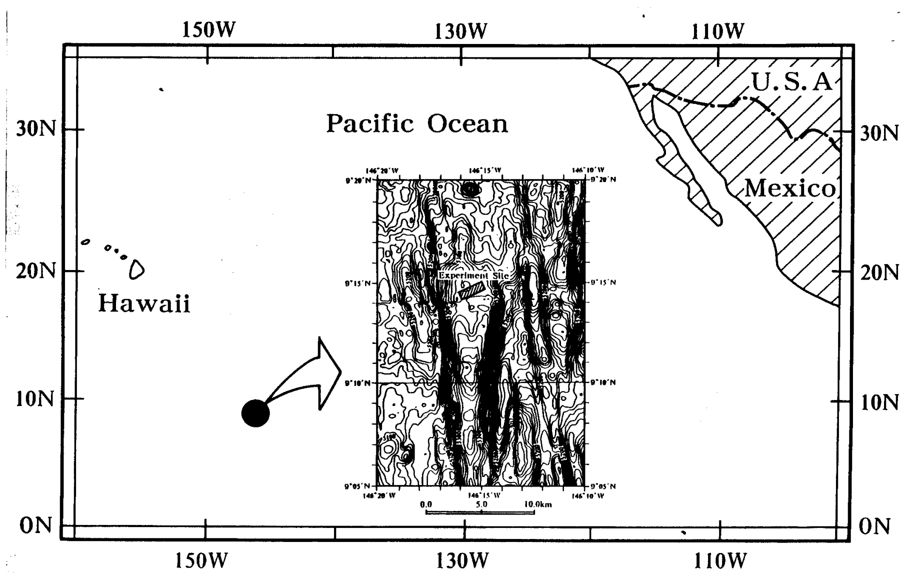

Figure 8 Location map for the field study of the benthic environment.

Besides the above, measurements were made of nutrients (phosphate, silicate, nitrate and nitrate) in overlying and pore water, and adenosine triphosphate (ATP) in sediment.

Environmental factor		Significance *	Main purpose
Chemical factors	Total organic carbon	◎	Impact indicator
	Total nitrogen	◎	As above
	Calcium carbonate	◎	As above
	Biogenic silica	○	Background description
	Radioisotope	○	Bioturbation (recovery process)
Physical factors	Current	◎	Prediction of sediment dispersion
	Sedimentation in JET	◎	Impact estimation
	Sedimentation rate in nature	○	Background description
Geological factors	Grain size	◎	Prediction of sediment dispersion
	Shear strength	△	Collector design
	Penetration strength	△	Collector design
Biological factors	Sedimentary bacteria	○	Impact indicator
	Meiobenthos	◎	As above
	Macrobenthos	◎	As above
	Megabenthos	◎	As above

*Significance was evaluated by the present authors.

Table 2 Parameters applied in JET.

3.2. Survey strategy

Sampling locations (figure 9) were selected at random from an area extending 100 m from the disturbance zone in JET 1, which permitted a statistical estimate of the natural environmental conditions. On the other hand, in JET 2, it was originally planned to collect three or four multiple-core samples from each of the three deposition areas selected on the basis of sediment-trap and current-meter results, and according to distance from the tow tracks. However, sufficiently precise sampler positioning was not possible; therefore, the sampling strategy was modified to the "line-transect method" (25, 50 and 100 m distance from the tow tracks). By means of several approaches of impact evaluation (see section 3.4 below), the environmental decline was identified in JET 3 and 4, so that it was necessary to consider another sampling strategy. The sediment samples in JET 3 and 4 were collected at random from areas broadly categorised as heavy deposition areas, medium deposition areas, light deposition areas and no deposition (reference area), respectively.

Fauna	**JET2**	**JET3**	**JET4**	**References**
Sedimentary bacteria	ns	#	#	10
Meiobenthos	significant	significant	ns	11
Macrobenthos	nd	Nd	(significant)	12
Megabenthos	nd	Nd	significant	13

ns = the difference was not statistically significant; significant = significant difference was observed; (significant) = significant differences were observed in some of the taxonomic groups; nd = no data; # = statistical approach was not done.

Table 3 Comparisons of faunal abundance between natural and post-disturbance conditions.

In general, the abundance of megabenthos is so low that it is almost impossible to survey with the sediment sampler[14]. In the case of JET, a video-observation system (hereafter referred to as FDC: Finder-installed Deep-Sea Camera) was used. During the observation, to maintain a 3-m width of coverage area, the assembly was towed with the object of keeping a constant distance of about 3 m above the sea bottom.

The observations were conducted along the line transects where the area was divided into deposition and no deposition areas. For quantitative output of the megabenthos study, it was necessary to observe several hectares, so that five transect lines were established in JET 4 (*Figure 10*).

3.3. Sample processing and size categories

3.3.1. Sample processing

To understand the character of benthic communities and the sediment, it is important to determine optimum methods of sampling and sample processing. The methodological studies in this project have been conducted since 1991.

Sediment samples, except for macrobenthos study, were collected by multiple corer. The sampling ability of both the multiple corer and box corer had been compared in advance, and it was concluded that the multiple corer was preferable to the box corer for a meiobenthos study[15] (see table 4).

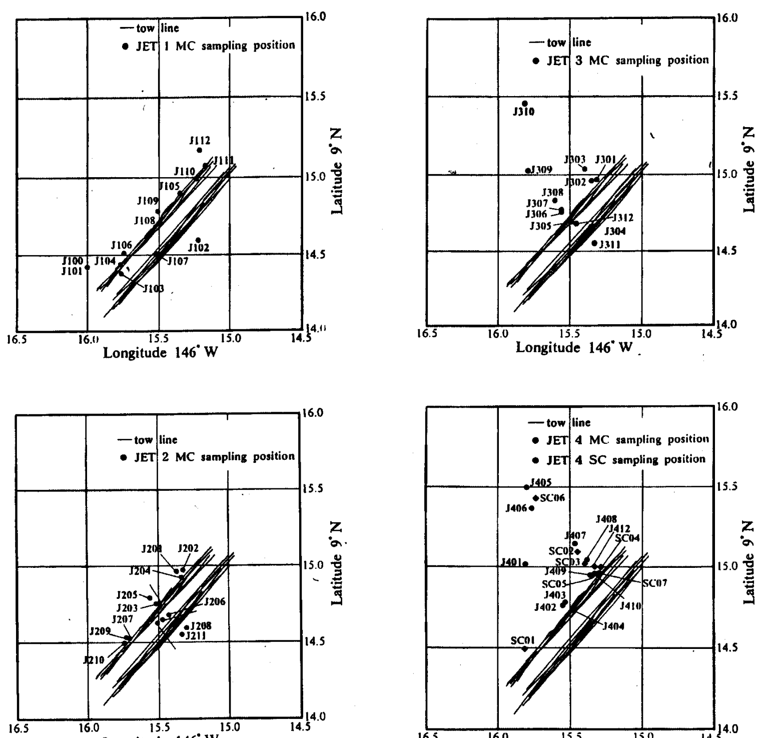

Figure 9. Sampling locations in JET 1, 2, 3 and 4.

3.3.2. Chemical and physical environmental parameters

The cylindrical samples taken with the multiple corer were subsampled with a cylinder 28 millimetres in diameter, cut into sections at the following locations:

JET 1: 0-0.25, 0.25-0-5, 0.5-0.75, 0.75-1.0, 1.0-2.0, 2.0-3.0 centimetres;

JET 2, 3 and 4: 0-0.25, 0.25-0.5, 0.5-0.75, 0.75-1.0, 1.0-1.5, 1.5-2.0, 2.0-3.0 cm.

These subsamples were then analysed for chemical parameters such as total organic carbon (TOC), total nitrogen (TN), calcium carbonate ($CaCO_3$) and opal. TOC and TN were measured with a CHN (carbon, hydrogen and nitrogen) analyser (Yanaco model MT-5) and $CaCO_3$ with a CO_2 coulometer. Opal was extracted over a five-hour period using 2M Na_2CO_3 and then analysed with the molybdenum-yellow absorption spectrometric method.

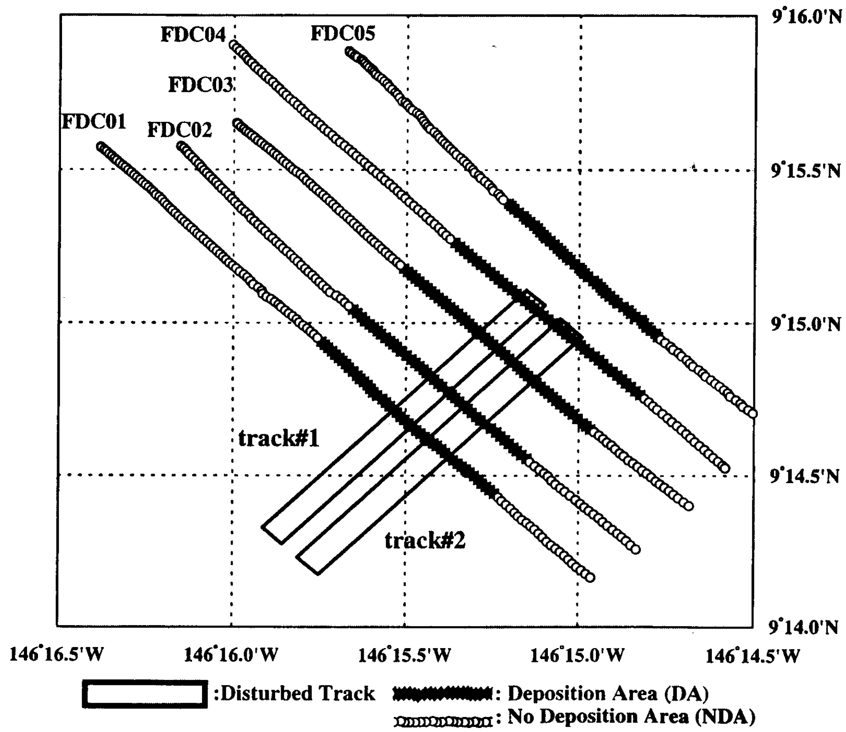

Figure 10. Location of the five FDC (Finder-installed Deep-sea camera) survey lines in JET 4[16].

Taxonomic group	Sampling point A	Sampling point B	Sampling point C
Foraminifers	*	**	Ns
Nematodes	**	**	Ns
Harpacticoids	**	**	*
Total meiobenthos	Ns	**	Ns

Ns = not significant; * = p<0.01; ** = p<0.05.

Table 4 Comparisons of meiofauna abundances collected using multiple corer and box corer at three different stations[17].

3.3.3. Biological parameters

As with the chemical environmental parameters, subsamples for meiobenthos were collected with a cylinder 28 mm in diameter and cut into sections at the following locations:

JET 1, 2, 3 and 4: 0-0.25, 0.25-0.5, 0.5-0.75, 0.75-1.0, 1.0-2.0, 2.0-3.0 cm.

The samples for sedimentary bacteria were collected by spoon from the same layers. The former was fixed with 10% buffered formalin, and the latter with 2% glutaraldehyde and stained with DAPI.

Macrobenthos samples were collected with a USNEL-type box corer, on which a 15 by 15 cm vegematic-style frame had been mounted to divide the sample into eight parts. The subsamples obtained were sliced into 0-1, 1-2, 2-3 and 3-5 cm segments, and fixed with 20% buffered formalin.

3.3.4. Size categories of benthic fauna

Benthic fauna were categorised for this study as follows.

?? Megabenthos: fauna identified by the video recorder;
?? Macrobenthos: fauna larger than 300 µm and smaller than 4000 µm;
?? Meiobenthos: fauna larger than 32 µm and smaller than 300 µm;
?? Sedimentary bacteria.

3.4. Impact evaluation

JET was designed to simulate some of the disturbance effects of redeposition on the patterns of the benthic community and subsequent succession. For this purpose, the relationship between redeposition thickness and biological responses should be addressed.

The biological responses were monitored with the methods described above. For redeposition thickness, the following approaches were tried:

?? Video observation: conditions of sediment deposition;

- ?? Calculation from discharged sediment: total amount of discharged sediment;
- ?? Colour-intensity analysis: conditions of sediment deposition;
- ?? Kriging method: conditions of sediment deposition;
- ?? Calculation using stereo photoanalysis: total amount of removed sediment;
- ?? 3-D time-dependent numerical model: sediment dispersion.

3.4.1. Video observation

According to video-observation data, deposition levels (=impact level) were recognised by the thickness of deposition on the manganese nodules[18] (figure 11). The areas were divided into four levels, as follows:

- ?? No deposition area: only natural deposition is recognised;
- ?? Light deposition area: the upper surface of the manganese nodules is partially covered by sediment;
- ?? Medium deposition area: the upper surface of the manganese nodules is mostly covered by sediment;
- ?? Heavy deposition area: the manganese nodules are completely covered by sediment.

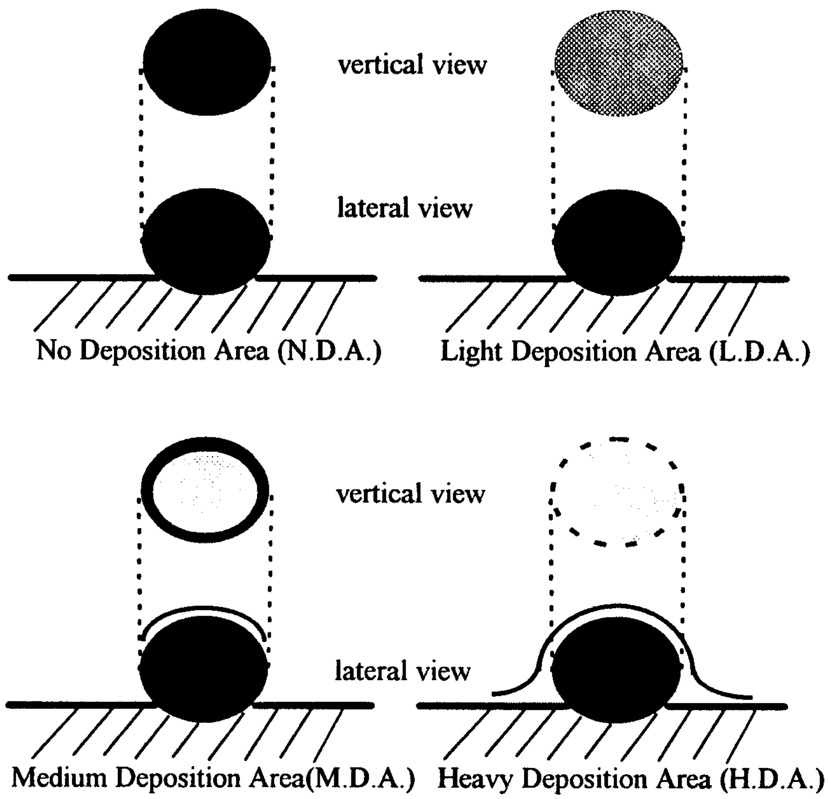

Figure 11 Deposition thickness on manganese nodules in each deposition category.

3.4.2. Calculation from discharged sediment

The discharged sediment slurry was sampled by a rosette sampler mounted atop a chimney (figure 12). The volume and mass of the sediment samples were measured and used for the following calculation:[19]

1. Average lift pump discharge
   = 125 l/second
2. Total towing time = 20 hours and 27 minutes
3. Total pump discharge = (125 l/s) x (73600 min)
   = 9,200,000 l
4. Average concentration of sample
   = 38.3 grams/l

5. Total mass of dried sediment discharged
= (9,200,000 l) x (38.3gm/l)
= 352 tons

6. Total volume of sediment discharged
= (9,200,000 l) x (269 millilitres/l)
= 2475 m^3 - based on 24 hours of sediment settling
= (9,200,000 l) x (295 ml/l)
= 2714 m^3 - based on 12 hours of sediment settling.

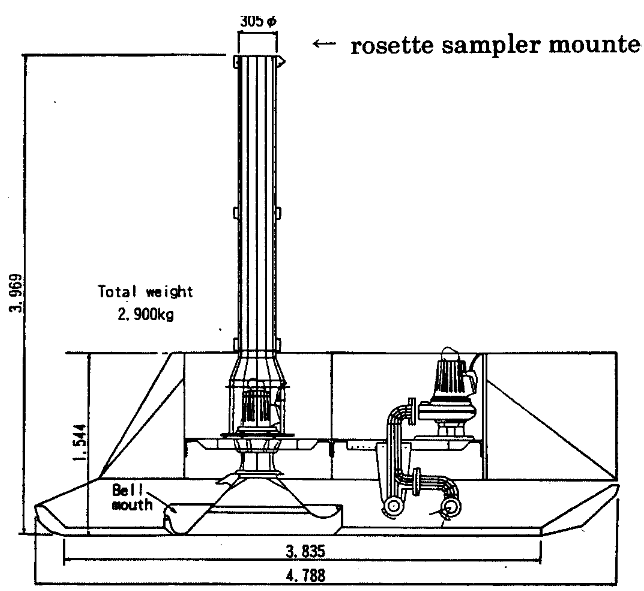

Figure 12 Disturber arrangement[20].

3.4.3. Colour-intensity analysis

An image analytical technique, which examines colour-intensity ratio between manganese nodules and the sediments in the seafloor photos, was used for detecting the resedimentation area[21] (figures 13 and 14).

3.4.4. Kriging methods

The theory and application of kriging is described in a number of texts[22]. Based on the sediment-trap data in this study, this method was applied to estimate the resedimentation area[23] (figure 15).

3.4.5. Calculation using stereo photoanalysis

A stereo photogrammetric technique for the seafloor photos was used to estimate the amount of deep-sea sediment removed[24] (figure 16).

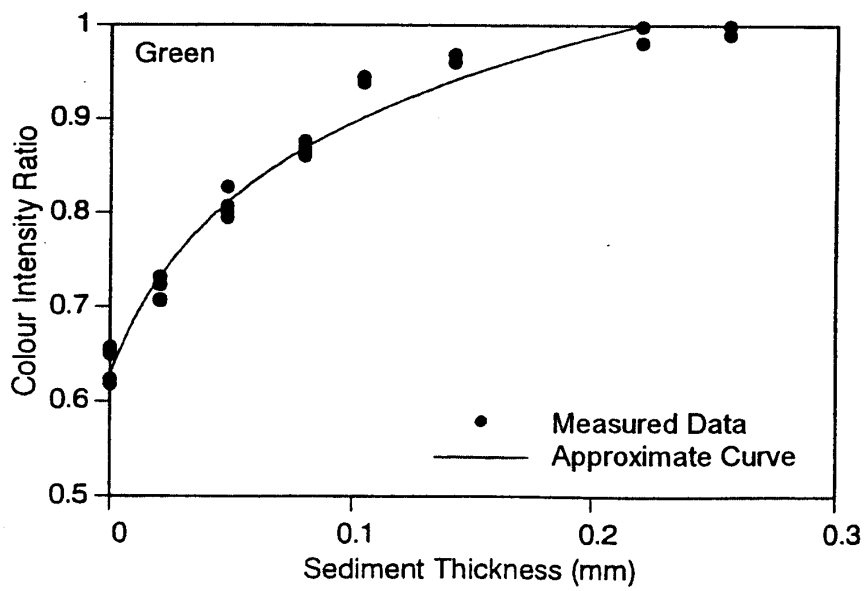

Figure 13 *Relationship between sediment thickness and colour intensity ratios[25].*

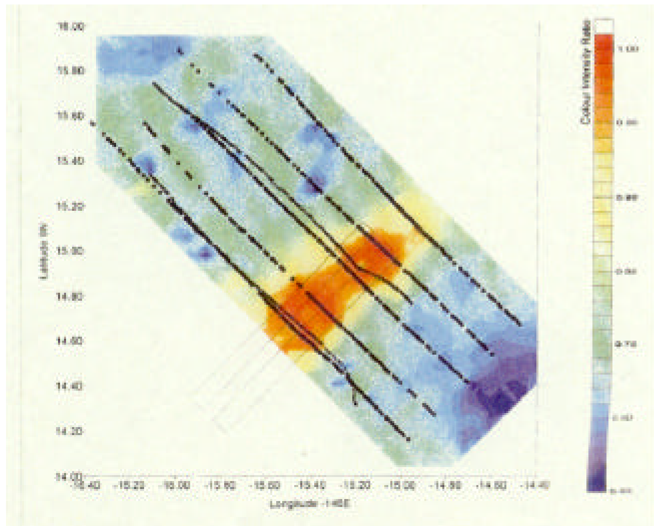

Figure 14 Thickness contour map of resedimentation[26].

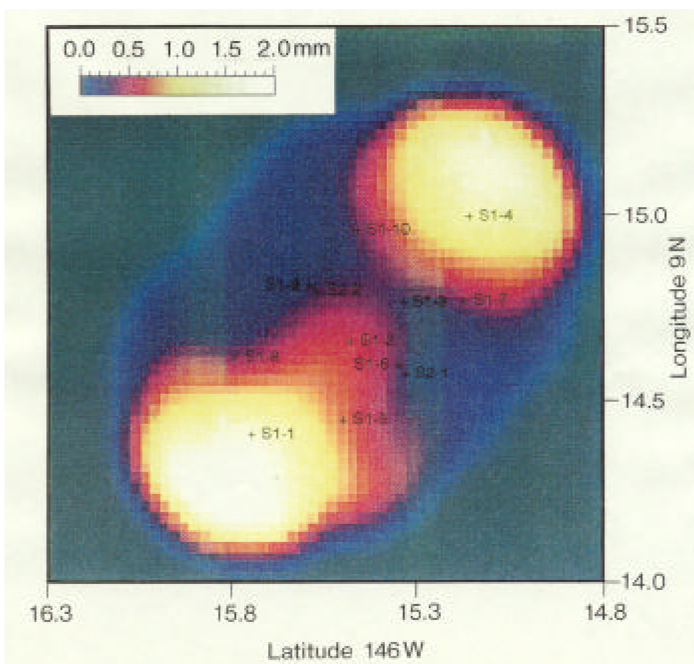

Figure 15 Resedimentation estimated by Kriging interpolation[27].

3.4.6. 3-D time-dependent numerical model

A three-dimensional time-dependent numerical model for the dispersion of resuspended sediment was developed to assess the physical aspect of benthic impacts (figure 17)[28].

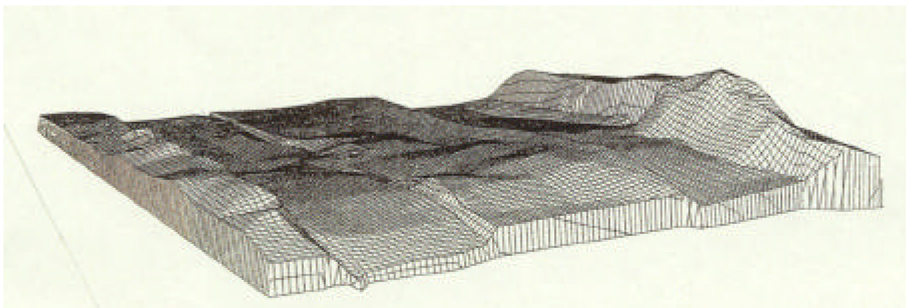

Figure 16 Geometry of disturber track measured from stereo photos[29].

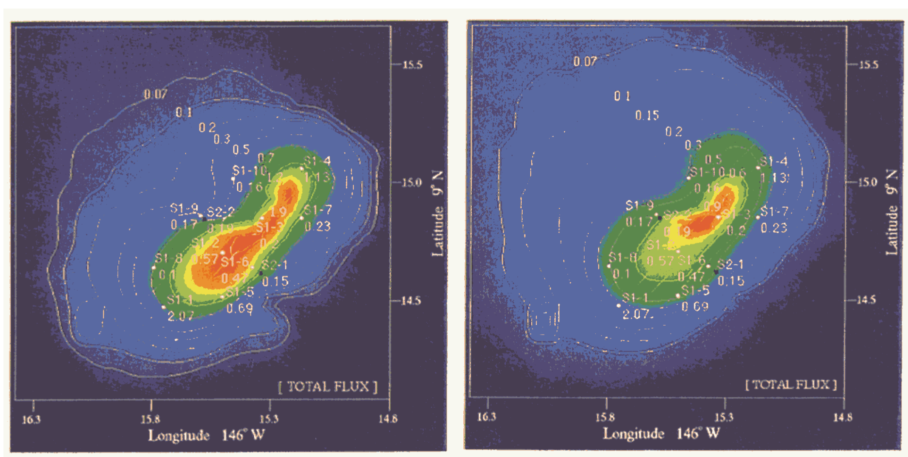

Figure 17 Simulated distributions of resuspended sediment concentration in a vertical section along disturber tow track of JET[30].

3.5. Database

Throughout the field study, data sets were accumulated. These need to be managed with some database system. In our case, Geographic Information Systems (GIS) play an important role in data management.

The use of GIS has many advantages. With such systems it is:

1) Easy to display a quantity of independent data on the same map,

2) Easy to compare data sets by using overlays, and

3) Easy to make contour maps, yielding additional knowledge.

Our database is still growing as data sets are obtained from other scientific organisations and governments. We hope that data sets concerning environmental studies of deep-sea mining in each country will be comparable and accessible in a uniform manner.

4. Conclusion

The project named "Environmental Impact Study for the Manganese Nodule Development of Japan" was carried out during 12 years and generated a significant amount of knowledge. That knowledge was accumulated step by step, after a good deal of trial and error. Moreover, that knowledge has been provided to the world through international symposia and journals. We hope our results will greatly contribute to the guidelines for the possible environmental impacts arising from exploration for polymetallic nodules in the ocean.

PRESENTATION AND DISCUSSION OF DATA STANDARDS UTILISED IN THE ENVIRONMENTAL STUDIES OF DORD (JAPAN)

Mr. Takaaki Matsui began his presentation by outlining the research procedures followed by the Deep Ocean Resources Development Company, Ltd. (DORD) and the Metal Mining Agency of Japan (MMAJ) in their environmental studies of the upper and benthic layers of the ocean. The survey had taken place in the Japanese exploration claim area, in the equatorial part of the northeast Pacific Ocean. In each environment, upper and benthic, the research had been conducted in three phases:

?? *Baseline study* – to understand the natural environmental conditions.

?? *Impact assessment study* – to understand the effects of mining. In the upper layer, cold water discharge and enriched nutrient experiments had been conducted. In the benthic environment, a deep-sea impact experiment had been performed.

?? *Impact prediction* – to calculate the harmful effects that might be caused by larger-scale mining, based on the results of the baseline and impact assessment studies.

Upper layer study

The survey of the upper ocean layer had been conducted from 1989 to 1996. The first two years had been devoted to examining the technique and conceptual design of a numerical model. Baseline sampling had begun in the third year, 1991. In the final two years, zooplankton-net sampling and conductivity-temperature-depth (CTD) observations had been carried out. There had been no upper layer study in 1994 because the benthic disturbance experiment was being performed.

The baseline study had been divided into three categories – for chemical, physical and biological environments. The chemical environmental study had been conducted to predict the impact of the high nutrient water that was supposed to be discharged at the surface during commercial mining. The parameters measured included nitrite, nitrate, phosphate and silicate – in seven layers, just as for the phytoplankton survey. The physical parameters of water temperature and salinity had been measured by CTD meters.

Plankton had been classified into pico-, nano-, micro- and macroplankton and bacteria, as well as five sizes of large zooplankton. Moreover, chlorophyll *a* and phaeopigment had been included in the investigation as parameters for understanding primary production.

For the survey, a line-transect strategy had been followed, using 11 stations located in a straight line (see figure 2 above). This area was at the boundary of the North Equatorial and the Equatorial Counter currents, and mixing occurred at the surface with upwelling from lower layers. The survey line ran north to south in the western part of the Japanese exploration area.

Discussing the approach to vertical observation and sampling, Mr. Takaaki noted that the photic layer in the ocean was regarded as shallower than the 200-metre depth distribution layer of the phytoplankton, where photosynthesis took place. For this reason, vertical water samples had been collected from seven layers at depths of 0, 20, 50, 75, 100, 140 and 200 m, using a rosette sampler. Observations in 1992 had indicated that, at all stations, chlorophyll *a* concentration reached a subsurface peak between 75 and 140 m, decreasing to zero near the depth of 200 m (see figure 4 above).

Impact assessment study

An enrichment experiment had been carried out to understand the effect of deep- seawater discharge on phytoplankton (see figure 7 above). The finding was that the abundance and composition of the phytoplankton community changed around concentrations of deep-sea water.

Impact prediction

A numerical model approach had been taken to predicting the dispersion of a cold water mass at the surface of the ocean. To gather data for this purpose, a field test had been conducted in the Japanese coastal area, in which cold water had been pumped up from a depth of 300 m and discharged at the surface. Temperature changes had been monitored by a thermistor-chain system. The numerical model developed using the experimental results predicted that cold water discharged in the Central Pacific Ocean would sink quickly.

Benthic study

Mr. Tomohiko Fukushima, describing the benthic study, noted that its results had been reported at the International Symposium on Environmental Studies for Deep-Sea Mining held in Tokyo in 1997.[31]

The goal in this study had been to evaluate the effect of deep-sea mining. For purposes of the study, the effect had been defined as the relationship between impact and damage, the impact was the redeposition of sediment and the damage was the change in the benthic community.

The impact mechanism was assumed to be as follows:

1. The nodule collector discharged sediment, consisting less of organic material than of sediment distributed on the surface of the seafloor.

2. The discharged sediment was redeposited, diluting the concentration of organic material on the surface of the seafloor. Organic material in the sediment was one of the important food sources, especially for deposit feeders.

3. The heavy deposition of sediment decreased food availability and the reproductive potential of benthic organisms. Thus, the abundance, diversity and distribution pattern of benthic fauna would be changed.

To evaluate that scenario, the Japan Deep-Sea Impact Experiment (JET) had been devised. In this project, magnitude of impact would be evaluated by estimating the redeposition thickness, comparing the environmental conditions before and after impact, as well as the environmental conditions of impact and non-impact areas. Damage to benthic fauna would be evaluated by comparing the abundance, diversity, community structure and distribution of the fauna before and after impact, and comparing the changes in those parameters with the magnitude of impact.

Separate experiments had been conducted for two kinds of impact: direct impact and resedimentation. Direct impact was being evaluated by an experiment named DIET, initiated in 1999 and using a scraper. Resedimentation had been evaluated by JET in 1994-96, using Deep-Sea Sediment Resuspension Systems (DSSRs).

The JET study site had been in the western part of the Japanese claim area (see figure 8 above), at a spot about 5000 m deep. The benthic environmental study had begun in 1989. After a preliminary survey in the first two years, the baseline study had been conducted during the following three years, 1994-96. Now, a modelling study was being considered.

As a first step for the preliminary and baseline studies, the parameters for evaluating impact had been decided (see table 2 above). These were: for the chemical environment, concentrations of total organic carbon (TOC), total nitrogen (TN), calcium carbonate, opal and radioisotopes; for the physical environment, deep-sea currents and sedimentation rates; for the geological environment, grain size and shear and penetration strength, and for the biological environment, sedimentary bacteria, meiofauna, macrofauna and megafauna.

Among the chemical parameters, the data sets for calcium carbonate, TOC and TN had been recognised as suitable indicators for sediment deposition. Radioisotopes Th-234 and Pb-210 were indicators for the recovery process and bioturbation rate. Among the physical parameters, deep-sea currents had been measured to develop a numerical model study, while sedimentation rates in the natural environment had been used for background description as a basis for estimating resedimentation. Among geological factors, grain-size measurements had been used for devising a numerical model, and penetration and shear strength would be utilised for future collector designs.
For the biological study, the abundance of sedimentary bacteria, meiobenthos, macrobenthos and megabenthos had been investigated to evaluate the effect of artificial rapid deposition. Different responses to the disturbance had been observed within those fauna, strongly demonstrating the importance of the biological studies.

Explaining the strategy of sampling and observation, Mr. Fukushima said that random sampling of sediments had been conducted using multiple corers, while line-transect observations had been carried out by video at various sites (see figure 10 above). In the pre-disturbance phase, sampling locations had been selected at random from an area extending 100 m from the disturbance site, permitting statistical estimation of natural environmental conditions. Monitoring studies immediately after the disturbance had been done in JET 2. The sampling stations had been decided according to a modified line-transect method at distances of 25, 50 and 100 m from the tow tracks. Sediment samples during JET 3 and 4 – one and two years, respectively, after the disturbance – had been collected at random from areas broadly categorised as heavy deposition, medium deposition, light deposition and no deposition areas.

During the video observation, to maintain a 3-m wide coverage area the researchers had tried to tow the assembly at a constant distance of about 3 m above the sea bottom. Observations had been made along lines transecting the deposition and no deposition areas. For quantitative output of the megabenthos study several hectares had to be observed, so that five transect lines had been established.

To understand the characteristics of the sediment and the benthic communities, it was important to determine optimum methods of sampling and sample processing. To this end, a methodological study had been conducted beginning in 1991.

Sediment samples, except those for macrobenthos studies, had been collected by multiple corers. After comparing the sampling ability of multiple and box corers, it had been concluded that the multiple corer was better for the meiobenthos study.

According to preliminary results, 87 percent of meiofauna were distributed in the upper 3 centimetres at this site. Therefore, the study had analysed the top 3 cm. Among the various sizes of benthic organisms, the megafauna had been identified by video recorder, macrofauna had been categorised as larger than 300 microns and smaller than 4 millimetres, and meiofauna as larger than 32 μm and smaller than 300 μm.

As JET had been designed to ascertain disturbance impacts, the experimenters had tried to determine the amount of redeposition. Since deposition thickness was not easy to measure, several approaches were necessary. The study had taken five approaches: (1) video observation, a simple way to learn about sediment-deposition conditions; (2) colour-intensity analysis, for the same purpose as video observation; (3) the kriging method; (4) stereo photoanalysis, and (5) numerical modelling. Colour-intensity analysis was an image-analysis technique that examined the colour-intensity ratio between manganese nodules and sediment on the seafloor, making it possible to recognise resedimentation and draw maps (see figure 14 above). The kriging method addressed resedimentation conditions using sediment-trap data (see figure 15 above). Stereo photoanalysis of a disturber tow track had produced a diagram showing the width of a track (see figure 16 above), in which the highest point of sediment moved was about 15 cm.

The JET experimenters had written a simple scenario that had to be carefully studied to confirm the theory. The environmental impact study for manganese nodule development of Japan had been carried out during 12 years, generating a great deal of knowledge. That knowledge had been accumulated systematically, with much trial and error. Moreover, the knowledge had been disseminated through international symposia and journals. Mr. Fukushima hoped it would greatly contribute to the guidelines of the International Seabed Authority.

SUMMARY OF DISCUSSION

Impact of disturber track

Referring to the damage caused directly by passage of the mining vehicle across the seafloor, a participant said he had learned, from research into deforestation in rain forests, that the effect on soil fauna depended hugely on how deforestation was carried out. If cutters walked in and took the trees away after cutting them down, the damage to the soil fauna was not particularly great. If a bulldozer was used, however, there was a huge impact on the biodiversity of the soil fauna, because the weight of the machine seemed to do something horrible to the environment, looked at from a nematode's or termite's point of view.

Mr. Fukushima responded that, unfortunately during the Japanese trial, samples had not been taken from the disturber's tow track. In a new project initiated in 1999, such sampling would be done at a depth of 200 m.

Chlorophyll distribution

Discussing why graphs on vertical distribution of chlorophyll showed a maximum concentration at 100 m and not nearer to the surface (see figure 4 above), a participant explained that those profiles had been recorded before any impact. They were the natural chlorophyll profiles, typical for oligotrophic waters, in which the chlorophyll maximum was usually at depths of 75-100 m or so because the nutricline was at those depths. Shade-adapted or low-light adapted phytoplankton lived at the depths near where they were able to obtain nutrients.

Effects on meiofauna and megafauna

To a question about the response of meiofauna and megafauna to the JET experiment, Mr. Fukushima said suspension feeders had not decreased significantly but deposit feeders had declined. The reason, in his opinion, was that the impact from the DSSR had been temporary for the former but not for the latter, because organic carbon in sediment had remained low after two years. This meant that deposit feeders had suffered for two years while suspension feeders had been affected for only one month. The same results had been obtained for macrofauna and meiofauna. Among macrofauna, polychaetes were the infauna deposit feeders and harpacticoids were external deposit feeders.

Length of study

Noting that the Japanese project had taken eight years (1989-1996) to produce results, while other ventures might take one to three years depending on the volume and density of research, a participant wondered what minimum experimental period and surface area might be needed to achieve conclusions and data that could be validated.

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Chapter 9 Data Standards Utilised in the Environmental studies of l'Institut français de recherche pour l'exploitation de la mer (IFREMER) and l'Association française pour l'exploration et la recherche des nodules (AFERNOD)

Dr. Myriam Sibuet, Director, Department of Deep-Sea Environment, Institut français de recherche pour l'exploitation de la mer (IFREMER), Centre de Brest, France

SUMMARY OF PRESENTATION

Dr. Myriam Sibuet began her remarks by stating that it was still too early for a general standardisation in deep-sea ecology because the understanding of this subject was still in its infancy, especially concerning the functioning of the deep sea. Of the relatively small group of 30 people that she led in France, only six scientists were working in deep-sea biology, chemistry and physical oceanography, and on the group's leading programme on hydrothermal vents, cold seeps and deep-sea basins.

The experience in deep-sea environmental studies gained by the Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea) could help to identify what was needed in the nodule areas. She would discuss what it had learned from studies on the structure and functioning of detritus-based ecosystems, and what sampling gear and other equipment were suitable for these studies. She would also describe Biocean, a multidisciplinary database devoted to the deep sea and to all the cruises that IFREMER had conducted to date, which could help to show how the data for this environment should be managed. Finally, she would speak about a proposal for a multidisciplinary cruise to the north equatorial Pacific nodule area allocated to the Association française pour l'exploration et la recherche des nodules (French Association for Exploration and Research of Nodules).

The general objective of the IFREMER Department of Deep-Sea Environment, which had close links with universities and occasionally with others in Europe, was to contribute to the knowledge and exploration of the deep sea by studying the structure and functioning of the benthic ecosystem. It had identified three types of ecosystems: in addition to the one based on detritus, including the nodule areas, there was another, more common than had previously been thought, based on chemosynthesis, including areas around hydrothermal vents, and a third system centred on active and passive margins and cold seeps.

Purposes and results of studies

In studying the cycle of organic carbon flux and the benthic response at the water/sediment interface, French scientists were trying to analyse the community structure at all levels. The aim was to approach the dynamics of the benthic ecosystem, in an effort to understand the role of the organic carbon cycle and to be able to evaluate the potential impact of industrial activity. Nodule collection and even exploration would cause a flow of particles to the sea bottom, and drilling into the bottom would leave a large quantity of debris. Interdisciplinary studies were necessary, but they could not be conducted everywhere. They would have to be based on permanent stations in order to examine the temporal variation of particle flux and other physical parameters. IFREMER proposed to study meio-, macro- and megafaunal communities, conducting in situ experimentation when possible, including colonisation and respiration experiments.

The studies would investigate carbon flux to the bottom, which was the primary energy source for the seabed. It was related to primary production and indirectly to the fauna, whose components recycled the carbon flux, a process also dependent on hydrodynamics near the bottom. Therefore, the study programme combined flux studies and hydrodynamics, in the belief that this was the best approach to understanding and evaluating the deep-sea faunal component quantitatively and qualitatively.

Dr. Sibuet outlined some results from a deep-sea basin study at a permanent station visited during several cruises over several years. It had begun in the 1970s with the Biogas programme, at which time IFREMER decided that it needed a permanent station to which it could return regularly to obtain replicate samples and time series. This had been followed by a large programme related to the Joint Global Ocean Flux Study (JGOFS) on the site called Eumeli (eutrophic, mesotrophic and oligotrophic) at 2000, 3000 and 4000-m depths, and a more recent project with the European Community at a permanent station on the Porcupine Seabight.

After some three or four years of work involving sieving, sorting, density analysis and identification of species, during which specimens had been weighed individually, a biomass distribution had been worked out for the three major categories of the benthic community -- meiofauna, macrofauna and megafauna. The research demonstrated differential changes among these class sizes, influenced partly by depth but mainly by the flux of organic carbon. At the eutrophic site, where a lot of organic carbon arrived on the bottom, the main beneficiaries were the megafauna. With less organic matter, there were many more macrofauna. At the oligotrophic site, as in the nodule area, meiofauna were the most important component and megafauna were relatively rare. This unexpected result showed the close relationship between size group and the flux of particulate organic carbon arriving on the bottom.

The second result concerned the variation in density of major components of macrofauna. During the collection period, September 1996 to October 1998, only polychaetes, which made up 80 percent of the macrofauna, showed some change. All the other groups -- isopods, tanaids and bivalves – displayed no change in total density. These data led the researchers to look at the matter in detail, employing a different treatment of the samples. During the European phase of the programme, it had been decided to look beyond total macrofauna in the box cores by examining them at different depth levels -- for example, 0-1, 1-3 and 3-5 cm -- to see if there was any temporal change in abundance in the vertical distribution. The distribution of fauna in deeper layers of the sediment could help to elucidate changes in behaviour or, in the case of nodules, a change due to an environmental impact. At this level of detail, some groups again showed no significant change in vertical distribution, but others had been influenced more or less over time. For example, nematodes, which had initially been mainly in the first layer (0-1 cm), were found in July 1997 largely in the second level (1-3 cm). The same was also observed in other groups. Although the way samples were examined could help to identify changes, it was too early to standardise methods for looking at variations in community composition and structure, because scientists were still searching for the best way to observe such changes. As she had shown, scientists were in the process of understanding the community structure of higher taxa. Obviously, a similar understanding at the species level was necessary, but results were sparse and not easily achieved.

Equipment

The deep sea could not be investigated with just a box corer or a trawl; many devices were needed – a fact that had guided IFREMER over the years. For example, a sediment trap provided data on the flux of organic carbon, the primary parameter controlling all development of life on the bottom. Different sampling devices were used to obtain fauna of different sizes. Other types of gear were put on the bottom for long-term monitoring, in a multidisciplinary autonomous vehicle.

For the ecology of the deep sea, IFREMER had chosen to work with three types of gear that were more or less standard. However, there was no standard method for collecting megafauna. French scientists used a beam trawl with a wooden beam 6 metres long, which primarily collected epibenthic fauna, mostly invertebrates. For sampling fish, much better trawls existed. Although megafauna were collected qualitatively, there was no good sampling strategy for quantitative sampling. The USNEL box corer, developed by the United States Naval Electronic Laboratory and initially used by P.A. Jumars and R.R. Hessler in the 1970s, was now internationally regarded as standard because its large box was relatively well sized for sampling the small components of the deep-sea benthic fauna. It was also important to sieve correctly the sediment collected with this box corer in order to sample small macrofauna. Researchers could be given a lot of discretion on the sieving levels, because much knowledge was available in the literature. Since 1976, IFREMER had decided to sieve at a mesh size of 250 microns. The multiple corer, which her group had been using for about 10 years, was being used not only for meiofauna at a 40-µm mesh size but also for bacteria and for the chemical compounds in the sediment.

In order to study the structure of the benthic community according to size, it was important to agree on the various types of gear, as each type was suitable for a different component of the fauna. The multiple corer might be used mainly for microbiota, the USNEL box corer had a limiting size of 250 µm for macrofauna, and the beam trawl was usually sieved at 1 centimetre.

In sieving, the gear must be chosen according to the taxa to be collected. For example, the USNEL box corer was used for macrofauna, while meiofauna were better collected with the multiple corer. Of course, nematodes and harpacticoids were picked up in the box core, but they were excluded from counts in order to achieve quantitatively correct samples. Among megafauna, specimens of many different large invertebrates and fish were needed in order to study the trophic behaviour of various species. These had to be defined at the species level to identify any changes due to impact, for example. Therefore, any research programme had to depend on progress in taxonomy, combining classic taxonomy based on the Linnaean system with molecular biology. Otherwise, too many errors would result.

Various kinds of equipment were being used to examine the deep-sea environment, Sibuet continued. Some gear had been initiated and built by her group, with help from the IFREMER Marine Technology and Information Systems Division. One example was the MAP (Module Autonome Pluridisciplinaire), a complex device that incorporated a camera to photograph the bottom on a regular basis over the course of one year; a nephelometer to analyze turbidity near the bottom and 10 m from the bottom, and current meters. It also held sediment trap moorings for the sequential capture of organic particles; during a year on the bottom, it collected two weeks of samples in each of its 24 bottles. One of the first models, built 10 years ago, was still considered the best because the structure of the new one was too large; to measure currents, a structure was needed that did not disturb the measurements. The long-term multiparameter monitoring that became possible with this module allowed for the simultaneous recording of particle flux, concentration of fine particles, current readings and bottom photography.

Displaying some of the results obtained with this multidisciplinary gear, she said the sediment trap had allowed researchers to identify an April 1988 event with a large amount of particle flux. A month later, the transmissometer had recorded a flow of fine particles in the water. The current meter, measuring the orientation and intensity of the current, had shown an eddy at exactly the time of the turbidity. Thus, with simultaneous measurement of the different environmental parameters, the event could be precisely localized.

Biocean database

Having data on all these parameters, and in collaboration with many people in France and elsewhere in Europe, IFREMER had decided 15 years ago to create a database on the taxonomy of the species collected. The Biocean database had since been improved by the installation of more modern computer software, Oracle. This had cost a lot of money, of course, but IFREMER now had a database organised the way it liked. In the first place, it worked on board, where data on each sample was placed in an initial data set, including information on the environment, fauna, water and sediment. It incorporated all the measurements made in situ, as well as the continuous ones from the autonomous vehicles. Photographs could also be added when available. In the second phase, all the data filed on board were imported on land into a real database – Biocean. Thus, the laboratory now had access to all the information about the various species, fitted into a zoological classification scheme and using classification management software, that enabled users to know which species had been obtained at various locations where the researchers had worked. The classification software was organised according to the taxonomy of each group, so that, as soon as the species was known, there were automatic links with phylum, class, family, genus, etc.

For impact studies of the nodule area, it would be important to have an ecologically oriented database in order to draw comparisons and analyse temporal changes. The types of possible studies included analyses of biodiversity, biogeography, relationships with physical and chemical conditions, and intra-site temporal evolution of environmental parameters and faunal composition. All such analyses could be part of impact studies on global changes in the deep-sea ecosystem, whether for deep-sea mining or fisheries, which had several approaches in common.

Future activities

IFREMER was interested in working in the French mineral exploration area in the North Equatorial Pacific Ocean, Sibuet stated. Only one thesis in biology had been done in that area under her direction, by Virginie Tilot. However, this thesis had been based entirely on photographs, and Sibuet thought it dangerous to rely only on photography because of the difficulty of identifying fauna without specimens from a trawl. A photograph showed only a distinction between invertebrates and fish, without enough detail to make it worthwhile. The geological survey of the northeast and southeast parts of the French area was nearly complete and the biological investigation was practically done, using photography but with only a few box-core samples, which were recorded in the Biocean database. They included some macrofauna but almost nothing from the western part of the area. Samples had been obtained in 1988 and 1991 cruises with the submersible *Nautile*, but after the sampling, they had been removed from the basket and nothing had been brought on-board.

She outlined a proposal by IFREMER for a multidisciplinary cruise in the coming five years, with the aim of complementing existing geological, biological and environmental information on both main parts of the French exploration area. Baseline geological knowledge would be sought on major benthic components, with the help of a geologist from the Institute. There would be a multibeam bathymetric survey and seismic sub-bottom profiling to obtain information on sediment stratigraphy and the sedimentation level. If the near-bottom survey was close enough to the bottom it could be used for biological research, but if it was too far away, fauna down to 2 cm in size could not be identified.

As part of the studies she had mentioned earlier on the biological structure and functioning of the detritus-based ecosystem in the nodule area, the epibenthic fauna would be observed and sampled to evaluate the global structure of that community, its spatial distribution, and possibly temporal changes if data from past cruises were precise enough. Sampling of the epibenthic fauna would be necessary to identify species and determine megafaunal diversity. In this regard, she underlined the need for an international network of taxonomists, because there were not enough taxonomists in France and maybe even internationally to help process the findings. Sampling of sediment for macrofauna would use an USNEL box corer to identify the overall structure of the communities and to evaluate bacterial activity. The aim was to relate all these parameters to environmental characteristics.

Sibuet did not know what type of gear would be available but hoped it would be possible to use the remotely operated vehicle ROV Victor 6000, developed at IFREMER. On its first cruise, in December 2000, that vehicle had worked remarkably well because it was linked with a fibre-optic cable for real-time video. Sampling devices linked to the ROV included tube corers for sediment fauna and chemistry, boxes for sampling or experimentation on fauna, and an in situ analyser for measuring pH, oxygen compounds and sulphates in near-bottom waters.

While IFREMER could organise one cruise to collect samples, long-term monitoring would require cooperation with other countries to keep a ship in the area and arrange for the mooring of sediment traps and current meters. This could not be achieved outside the framework of international collaboration to obtain enough ship time.

SUMMARY OF DISCUSSION

Biological and environmental research

Asked whether the French were planning any water-column ecological investigations, Sibuet replied that, regrettably, they were not because IFREMER had never developed this speciality. The only laboratory in France looking at this subject was a group near Nice in the south of

France, but its research was oriented toward the Mediterranean Sea. She hoped more work would be done on the water column just above the bottom. Nothing was known about near-bottom plankton and larvae, due to the lack of good devices for that environment. She thought this could be achieved in an international framework, as it would be interesting to see whether the functioning and structure of these communities differed from one exploration area to another.

Referring to data on temporal variations at a single site, a participant asked how the researchers made sure that they were investigating exactly the same site each time. Sibuet replied that the study had relied on replicates -- for example, six to eight box cores each time at nearly the same place. The place could not be exactly the same, but the researchers tried to do their best and believed that their statistics were correct enough.

The same questioner asked whether there had been an accurate analysis of the sediments from which biotic samples had been taken, to ensure that they came from the same type of surroundings. Sibuet responded that, for the physicochemical characteristics of deep-sea sediment, granulometry had been used along with chemical analysis of such ever-present parameters as organic carbon and nitrogen. The granulometry showed no significant change, with the sediment remaining a smooth mud. Organic carbon was a bad indicator that did not change enough. The best parameter was carbon flux, whose variations were not confined to the sediment layer.

Some samples had displayed a temporal change in lipids -- not in terms of total amounts but in reference to a special lipid, which had been buried. These changes were difficult to analyse without detailed research into biology and chemistry.

Asked to elaborate on her data showing a seasonal cycle in the density of polychaetes, Sibuet said that samples from a tropical environment showed minimal seasonal variation in the flux of particles, whereas a strong seasonal change occurred at a temperate station in the northeast Atlantic Ocean. For the benthic community, however, it was difficult to measure response to seasonal changes in particle flux. Moreover, without information on the natural changes, it would be impossible to see variations resulting from an impact.

Asked for an estimate of the microbial contribution to the biomass, Sibuet said that, with the help of a microbiologist, her laboratory had tried to identify all the useful methods in this field. She had been astonished to see that there was no ideal method to calculate the total biomass of bacteria. In any case, such a calculation would not reveal anything about the activity of the bacteria, since they might be dormant. She had been told that many bacteria were unable to function all the time, so that 90% of the bacteria on the bottom might be dormant, becoming active only when enough material arrived. This flexibility in behaviour made such studies difficult. Activity measurements done onboard were biased by the fact that they did not measure what the bacteria were doing on the bottom. While progress in molecular biology had made it possible to obtain a good picture of diversity and the activity associated with each type of bacteria, the measurement of active biomass was difficult. Measurement of adenosine triphosphate (ATP) was not the best method. Thus, standardisation would not be possible in this area.

International cooperation

Asked to amplify her views on international cooperation, Sibuet said she thought ship time should be the first consideration. Long-term monitoring of the bottom would require different types of devices for bottom photography, current measurement, nephelometry, and particle flux and collection studies. Devices for these studies had to be put in position and later recovered. Cooperation would also enable scientists to come together frequently to present the results of their laboratory work. The aim should not be to indicate to each laboratory what it should do.

Databases

Asked whether the Biocean database was a suitable model for the International Seabed Authority, she replied that many laboratories wanted to have their own database. Biocean stored all the data from IFREMER cruises. As a minimum, each group should have this kind of database, which all could share. The Biocean model could be generalized but the database belonged to the laboratory that had done the studies and was shared by the scientists who had contributed the data.

Standardisation

Regarding Sibuet's comment that it was too early for standardisation in deep-sea ecology, a questioner asked when and how the necessary standardisation could be achieved. She replied that a minimum level of standardisation would help in such areas as equipment, sieving methods and sample processing. However, not everything could be standardised because, for example, not everybody agreed about what was the best equipment. The trawl was not the best candidate, but the box corer and the multiple corer might be easier to standardise. Nor was it easy to standardise processing because, whereas evidence of change was minimised when analysing the total sample from a box corer, change became apparent when the core was split into different levels. With researchers in the infancy of their understanding of how to see natural changes, it was too early to standardise, although the stage had been reached where there was enough understanding to show the need for more detailed research. She did not like the word "standardisation" when it was used to minimise information gathering. Impact studies had to be based on the best level of science. An oil company might like to have a baseline study with minimum effort, but that could not be done. The effort to do good science must not be minimised, when what was needed was more detailed understanding.

The moderator, Craig Smith, commented that standardisation was obviously a complex issue. On the one hand, scientists would like to compare measurements of certain parameters across the whole Clarion-Clipperton Fracture Zone (CCFZ). For example, to understand species ranges, a standardised taxonomy was needed to see whether an animal identified at one end of the zone corresponded to something at the other end. If a coherent database was to be set up, there would have to be a set of standards or protocols for submitting the data, so that one group's measurements of a particular parameter were not totally different from another's. Some basic issues of standardisation could be recognised, such as using a 250-µm screen for box-core processing.

On the other hand, he said that certain kinds of measurements or studies should not necessarily be standardised. These included process studies -- site-specific investigations at the forefront of science. For example, in time-series work on a particular phenomenon a researcher might want to change a sampling protocol or time series to get a better resolution or better understanding of what was going on at a particular site. A change of technology might be required to adopt the newest scientific method. People should not be forced to measure something in a certain way when they had a better way. In his own research, he often did not do things the way others did, preferring to modify his approach to suit the problem.

Sibuet agreed with Smith, emphasising that standardisation could not applied on all levels. In taxonomy, for example, no new tool was need for standardisation, since the Linnaean system had been in use since 1715. A problem arose only when a taxonomist did not make a proper identification. Molecular biology would be needed in future to identify diversity, but not species. She agreed that, for a database, the approach, the protocol and the type of data must all be the same. In fact, the Biocean database had been organised precisely in order to compare samples obtained with the same methods.

She had rejected papers that compared macrofauna figures based on sieves of different sizes. John D. Gage, in a recent paper,[1] had given good advice to oil companies when he showed how important it was to sieve at 250 µm -- or 297 µm in the United States, where the measurement system was not the same as in France. Several people in recent years had favoured 500 µm but, like Gage, she did not agree, because people had to work at the size of the small deep-sea fauna if they wanted to examine representative components. For meiofauna and macrofauna, there was no doubt that a common protocol was needed. Megafauna were much easier to deal with because they could just be collected; nevertheless, while the species might be known, they could not be quantified unless photography provided enough information. Unfortunately, photographs were limited to the epibenthic fauna, excluding the burrowers; for echiurids (spoonworms) and echinoids, which were burrowers, photography gave no information.

Another participant, supporting Sibuet's remarks about sieve sizes, said he was delighted that everyone was using 32- or 45-µm sieves for deep-sea nematodes. When a 63-µm sieve was used, more than half of the nematodes were lost, including all of the smaller species. As to their identification, nematodes and other meiofauna were more like bacteria than the other metazoa in that the Linnaean system could not be used. A DNA-based system would be more practical, but then the units should not be called species. Instead, the term used was molecular operational taxonomic unit (M-OTU). This approach would be effective for monitoring in mining areas, but it disobeyed the Linnaean rules. Standardisation was needed in this area as well, since different gene collections used in analysis gave slightly different classifications.

Sibuet agreed that the molecular approach was the only way to standardise such work. However, it gave information on diversity, not on species.

Notes and references

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Chapter 10 Data Standards Utilised in the Environmental Studies of the Korea Ocean Research and Development Institute (KORDI)

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Paper by Ki-Hyune Kim, Woong-Seo Kim, Sang-Mook Lee, Cheong-Kee Park and Seung-Kyu Son

ABSTRACT

Having begun exploration for deep-sea mineral resources in 1983, the Republic of Korea is now carrying out a detailed exploration survey in its registered area to fulfil its obligations to the International Seabed Authority. Korea’s unshaken calling is to be successful in exploiting deep-sea resources and conducting related environmental studies to provide our nation with the resources it lacks. Issues of environmental protection are especially important in relation to deep-seabed mining activities. Thus, beginning in 1991, the Government has carried out an environmental programme of physical oceanographic measurements, monitoring of benthic animals, analysis of suspended materials in the water column, meteorological information gathering and other activities in the area. This paper provides information on Korea’s advanced research system, as well as some results of environment studies and data processing.

1. Introduction

The International Seabed Authority has established a mining code. The code regulates and guides deep-seabed exploration for polymetallic nodules containing manganese, nickel, copper and cobalt, located on the seafloor in regions which are beyond national jurisdiction but which are subject to the United Nations Convention on the Law of the Sea. One of the important aims of the mining code is to ensure that the marine environment of the registered area is protected from serious harm. The regulations require the collection of information on environmental baselines that can be used to assess the likely effects of mining activities on the marine environment.

Since becoming a pioneer investor in 1994, the Republic of Korea has concentrated its exploration on manganese nodules in the Clarion-Clipperton Fracture Zone (CCFZ) and on related environment studies that are necessary for preservation of the natural environment, environmental assessment and protection.

2. Geological Survey

2.1. Geophysical instruments

2.1.1. Navigation system

?? Positioning using satellite (type: Differential Global Positioning System (DGPS); resolution: 1 metre)

?? Providing accurate position and time using DGPS information

✍ Type: KonMap system
✍ Hardware: KonMap system personal computer
✍ Software: Hydaq, Hydmap

2.1.2. Marine data management

?? Providing comprehensive information for cruise

✍ Type: MDM 300 system
✍ Data logger: HP425S workstation
✍ Software: MDM 300 system S/W, Ingres RDBMS (relational database management system), Wings spreadsheet

2.1.3. Multibeam echo sounder

?? Providing depth information

✍ Type: SeaBeam 2000
✍ Source: 12 kilohertz (11-16 kHz)
✍ Operational range: 10 to 11,000 m
✍ Swath angle: 120 degrees
✍ Coverage: 200 percent

2.1.4. High precision depth recorder

?? Providing depth information using two transducers

✍ Type: Simrad EA-500
✍ Frequency range: 12-200 kHz

2.1.5. Sub-bottom profiler

?? Providing high resolution, sediment seismic images penetrating down to 50 m from the seafloor

✍ Type: Bathy-2000P system
✍ Source and depth range: 3.5 kHz, 2-10,000 m
✍ 12 transducers in the shallow and deep-water portions

2.1.6. MR1 side-scan sonar

?? Providing high-resolution topographic information[1]

✍ MR1 system at University of Hawaii

2.1.7. Multi-channel seismic system

?? Providing geological and geomorphological information

✍ Source: Sleeve Gun 2 sets (group interval: 25 m; lead-in cable: 150 m)
✍ Recorder: SN358 system, DFM 480 camera

2.1.8. Marine magnetometer

?? Providing magnetic information

✍ Geometrics G-886 marine magnetometer

2.2. Devices for geological and geotechnical sampling

2.2.1. Free-fall grab (FFG) sampler

?? Acquiring polymetallic nodules

- ✍ Four samplers deployed at proper intervals (about 200-300 m) along a line at each sampling site
- ✍ Composition: float, grab, ballasts
- ✍ Coverage: 0.25 m^2 each

2.2.2. Free-fall grab sampler with camera

- ?? Acquiring photographs of bottom surface where polymetallic nodules were sampled

- ✍ Lens angle in water: 46°

2.2.3. Cable-photo grab sampler

- ?? Providing information on polymetallic nodule population and sediment properties

- ✍ Coverage: 0.9 m^2
- ✍ Dimensions: 96 by 67 by 70 centimetres
- ✍ Sampling depth: 30 cm

2.2.4. Spade corer

- ?? Acquiring sediment and polymetallic nodules distributed on the top of the sediment

- ✍ Holds a 0.1-m^2 stainless steel sample box and has a maximum effective penetration of 50 cm
- ✍ Units: special flow-through head design, automatic door closing device, pre-trip preventer bar with posi-action hook, stainless sample box with detachable handles, box bottom plate
- ✍ Frame size: 165 x 195 x 220 cm
- ✍ Spade size: 20 x 30 x 60 cm

2.2.5. Multiple corer

- ?? Acquiring bottom-sediment samples

- ✍ Diameter: 9.5 cm
- ✍ Length: 60 cm
- ✍ 8 units

2.2.6. Piston corer

?? Acquiring bottom-sediment samples

- ✍ Diameter: 9.5 cm
- ✍ Maximum penetration depth: 12 m

2.2.7. Dredge

?? Acquiring polymetallic nodules

- ✍ Diameter: 100 cm
- ✍ Length: 180 cm

2.2.8. Sediment trap (mooring)

?? Acquiring sediment flux in water column

- ✍ Aperture diameter: 80 cm
- ✍ Height: 150 cm

2.2.9. Deep-tow imaging system

?? Acquiring real-time bottom-surface images

- ✍ Camera units: 35-millimetre still camera, continuous video images, 7500 m of coaxial cable, 800 frames of 35-mm photographs

2.3. Analytical methods

2.3.1. Manganese nodule geochemistry

?? Sampling: Spade corer and free-fall grab sampler

?? Baseline for classification: surface texture (four types), external pattern (six types), size (six ranges)

?? Separation of nodule and sediments (detritus)

?? Dehydration

?? Crushing in jaw crusher and repeated sieving through no. 5 mesh size. Small amounts of crushed samples were repeatedly ground into less than 100 mesh size using automatic agate mortar and sieves.

?? Dehydration and weighting (0.2 gram)

?? Chemical treatment: mixed acid (HCl 6 millilitres, HF 2 ml), evaporation, adjustment

?? Major elements: Mn, Fe, Co, Cu, Ni, Zn

?? Minor elements: Al, Ca, Mg, K, Na, Ti, P, Ba, Cr, Sb, V, Pb, Cd, Sc, Rb, Mo, Y, Zr

?? Rare earth elements (REE): Th, U

?? Measurement system: ICAP-AES (inductively coupled argon plasma - atomic emission spectrometer), ICP-MS (inductively coupled plasma - mass spectrometer)

2.3.2. Sediment geochemistry

?? Sampling interval: 2-5 cm

?? Crushing in jaw crusher and repeated sieving into no. 5 mesh size. Small amounts of crushed samples were repeatedly ground into <100 mesh size using automatic agate mortar and sieves.

?? Dehydration and weighing (0.2 g)

?? Chemical treatment: mixed acid (HCl 6 ml, HF 2 ml), evaporation, adjustment

?? Major elements: Mn, Fe, Co, Cu, Ni, Zn

?? Minor elements: Al, Ca, Mg, K, Na, Ti, P, Ba, Cr, Sb, V, Pb, Cd, Sc, Rb, Mo, Y, Zr

?? Measurement system: ICAP-AES

2.3.3. Geotechnical properties

?? Undisturbed core sediment

?? Multiple corer (diameter 9.5 cm, length 60 cm, 8 each/set)

?? Analysis items: specific gravity (grain density), bulk density, shear strength, grain size, water content, sediment texture, porosity

?? Measuring equipment: pycnometer, motorised vane system, automatic grain-size analyser

2.3.4. Sedimentation rate

?? Multiple, spade and piston core sediment

?? Isotopic analysis: Be-10 (Pliocene)

?? Paleontological analysis: Radiolaria (Miocene)

?? Paleomagnetic analysis: accelerator mass spectrometry (AMS), rock and paleomagnetic properties (Pliocene)[2]

2.3.5. Sediment-mixing rate

?? Spade core sediments

?? Excess Pb-210

?? Excess activity of the radionuclide

?? Particle-mixing coefficient

?? Sediment-accumulation rate

2.3.6. Seafloor-image analysis

?? Data acquisition: digital still camera (DSC), still photographs, video-image data

- ?? Pattern recognition: seafloor pattern in CCFZ (seven types), nodule pattern and abundance in CCFZ (eight types)
- ?? Correlation of detailed seafloor type and nodule pattern
- ?? Observation equipment: towed deep-sea camera system

2.3.7. Visual analysis of core sediment

- ?? Multiple, spade and piston core sediments
- ?? Bioturbation type and pattern, colour variation, sediment types, sediment layer, erosional trace
- ?? Image analysis

2.3.8. Predicted simulation with particle sizes for resuspension and reprecipitation

- ?? Environmental boundary
- ?? Diffusion coefficients
- ?? Collision effect and flocculation

3. Biological Survey

3.1. Phytoplankton

3.1.1. Cell numbers

- ?? Seawater sampling with 10-litre Niskin bottles attached to a rosette sampler
- ?? Sampling depths: surface, 10, 30, 50, 75, 100, 120, 150, 200 m
- ?? Subsample: 1 l of seawater from sampling bottles
- ?? Fix with Lugol's solution

?? Concentration of cells by settlement

?? Identification and enumeration under a microscope

?? Investigation of vertical distribution of phytoplankton cell numbers

3.1.2. Chlorophyll *a* concentration

?? Sampling methods as in section 3.1.1 above

?? Measuring size-fractionated chlorophyll *a* concentration by total, <20 microns (nano-size) and <3 µm (pico-size), using a Turner Design fluorometer

?? Investigating vertical distribution of chlorophyll *a* concentration and subsurface chlorophyll *a* maximum layer

?? Comparing chlorophyll *a* concentrations between impact zone and preservation zone

3.1.3. Primary production

?? Measuring primary production by phytoplankton of total, <20 µm and <3 µm sizes, using radioisotope C-14

?? Investigating P-I (photosynthesis/irradiance) curve

?? Experimenting on additional effect of nutrients extracted from the sediment

3.2. Zooplankton (metazoan)

3.2.1. Species composition and abundance

?? Sampling zooplankton with a bongo net (diameter 60 cm, net length 300 cm, mesh size 300 µm) by towing the net vertically at a speed of 25-30 m/minute or with an opening/closing net to investigate the vertical distribution of zooplankton (0-50, 50-200, 200-3000, 3000-4800 m)

- ?? Fixation of zooplankton with formalin
- ?? Identification and enumeration under a microscope
- ?? Converting the count numbers to individuals/m^3 according to the filtered volume of seawater measured by a flowmeter attached to the mouth of the net

3.2.2. Biomass

- ?? Freezing the sample and transferring to the laboratory
- ?? Drying samples in an oven at 60º for 24 hours
- ?? Measuring dry weight on a microbalance (Mettler Co.)
- ?? Measuring carbon and nitrogen content using AA (atomic absorption) (EA 1110, Carlo Ebra, Inc.)
- ?? Calculating C/N ratio

3.2.3. Grazing experiments (effects of suspended sediment)

- ?? Sampling seawater from the surface, and filling a 2-l polycarbonate experimental bottle (Nalgene)
- ?? Collecting copepods to be used in the experiments by towing a net, and separating them from the ambient water
- ?? Putting five adult copepods in the experimental and control bottles (n=4)
- ?? Adding sediment of 0.002, 0.02, 0.2 and 2.0 g to each treatment
- ?? Incubating the experimental bottles for 12 hours
- ?? Measuring chlorophyll *a* concentration, calculating grazing rates and investigating the effect of suspended sediments on the grazing rates of copepods

3.3. Zooplankton (protozoan)

3.3.1. Species composition and biomass

- ?? Sampling seawater in 1000-ml and 60-ml quantities for protozoans and heterotrophic flagellates, using 10-l Niskin bottles

- ?? Fixing protozoans with Lugol's solution in a final concentration of 1.0% and flagellates with glutaraldehyde in a final concentration of 0.3%

- ?? Enumerating protozoans under an inverted microscope (Olympus IX-70), and classifying flagellates into two groups, heterotrophic and autotrophic flagellates, using dyes such as DAPI and Primulin

- ?? Investigating the distribution patterns of mixotrophic ciliates

3.3.2. Grazing rates

- ?? Sampling 12-l seawater bottles and filtering protozoans through a 200-µm mesh screen

- ?? Using a 2.7-l polycarbonate (PC) bottle for incubation

- ?? Diluting the 200-µm filtered seawater with 0.45-µm filtered seawater by 0, 30, 55 and 80%, and adding nutrients such as nitrate and iron to stimulate phytoplankton growth

- ?? Measuring chlorophyll *a* concentration at t=t0 by filtering 500-µm seawater

- ?? Incubating experimental bottles for 24 hours and measuring chlorophyll *a*

4. Clculation and estimation of nodule Abundance and metal tonnage

4.1. Nodule abundance at stations

4.1.1. Data acquisition

?? Using FFG (free-fall grab) and CPG (cable-photo grab) samplers, abundance data were acquired at sampling sites.

?? Manganese nodules were collected from one site and five sea-bottom photographs, including one photograph from the sampling site, were obtained at each station using CPG samplers.

?? At each station, four FFG samplers and one or two camera-equipped samplers were deployed. Using the sea-bottom images, nodule abundance was calculated from the correlation between nodule weight and coverage.

4.1.2. Data correction

Calculated nodule abundance is generally less than the actual figure for the following reasons:

?? Only part of the total surface was sampled.

?? It was impossible to scoop up the largest nodules.

?? The smallest nodules were lost.

?? FFG samplers landed obliquely or not at all, due to water currents.

?? FFG samplers operated abnormally because of the physical properties of the seafloor sediment.

Therefore, a correction factor must be applied to eliminate these abundance-reducing factors.

4.1.3. Calculation method

?? Distribution of nodule coverage, shape and size were analysed. The correlation between nodule weight and coverage was used to calculate nodule abundance directly from the sea-bottom images.

?? The abundance data from the photographs were compared with those from the FFG samplers to derive a correction factor for the FFG sampling data.

Correction formula used to estimate abundance:
$Y = 1.3 ? X$
Y: bottom abundance (C. Ab. of FFG sample)
X: sample abundance (Ab. of FFG sample)
The constant was 1.3, the mean of 1.29 and 1.31 in 1994.

4.2. Nodule tonnage

4.2.1. Average nodule abundance at each station

?? Arithmetic means of the nodule abundance at the 4 or 5 sampling sites were calculated.

?? Abundance figures were corrected for each site.
?? Average abundance includes null abundance and abundance when no analysis was available.

4.2.2. Total nodule tonnage in each sector

1) To estimate the abundance of manganese nodules in an area, we delineated a cell at intervals of ten minutes centred on each station, then multiplied the average density of nodule abundance of stations in the cell by the cell area, using Universal Transverse Mercator (UTM) coordinates.

2) Another method, without delineating a cell, is to multiply the total area of a sector by the nodule abundance or the average of abundance density at each station.

3) Variogram analysis can be used to estimate abundance. However, confidence in the results is low, because the spacing is so far apart. Total amounts of nodules estimated by methods 1 and 2 show few discrepancies.

4) Metal tonnage:

?? Samples from each station were selected. The coverage, shape and size distribution of nodules were analysed. A nodule was selected as a representative type and its metal contents were analysed.

?? Metal accumulations of Mn, Ni, Cu and Co at each station were calculated by multiplying the metal percentage by the average nodule abundance and by a “wet” factor of 0.7 (in situ nodules average 30% water by weight).

?? The total metal tonnage of each metal in each sector was obtained by multiplying the average metal accumulation by the area of the sector.

?? The maximum and minimum tonnages of each metal were obtained by adding and subtracting twice the standard error of the means of metal accumulation.

?? Data were presented in dry tons.

?? These formulas were used in the calculation:
a = Average nodule abundance × metal content (%)
b = Value of *a* × wet factor (0.7)
c = Value of *b* × total area of each sector

5) Investigation of the abundance of manganese nodules and the value of metal tonnage:

?? Expressed by total area of a sector and wet tonnage. Nodule tonnage = average abundance of a sector × total area of a sector.

?? Manganese nodules generally have a high moisture content and high porosity, differing greatly in situ from their condition when they are measured. Therefore, tonnage generally means wet tonnage.

?? We submitted wet tonnage data in 1994 when we registered our mining area with the United Nations, just as France did. (We used average abundance, while France expressed abundance in terms of maximum and minimum.)

4.3. Statistical analysis

Kriging was not used to estimate abundance because:

- ?? Adequate sampling data were lacking for variogram analysis.
- ?? The sampling interval was 25-35 kilometres, too great a distance for variogram analysis and kriging.
- ?? Other countries also calculate nodule abundance arithmetically. (France did not use geostatistical methods because of the lack of data for most blocks in its area.)

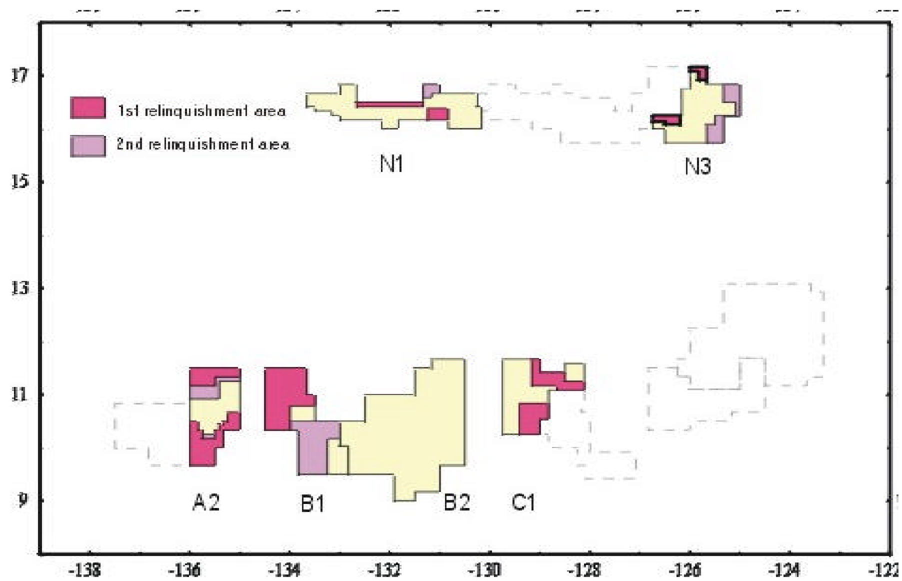

Figure 1 Map of the relinquishment areas in the Republic of Korea's allocated area.

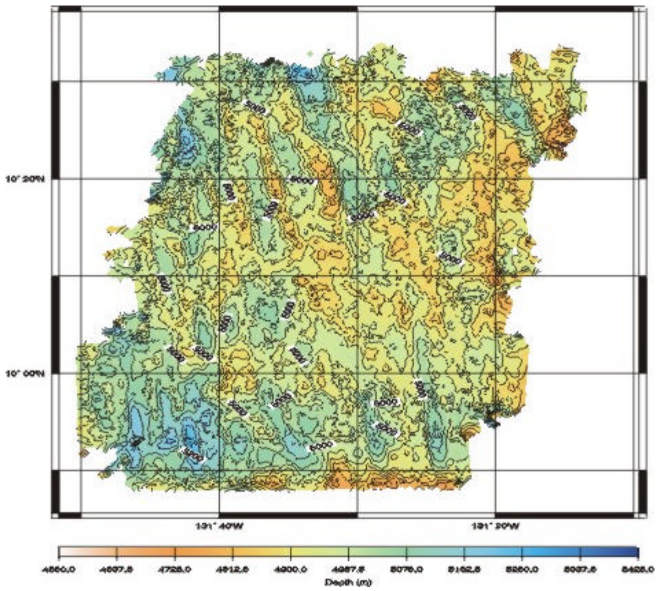

Figure 2 *Bathymetric map of the allocated area.*

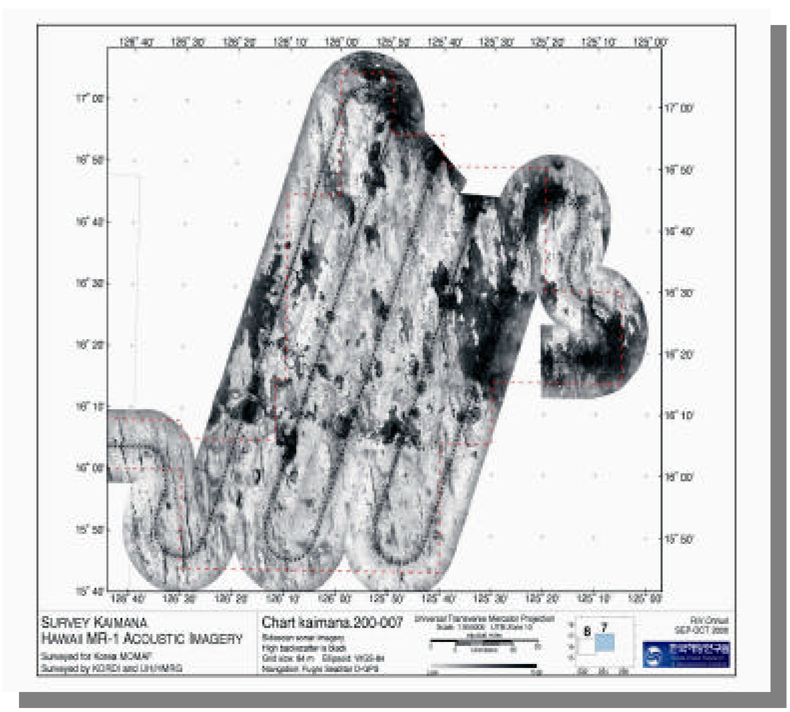

Figure 3 *Example of deep-towed side-scan data for the Korean allocated area.*

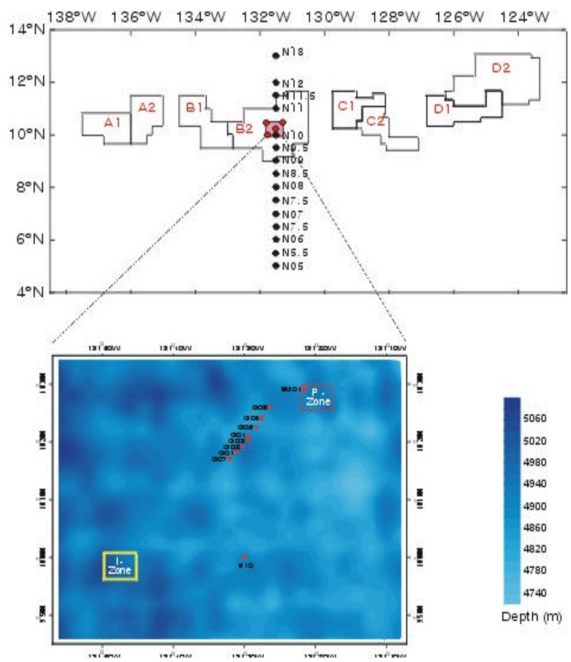

Figure 4 *Sampling-sites map of KODOS 99-2 (environments).*

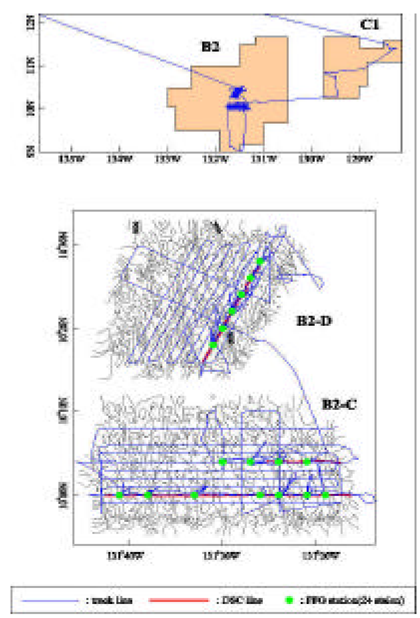

Figure 5 *Survey lines in the allocated area.*

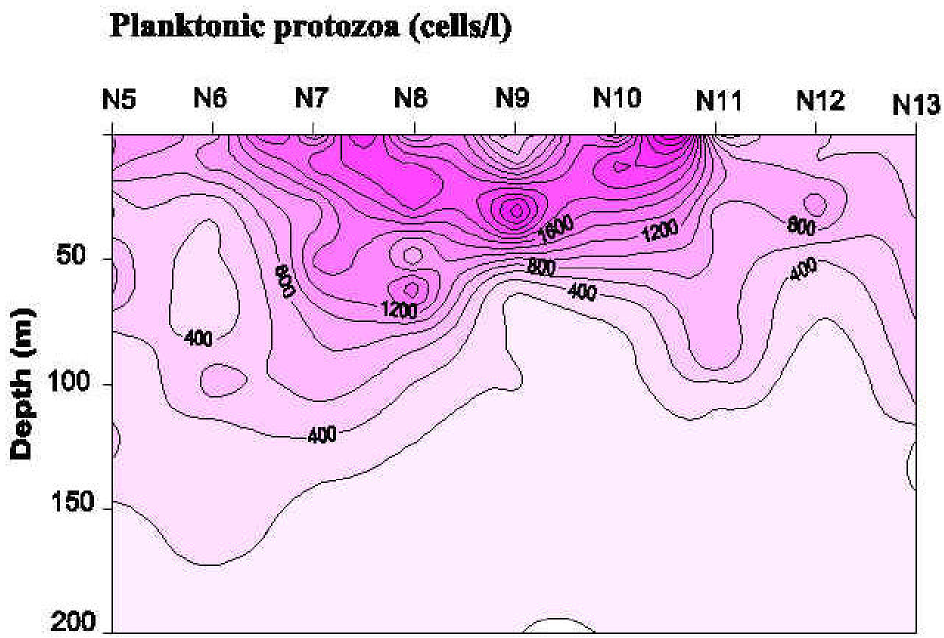

Figure 6 *Distribution of planktonic protozoan biomass at each station (June 1999).*

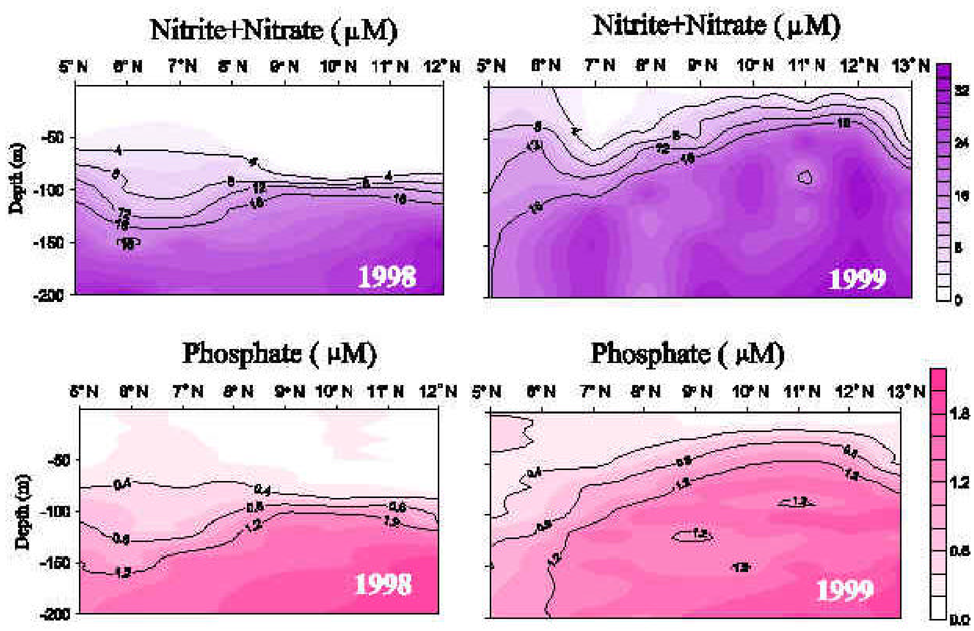

Figure 7 *Contours, along 131.5? west longitude, of nitrate + nitrite and phosphate in the northeast equatorial Pacific Ocean, 1998-99.*

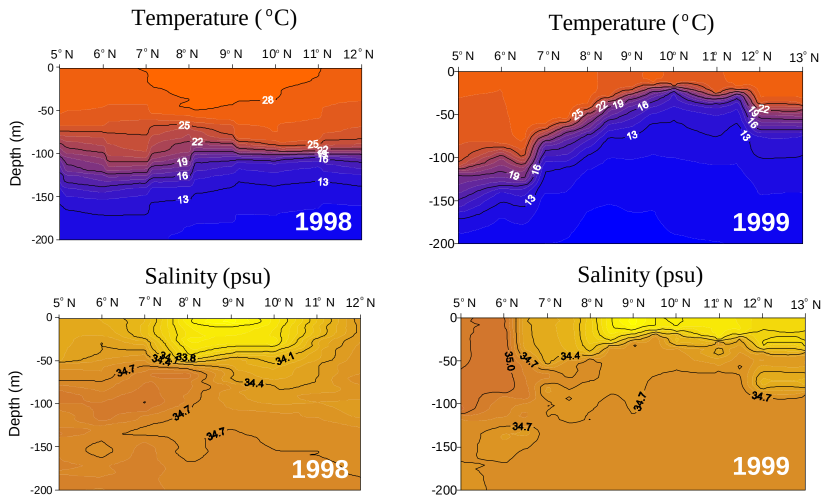

Figure 8. Contours along 131.5 W of water temperature and salinity between 1998 and 1999 in the northeast Equatorial Pacific.
In the summer of 1998, study area was immediately after the influence of El Nino. And, in 1999, study area after La Nina.

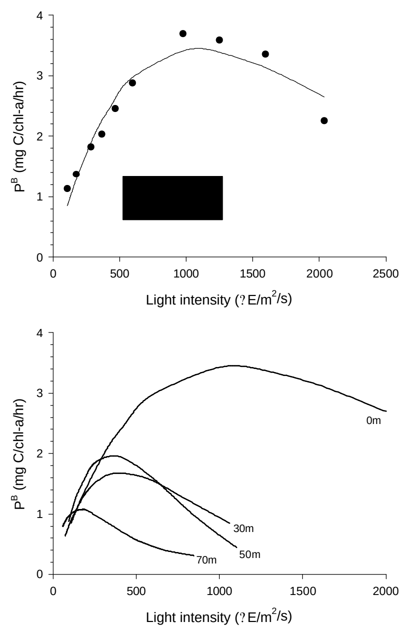

Figure 9 Typical P-I (photosynthesis/irradiance) curves in the study area (July 2000).

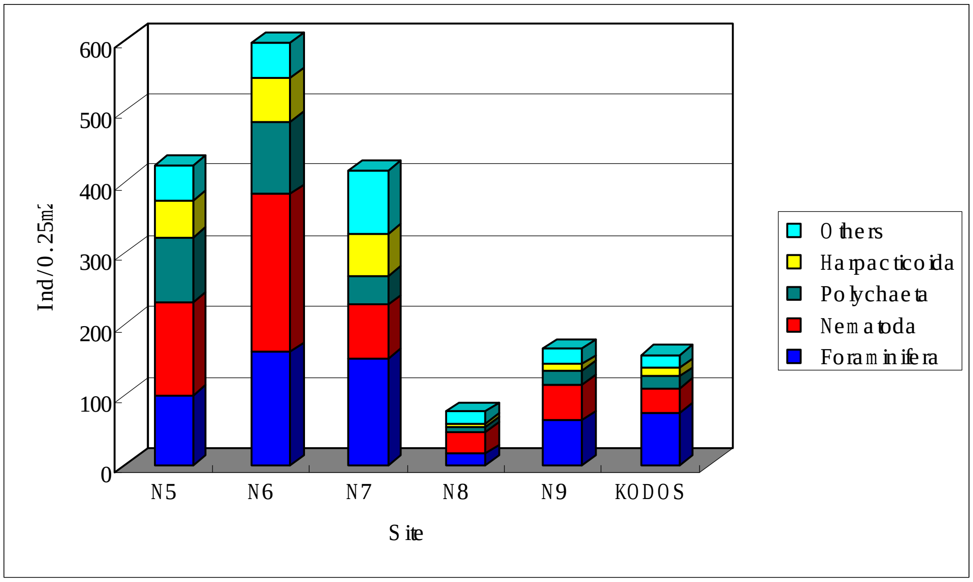

Figure 10 *Abundance and faunal composition of macrobenthos collected at sites in the KODOS 98-2 to KODOS 00-4 area (July 2000).*

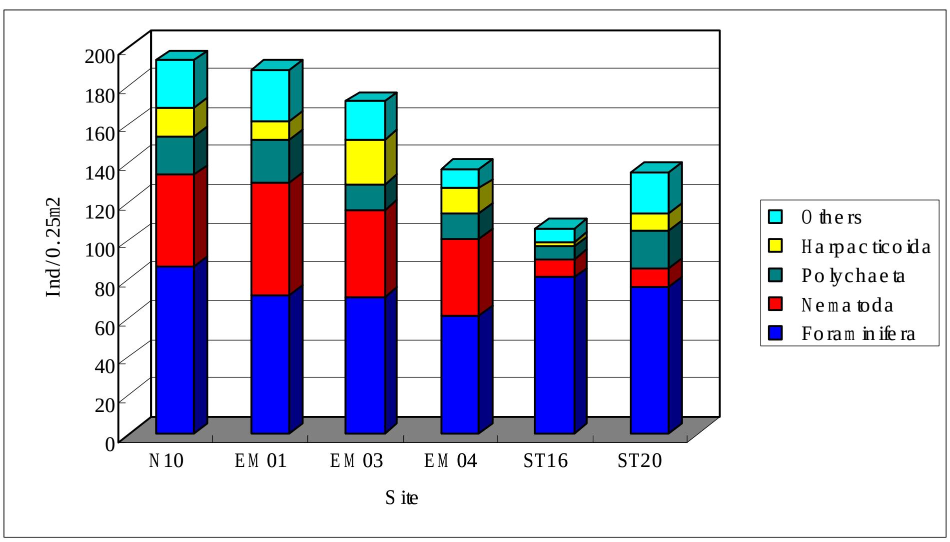

Figure 11 *Comparison of faunal composition and abundance of macrobenthos along the latitudinal gradient from 5-10?north latitude (July 2000).*

PRESENTATION AND DISCUSSION OF DATA STANDARDS UTILISED IN THE ENVIRONMENTAL STUDIES OF KORDI (REPUBLIC OF KOREA)

Dr. Woong-Seo Kim, speaking about the biological and chemical aspects of the investigations by KORDI, said he would address three topics: the scope of the environmental baseline studies, the methodology used and some of the results.

Scope of environmental studies

The environmental studies had been performed for about 10 years, from 1991 to 2000. In 2000, they had run from 10 July to 5 October, for 81 days. The survey had covered 119,000 kilometres, with a cruise distance of about 27,000 km. Geophysical surveys had been carried out along a linear distance of about 13,000 km.

The sampling stations during the 1999 survey of the Korea Deep Ocean Study (KODOS) had been located between 5 and 13 degrees north latitude to investigate gradients due to latitudinal differences (see figure 4 above). The intensive survey area (see figure 5), where the preservation zone and the impact zone were located, had been the site of geophysical surveys (blue line), a deep-sea camera survey (red line) and free-fall grab stations for sampling (green dots).

To collect manganese nodules, the free-fall grab (FFG) sampler had been used 196 times at 49 stations. Sediment had also been collected with box corers (3 times), piston corers and multiple corers (12 times). Megafaunal specimens had been collected twice and meiofauna six times, using beam trawls twice. Plankton samples to measure chlorophyll *a* had been gathered eight times and zooplankton, using a bongo net, four times. Conductivity-temperature-depth (CTD) measurements had been taken of seawater samples and currents had been measured. Deep-sea cameras had been operated six times and meteorological data had been obtained for the 81 days of the cruise.

Methodologies for biological studies

Dr. Kim said that, for the biological survey, phytoplankton had been collected to measure cell numbers. First, seawater had been collected with 10-litre Niskin bottles at sampling depths of 10, 30, 50, 75, 100, 120, 150 and 200 metres below the surface. One litre of seawater had been sampled from each bottle, after which water samples had been fixed with Luger's solution and the cells concentrated by settlement. The cells had been identified and counted under the microscope, and vertical distribution data for phytoplankton had been recorded in terms of cell numbers.

The same counting methods had been used to assess chlorophyll *a* concentration. Size-fractionated chlorophyll *a* had been measured in relation to total phytoplankton and to fractions of less than 20 microns and less than 30 µm, using a Turner Design fluorometer. The vertical distribution of chlorophyll *a* concentration and the subsurface chlorophyll *a* maximum layer had also been investigated. Chlorophyll *a* concentrations in the impact and preservation zones had been compared. Measurements had been made of primary production by photoplankton – total and less than 20 µm and <3 µm-sized organisms – using radioisotope C-14. P-I (photosynthesis/irradiance) curves had been calculated to understand the characteristics of phytoplankton photosynthesis. Experiments had been conducted on the effects of nutrients extracted from the sediment to examine how the discharge of sediment would affect phytoplankton communities.

To get data on the species composition and abundance of zooplankton, samples had been taken with a bongo net 60 centimetres in diameter and 300 cm long, with a mesh size of 300 µm. The net, with an opening and closing device, had been towed at a speed of 25-30 m/minute to investigate the vertical distribution of zooplankton from the surface to 50 m, 50-200, 200-3000 and 3000-4800 m. Collected zooplankton had been fixed with formalin and then identified and enumerated under a microscope. Count numbers had been converted to individuals per square metre according to the filtered volume of seawater measured by flow meters attached to the mouth of the net.

To evaluate biomass, the samples had been frozen, transferred to the laboratory and dried in an oven at 60° Celsius for 24 hours. The dry weight had then been measured on a Mettler microbalance. Carbon and nitrogen content had been measured using atomic absorption (AA) analysis, and the carbon-to-nitrogen ratio calculated.

Grazing experiments had been performed to examine the effect of suspended sediment. The first step had been to sample seawater from the surface by filling 2-l experimental polycarbonate Nalgene bottles. Then copepods had been collected by towing the net by hand and separating them from the ambient water under the microscope. Five copepods had been placed in the experimental bottles, to which had been added sediments of 0.002, 0.02 and 0.2 and 2 grams, with the fifth bottle kept as a control. After 12 hours of incubation, chlorophyll *a* concentration had been measured and the grazing effect calculated to see how the suspended sediment affected zooplankton-grazing rates.

For the protozoan zooplankton, data had been gathered on species composition and biomass. Seawater in 1000- and 60-millilitre quantities had been sampled for protozoans and heterotrophic flagellates, respectively, from 10-l Niskin bottles. The protozoans had been fixed with Luger's solution in a final concentration of 1 percent and the flagellates with glutaraldehyde in a final concentration of 0.3%. Protozoans had been counted under an inverted microscope, and the flagellates separated into heterotrophic and autotrophic flagellates, using dyes. The distribution patterns of mixotrophic ciliates had been investigated.

To measure the grazing rate of protozoan zooplankton, KORDI scientists had sampled 12 l of seawater and filtered the protozoans through 200-µm mesh screens. Next, in 2.7-l polycarbonate bottles used for incubation, the original seawater had been diluted by the addition of 0.45-µm filtered seawater in amounts of 0, 30, 55 and 80% of the initial concentration, with added nutrients such as nitrate and iron to stimulate phytoplankton growth. After measurement of initial chlorophyll *a* concentration, the experimental bottles had been incubated for 24 hours. At the end, the new levels of chlorophyll *a* concentration had been measured and the grazing rate calculated.

A chart showing the distribution of planktonic protozoans from 5-13° N (see figure 6 above) demonstrated a high density between 6° and 11° N, and indicated that most of the protozoans were in the upper 50-m layer.

For bacterial biomass estimates, seawater had been sampled from the depths of 400, 500 and 600 m, and at some stations at 650, 750, 1000 and 1200 m. The bacteria had been stained with DAPI and Primulin, and filtered through 0.2-µm polycarbonate membrane filters. They had then been counted under a microscope and an analysis had been undertaken to estimate bacterial biomass.

To study bacterial productivity, fresh thymidine had been added to a seawater sample, which had then been left to incubate for 30 min. Next, DNA had been extracted by using trichloroacetic acid (TCA) for 50 min in ice-cold water. After passing the resulting samples through 0.2-µm filters, the researchers had measured the radioactivity with a liquid scintillation counter, and then calculated the newly reproduced bacterial cell numbers. Extracellular enzymatic activities had also been tested.

For the macrobenthos, sampling gear such as 50 by 50 cm box corers had been used, along with various grabs, dredges and beam trawlers. Subsampling had been done with cylindrical subcores in five sections: from the surface to 2 cm, 2-4, 4-6, 6-8 and 8-10 cm. Animals had been passed through wire-mesh sieves made of stainless steel or bronze gauze. The resulting samples had been fixed and preserved with 10% formalin, stained with rose bengal solution, and then identified and counted. Other subjects of investigation had been species composition and abundance, spatial distribution patterns and vertical distribution in the sediment. Epifauna on the surface of manganese nodules had been observed, along with other macrobenthic animals, by deep-sea camera systems.

For the meiobenthos, the sampling gear had consisted of various grabs, box corers and multiple corers. Subsampling had been done with cylindrical subcores, and samples had been sieved using mesh sizes of 1000, 500, 350, 125, 63 and 32 µm. Samples had been fixed and preserved with 10% formalin or glutoraldehyde, and then the specimens had been concentrated, extracted, stained, identified and counted under a microscope. Species composition and abundance had been investigated, along with spatial distribution and vertical distribution in the sediment.

Specimens from about 40 genera of copepods had been collected but, as they had not been easy to identify down to the species level, they had been classified by genus. Zooplankton abundance ranged from maxima in the thousands to minima in the order of single digits per cubic metre. The copepods had been the most dominant taxonomic group, consisting of up to 60% of the total.

Methods for chemical oceanography

Sampling, sample storage and quality controls for chemical oceanography research had followed methods of seawater analysis by Grasshoff et.al.[3] Seawater had been sampled with Niskin bottles attached to CTD rosette systems and the samples kept at less than -10° C until analysis. Nutrient content had been measured by spectrophotometry methods according to Parsons or Grasshoff and others[4]. Nitrate and phosphate concentration had been measured by autoanalysers, and nitrite and silicate by spectrophotometers according to Parsons et.al.

For pore-water chemistry, the sediment had been sampled with box corers, piston corers or multiple corers. Sediment cores had been subsampled and put in a nitrogen-filled glove bag. Pore water had been extracted by centrifugation at 1500 g for 5 min, with a nearly 80% recovery rate. It had then been passed through 0.45-µm Millipore filters. For redox conditions, Eh and pH had been measured using Eh/pH electrodes.

For organic and inorganic carbon, sediment had been sampled with box, piston or multiple corers, then subsampled by cutting the cores evenly, putting them in bottles and keeping them in freezing conditions until they had been freeze dried, ground in gauge mortar and placed in a drier. Total carbon had been measured with an elemental analyser; then, after treatment to remove inorganic carbon, organic carbon had been measured with an elemental analyser and inorganic carbon had been calculated by subtracting organic carbon from the total carbon content.

Methodologies for geology and geophysics

Dr. Sang-Mook Lee, speaking of the geological and geophysical exploration conducted by the Republic of Korea in the Clarion-Clipperton Fracture Zone (CCFZ), described some of the instrumentation, sampling methods, data formats, types of analysis and kinds of estimation involved.

For navigation and logging, KORDI relied on a differential global positioning system (DGPS) that was slightly different from the kind used near the coast. Because the satellite transmitted differential data, it offered a better and more stable performance far out in the CCFZ than a regular GPS. KORDI had underwater navigation systems to track tow bodies, but as they were currently limited in range, consideration was being given to extending this system to full ocean-depth capability. KORDI was wondering what to do about its marine data-management system, introduced in 1992 and used to log geophysical and other data, now that it was becoming obsolete because so many new instruments and types of measurements had been introduced.

KORDI employed three methods for bathymetric surveys. The first was a multibeam system, the SeaBeam 2000, which provided up to three times the water-depth coverage of other systems. In deep water, it had a resolution of about 100 m, so nothing smaller than that could be properly evaluated. The multibeam system had a side-scan sonar capability, enabling it to record both bathymetric and side-scan information as the ship travelled along at 12-13 knots. However, the side-scan instrument on the multibeam was inferior to standard side-scan sonar. KORDI also had a precise depth-measurement device that fed into the data-management system in real time. Finally, there was a sub-bottom profile system, which did a frequency sweep from 3-9 kilohertz and provided a good subsurface image of the upper 100-200 m. It used the SEG-Y format -- a standard format, with many variations, for seismic and time-series signal information.

As this bathymetric information was recorded in real time, a trained graduate student was in charge of selecting and compiling data, and removing erroneous data, manually, ping by ping. The information was then compiled into a bathymetric map of the area traversed.

Dr. Lee said that that when he had arrived at KORDI after working mostly in the tectonic plate margin environment, he had wrongly regarded the manganese nodule area as the most boring place in the world, where nothing was happening. He had not imagined how complex it was, how many geologic faults and different types of abyssal volcanic plains existed in the area.

To obtain a better side-scan sonar image of the entire survey area, KORDI had contracted with the University of Hawaii to rent its MR-1 side-scan sonar system. This was a big, surface-towed device much like the GLORIA system but with much higher resolution, although with lesser coverage. Within a month last year, KORDI had covered more than 100,000 km^2 of the CCFZ. Reviewing the results, he had been surprised to find abyssal hills and hill-like structures, linear faults, flat areas and a sort of volcanic outflow area, with many small volcanoes. Based on that information alone, he thought he knew which areas to relinquish. The undersea terrain would be a nightmare for a crawler or collector, which would be unable to cross some of the steep hills.

KORDI also had a deep-tow side-scan sonar system that operated at full ocean depth, which meant that it could descend to 6000 m and fly about 100 or 200 m above the seafloor. From there it could image 2-4 km swaths in real time, transmit the data to the ship, and also provide a bathymetry profile and a more accurate sub-bottom profile than could be done from the ship 5 km above.

KORDI was having trouble with a 10-km coaxial cable linked to the deep-tow system, originally bought from the former Datasonics, which was now owned by Benthos, Inc. Once the problem was resolved, this should be an important tool for precise seafloor imaging and for environmental studies.

Lee said KORDI also did much standard geological sampling, using free-fall grabs, multiple corers, piston corers, dredges, sediment traps and the like. Once collected, the nodules were classified according to texture, shape and size, weighed wet and after drying, and were subjected to major or minor mineral analysis, focussed on metal content. Box-core samples were measured onboard for their geotechnical properties. Estimates of sedimentation rates were prepared, using isotopes, micropaleontology or paleomagnetic means, while other estimates were made of sediment-mixing rates, accumulation rates and other sedimentation properties. Abundance estimates were produced for the nodules, using a correction factor of 1.29; the entire area was divided into a grid of cells 10 min on a side and an arithmetic mean was computed for each cell. Other statistical techniques, such as variogram analysis and the kriging method, were sometimes used as well.

Standardisation

Concerning standardisation of geophysical data collection, Lee said KORDI had no urgent need to do this so far because it was working most of the time on a single research vessel and did not have to compare with others. Any move toward standardisation must take account of rapid technological changes, especially as more elaborate research was being done that went beyond minimum requirements. Even formats such as SEG-Y had variations for good reason, adapted to the strengths of individual measuring devices. Standardisation might be useful for environmental studies, but he hoped the burden on investigators would be minimised. He was supposed to supply information to at least four databases, including one belonging to KORDI, another to his Government and one at the South Pacific Applied Geoscience Commission (SOPAC). It should prove worthwhile if geophysical data such as surface images could be standardised to promote meaningful, practical and achievable scientific work.

Future studies

Regarding future environmental studies, Lee said KORDI was currently focussing on the relinquishment in 2002 of part of the Korean claim area to ISA and thus had postponed further environmental work until 2003. Much data had been gathered from the sea surface during the last ten years, but there had been no moves toward measurements near the seafloor. This was a challenging area, as deep-tow systems could not be towed at more than two knots. KORDI was planning to focus on thorough investigations of several local representative areas instead of the broad regional studies that it had been conducting. Rather than concentrating exclusively on manganese nodules, it wanted to develop technologies useful in other areas of marine science, and it was working in hydrothermal and other areas on the seafloor. Technology and vehicles that could operate at the five-km depths where nodules were found could do many other things in shallower environments. For instance, his Institute was thinking of working after 2003 on very high frequency near-bottom acoustic measurements to understand nodule distribution, an area on which the Americans had discontinued research in the 1980s. Since it would provide a high quality image of the seafloor, this work might be of interest in environmental studies. Recently, the Korean Government had approved the development of ROVNav (remotely operated vehicle – navigation) as a multipurpose transceiver technology with applications in the manganese nodule area.

SUMMARY OF DISCUSSION

Fauna

Asked about the condition of megafauna collected with otter trawls and beam trawls, and specifically whether they had been ground by the nodules in the trawlers, Dr. Kim said many had been damaged by beam trawlers but a number of good specimens had been retrieved.

Macrofauna had been collected from as far down as about 4800-5700 m. Large colonies of foraminiferans had been found on the manganese nodules. Macrofauna and meiofauna had been differentiated by species but the data had been compiled only at the genus level.

Other environmental studies

Lee said sediment traps to look at temporal variability in organic carbon flux to the seafloor had been deployed for one year, in 1995. There was a plan to expand environmental baseline studies during the 15-year period beginning in 2003, to include biology, geology, geophysics and chemistry relating to the remaining Korean area.

A participant commented that the use of side-scan sonar, which threw light on the variability of the seafloor, should be considered for benthic community investigations.

Notes and References

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Chapter 11 Data Standards Utilised in the Environmental Studies of Yuzhmorgeologiya (Russian Federation)

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World ocean pollution is a global problem affecting the interests of all humanity. Investigation activities connected with future mining, carried out by industrial countries in the framework of national programmes and international projects, have shown that the study of this problem and the development of environmental protection activities will take a long time and require the contribution of many countries.

Yuzhmorgeologia, one of the contractors with the International Seabed Authority, has been investigating effects on the deep-sea environment since 1982. From 1991 to 2000, it carried out these investigations together with United States licensees, taking part in the BIE (Benthic Impact Experiment) programme. Beginning in 2001, Yuzhmorgeologia started its own ecological investigations in the Russian Experimental Polygon (REP).

To achieve effective ecological controls, new scientific studies are needed, organised around complex investigations of the benthic ecosystem.

Sediment disturbances connected with nodule mining have their initial impact on the benthic community. It is presumed that benthic organisms will be affected by (1) direct physical contact with the mining device, (2) burial under a layer of resuspended sediment and (3) decrease in the availability of food. The necessity of studying these problems before commercial mining begins in the Clarion-Clipperton Fracture Zone (CCFZ) was a main impetus for the several international model experiments on benthos impacts – DISCOL (Disturbance Recolonisation [Germany]), BIE, JET (Japan Deep-Sea Impact Experiment), INDEX (Indian Deep-sea Environment Experiment) and studies by the IOM (Interoceanmetal Joint Organisation).

The main aim of all these experiments was to create a relatively large disturbance of the upper sediment layer by using a mining-simulator device, and to investigate the ecosystem response to this disturbance immediately and some years afterward. Thus, the programmes included three main phases:

?? Baseline investigations in the selected polygons,
?? Disturbance of the benthic ecosystem, and
?? Monitoring of the disturbed sites and reference sites.

The first two polygons (BIE-I and BIE-II) were created in an American licence site having low nodule density (on the border of the Russian site) at coordinates 12 degrees 56 minutes north latitude and 128° 36' west longitude. Polygon selection was done using methods such as echo-sound survey, sonar survey, photo-video profiles, measurement of near-bottom currents, and baseline biological, chemical and geological sampling.

All these investigations were carried out immediately after the disturbance, one year later and seven years later. Resuspended sediment plume was tracked using near-bottom CTD (conductivity-temperature-depth) profiles. The thickness of the resuspended sediments was measured using sediment traps, current-meter stations with transmissometers and X-ray photos of sediment cores. The location of all underwater devices was fixed with a global positioning system (GPS) based on navigational satellites and an acoustic undersea navigation system, ASMOD.

The central place in the BIE experiment was occupied by the disturber, which was designed by the United States firm Sound Ocean Systems, Inc.

All cruises during the BIE experiment were carried out on the Russian scientific vessel *Yuzhmorgeologia*.

1. Hydrophysical investigations

Eight bottom-current-meter stations with 13 current meters were employed in the BIE experiment. Current meters were placed at intervals of 5-120 metres above the bottom. Near- bottom current velocity, current direction and temperature were measured every hour. From the data sent by these stations, it was established that the hydrodynamic regime of the near-bottom area is characterised by low-energy currents with varying directions and mean velocities of 3-4 m/second; maximum velocity was 10 m/s. Water temperature was about 1.5° Celsius and did not change.

2. Hydrochemical investigations

Hydrochemical studies were carried out within baseline experimental polygons in surface, near-bottom and pore waters. Measured hydrochemical parameters included biogenic compounds – phosphate (PO_4), nitrite (NO_2), nitrate (NO_3) and silicate (SiO_2) -- and the heavy metals Zn, Cd, Pb and Cu.

The area investigated has a low biogenic content. Even in their accumulation zone (up to 200-300), nitrate concentrations ranged from 25-30 micrograms/litre, phosphate from 2.2-3.3 µg/l and silicate from 30-32 µg/l.

In the near-bottom water layer, the nitrite content is highly variable: 0.05-2.4 µg/l. Nitrate distribution in this layer greatly exceeds that of nitrite: between 37 and 46 µg/l. Average phosphate concentration is 2.3 µg/l.

In the pore water of upper sediment layers, higher nitrite concentrations were found, and we might suspect intensive bacterial processes at the sediment/water interface. The nitrite concentration in pore water is at the maximum in the 0-0.5 centimetre layer (0.4 µg/l on average) and decreases at the sediment-core bottom to 0.2 µg/l. Nitrate distribution in pore water is more even, ranging from 45 µg/l in the 0-0.5 cm layer to 54 µg/l in the 20-30 cm layer.

Dissolved silicate content increases in the sediment core from top to bottom. Silicate concentration in the 0-1 cm layer is 180 µg/l but in the 45-50 cm layer it is 540 µg/l.

Phosphate concentration in pore water changes slightly, from 2.5-3.5 µg/l.

3. Biological investigations

3.1. Macrofauna

Sediment samples for macrofauna study in our expeditions were taken with a 0.25-m^2 box corer. The box was divided by metal plates into three parts: a half-section (1250 cm^2) and two quarter-sections (625 cm^2 each).

Macrofauna samples were taken separately from the half-section as well as from one of the quarter-sections. The other quarter-section was used for hydrochemical and geological investigations.

Top water was removed from the box through a 0.3-millimetre screen and the residue was later added to the 0-2 cm layer sample. Samples were divided into layers 0-2, 2-5 and 5-10 cm deep. The 0-2 cm layer was put into 2-l bottles and fixed with 4 percent formalin as soon as possible. The 2-5 and 5-10 cm layers were washed in a washing device through the 0.3-mm screen, using elutriation techniques. Material remaining on the screen was put in 1-litre bottles and fixed with 4% formalin.

After about three weeks, all macrofauna samples were washed with fresh water to remove formalin and seawater, and fixed with 80% ethyl alcohol. Rose bengal was added to each sample to stain the animals. All macrofauna samples were packed and transferred to the laboratory for further sorting and analysis.

In the laboratory, samples were sorted and benthic macrofauna were counted and identified to higher taxa -- class, order and family. Specimens of one taxon from each sample were transferred into 20-millilitre vials and stored as collection material for future investigation and species identification.

Our results show that the number of macrofauna varied from 30 to 101 individuals/0.25 m^2 and that, even seven years after the disturbance, mean macrofauna numbers in the track zone were significantly lower than in resedimentation and reference areas (57, 70 and 68 ind/0.25 m^2, respectively).

3.2. Meiofauna

Sediment samples for meiofauna studies in our expeditions were taken with an eight-tube multicorer (tube diameter 9.5 cm) or by inserting the multicorer tube into a box-core sample. Another multicorer tube was used for hydrochemical and geological investigations.

Top water was removed from the tube through a 0.063-mm screen and the residue was later added to the 0-0.5 cm layer sample. Samples were divided by layers at 0-0.5, 0.5-1, 1-1.5, 1.5-2, 2-2.5, 2.5-3, 3-4, 4-5 and 5-6 cm. Samples from all layers were put in 0.2- and 0.5-l bottles, and fixed with 10% formalin.

After about three weeks, all meiofauna samples were washed with fresh water to remove formalin and seawater, and fixed with 80% ethyl alcohol. Rose bengal was added to each sample to stain the animals. All meiofauna samples were packed and transferred to the laboratory for further sorting and analysis.

In the laboratory, samples were sorted and benthic meiofauna were counted and identified to higher taxa -- class, order and family. Specimens of one taxon from each sample were transferred to 20-ml vials and stored as collection material for future investigation and species identification.

Our results show that the number of meiofauna varied from 1,540 to 22,365 ind/0.25 m^2, but compared to the meiofauna seven years after the disturbance, the mean meiofauna number in the track zone was a little higher than in the resedimentation and reference areas (14,210, 12,425 and 10,605 ind/m^2, respectively).

3.3. Megafauna

Photo profiles were used to assess megafauna numbers, taxonomy and distribution.

Deep-sea photographs were taken using a unique underwater apparatus called "Neptun", designed at Yuzhmorgeologia. Using the Neptun we can make photo and video surveys simultaneously. Neptun consists of a metal frame mounted with a photographic camera, video camera, flash lamp, constant lamp, echo sounder and electronic block. The apparatus was towed at about 3 m above the bottom, using a cable wire and a video-camera bottom picture. Ship speed during the towing was 1-1.2 knots.

The photo camera was triggered automatically whenever two events coincided – the end of a 10-15 s interval for charging the flash and echo-sounder data registering a distance of 300 plus or minus 20 cm off the bottom. These two conditions produced a random distribution of images for the photo profile -- very important for statistical data processing. Intervals between frames were from 10 s to 1 min, with most between 17 and 20 s. Depending on distance to the bottom, the squares covered in the photographs ranged from 3.8-4.4 m^2 (example in figure 1). Together with the bottom image, the frame number, relative time and distance to the bottom were printed for each frame.

During the photo survey, the underwater navigation system gave coordinates to the apparatus every two minutes.

In the laboratory, each frame was transferred to digital format (mostly .tif files) and saved on compact disks (CDs).

The digital image format of the photographs will make it possible to create a deep-sea photographic database.

Figure 1 *Holothurian moving close to the disturber track, seven years after the experiment.*

4. Proposals

1. To evaluate environmental baselines:

?? Select an investigation polygon (4-5 kilometres²) similar to the mining site in its physical, chemical and biological conditions, using photographic and/or television profiles, bathymetric surveys and echo-sounder surveys;

?? Take at least 30 bottom-sediment samples in this polygon to describe the numbers and taxonomic content of meiofauna and macrofauna and the chemical characteristics of pore water and sediment, and undertake a geological granulometric analysis.

2. To describe macrofauna:

?? Use a 0.25-m² box corer;

?? Section the sediment core into three layers (0-2, 2-5, 5-10 cm);

?? To wash the samples use an elutriation device and a 0.3-mm sieve;

?? To fix the samples use 4% formaldehyde and 80% alcohol;

?? To stain the samples use rose bengal;

?? Sort the samples and identify animals to the higher taxa (class, order, family);

?? Store the sorted animals in 80% alcohol as collection material.

3. To describe meiofauna:

?? Use a multicorer (tube diameter at least 9.5 cm) or insert tube in a 0.25-m² box corer;

?? Section the sediment core into nine layers (0-0.5, 0.5-1, 1-1.5, 1.5-2, 2-2.5, 2.5-3, 3-4, 4-5 and 5-6 cm);

?? To fix the samples use 10% formaldehyde and 80% alcohol;

- ?? To wash the samples use a 0.063-mm sieve;

- ?? To stain the samples use rose bengal;

- ?? Sort the samples and identify animals to the higher taxa (class, order, family);

- ?? Store the sorted animals in 80% alcohol as collection material.

4. *To describe megafauna and bioturbation:*

- ?? Use photographic and/or television profiles.

5. *To create a central database:*

- ?? Convert (if possible) photo- and television-profile data into digital format, using a film scanner or computer video card;

- ?? Convert (if possible) animal images into digital format, using a photo or television camera mounted on a microscope.

PRESENTATION AND DISCUSSION OF DATA STANDARDS UTILISED IN THE ENVIRONMENTAL STUDIES OF YUZHMORGEOLOGIA (RUSSIAN FEDERATION)

Mr. Melnik, describing the work done by Yuzhmorgeologia during the Benthic Impact Experiment (BIE), noted that his organisation had begun its experiment in 1991, continued it in 1992 with Craig Smith, and started a similar experiment in 1993. This experiment closely resembled those performed by scientists from Japan, India and the Interoceanmetal Joint Organisation (IOM). The main purpose of the experiment was to create a plume and move a huge amount of sediment, thereby creating a large resedimentation event, in order to see the reaction of the benthic community to the resedimentation. This was still too far from real mining activity because all the manganese nodules remained on the seafloor rather than being recovered onboard.

From 1991 to 2000 Yuzhmorgeologiya had carried out this study together with United States contractors in the American-licensed site. In the second part of BIE, beginning in 2001, Yuzhmorgeologia had started its own ecological investigation in the Russian Experimental Polygon (REP). In selecting the site for the BIE experiment, the researchers had looked for an area of clear sediment without manganese nodules or with low nodule density.

Sediment disturbance associated with nodule mining would create in the first place an impact on the benthic community. It was presumed that benthic organisms would be influenced by direct physical contact with the mining device, burial under a layer of resuspended sediment and a decrease in available food. The need to study this problem before commercial mining took place in the Clarion-Clipperton Fracture Zone (CCFZ) had been the main motivation for several international model experiments impacting the deep-sea benthos, including BIE, the Japan Deep-Sea Impact Experiment (JET), the Indian Deep-sea Environment Experiment (INDEX) and work done by IOM.

The main design of the Russian experiment had been to create a relatively large disturbance of the upper sediment layer, using a mining-simulation device, in order to investigate the ecosystem's response to the disturbance immediately and some years afterward. The project had included baseline investigation within the selected polygons, the benthic ecosystem disturbance itself, and monitoring of the disturbed site and a reference site. The studies had been carried out immediately after the disturbance, one year later and seven years later – close to the timetable of the DISCOL experiment. The resuspended sediment plume had been tracked using near-bottom CTD (conductivity-temperature-depth) profiles. The thickness of the resuspended sediment had been measured with sediment traps, current-meter stations, transmissometers and X-ray photos of sediment cores. Locations of all underwater devices had been fixed with a global positioning system (GPS) using navigation satellites and an acoustic underwater navigation system, ASMOD, created within Yuzhmorgeologia. At the centre of the experiment was the disturber, designed by the United States firm Sound Ocean Systems, Inc. That company had created a first generation disturber, and for the BIE-II experiment it had built a more powerful second generation device. A similar device had been lost during the Japanese experiment. All BIE cruises had been carried out on the Russian vessel *Yuzhmorgeologia*, a large capacity ship of 5600 tons with a big bottom tank and an excellent wire-cable winch.

Oceanographic findings

For the physical oceanographic studies, eight bottom-current-meter stations with 13 current meters had been established in the BIE experiment. The current meters had been placed at intervals from 5-120 metres above the bottom. Near-bottom current velocity, current direction and temperature had been measured once an hour. From the data provided by these stations, it had been established that the hydrodynamic regime was characterised by low-energy currents, at a mean velocity of 3-4 m/second and a maximum of 10 m/s. Water temperature had been about 1.5 degrees Celsius and did not vary.

Chemical oceanographic data had been close to the numbers reported by other speakers.

Biological studies

For macrofauna, sediment samples in BIE-II had been collected with a 0.25-m² box corer similar to the USNEL model. During the latest expedition, however, some of the box corers had a metal plate dividing them into three parts – a half-section of 1250 centimetres² and quarter-sections of 625 cm² each. This type had been found useful because there was less water movement inside the corer once it was brought on deck. The macrofauna specimens were collected in the half-section and one of the quarter-sections, while the other quarter was used for geochemical and geological studies and for meiofauna tubes.

Describing the procedure followed by the Russian researchers, he said the top water had been removed from the box core through a 0.3-millimetre screen, with the residue added later to the top 2-cm layer. The samples had then been divided into three layers, 0-2, 2-5 and 5-10 cm from the top. As soon as possible, the 0-2 cm layer had been put into 2-litre bottles and fixed with 4 percent formalin, without washing. The 2-5 and 5-10 cm layers had been passed through a 0.3-mm screen using an elutriation technique. What was left on the screen had been put into 1-l bottles and fixed with 4% formalin. After about three weeks, all macrofauna samples had been washed with fresh water to remove the formalin and seawater, and fixed with 80% pure alcohol. Rose bengal had been added to each sample to stain the animals. All macrofauna samples had been packed and transferred to the laboratory for further sorting and analysis. In the laboratory, the samples had been sorted and the benthic macrofauna counted and classified into higher taxa – class, order and family. Specimens of one taxon from each sample had been transferred into 20-millilitre vials and stored as collection material for future study and species identification.

According to preliminary results, the number of macrofauna had varied from 30 to almost 101 individuals per ¼ m^2. Even seven years after the disturbance, the mean macrofauna number in the track zone had been significantly lower than in the resedimentation and reference areas: 57, 70 and 68 ind/0.25 m^2, respectively.

Sediment samples for meiofauna study had been taken with an eight-tube multicorer having a tube diameter of 9.2 cm or by inserting the multicorer tube into box-core samples. Another multicorer tube had been used for hydrochemical and geological studies. The top water had been removed from the tube through a 63-µm screen and the residue later added to the 0.5-cm top layer of sediment. The 63-micron sieve had first been used in 1992 and it continued to be used in 1993; the researchers could not switch to 45 or 32-µm sieves because the animal counts would not be comparable. Next, the samples for meiofauna had been divided into six 0.5-cm layers from the 0-3 cm section and three 1-cm layers from the 3-6 cm section. The samples from all layers had been put into 0.2- and 0.5-l bottles, and fixed with 10% formalin. The protocol for meiofauna sample processing was very close to that for macrofauna.

The results showed that the total number of meiofauna ranged from 1,500 to almost 22,000 ind/0.25 m^2. Comparing this to the situation seven years after the disturbance, the mean meiofauna numbers in the track zone were a little higher than in the resedimentation and reference areas: 14,000, 12,000 and 10,000 ind/m^2, respectively.

As to the megafauna, photo profiles had been used to assess their numbers, taxonomic groups and distribution. Deep-sea photographs had been taken using the underwater apparatus "Neptun", designed by Yuzhmorgeologiya. Using the Neptun, photo and video surveys could be made simultaneously. Neptun consisted of a metal frame, a video camera, flash lamp, constant lamp, echo sounder and an electronic log. The apparatus was towed at about 3 m above the bottom, using a cable bar and the video camera's picture of the bottom. Ship speed during the tow was 1-1.2 knots. The camera operated automatically whenever two events coincided – the end of a 10-15 s period for charging the flash and echo-sounding data reporting a distance to the bottom of 300 plus or minus 20 cm. Those two conditions made for a random distribution of the photo profile – an important factor for data processing. The time intervals between frames were from 10 s to 1 min, mostly in the range of 17-20 s. Depending on distance to the bottom, each photograph covered between 3.8 and 4.4 m^3. Printed on each bottom image were the frame number, relative time and distance to the bottom. During the photo surveys, the underwater navigation system gave a co-ordinate for the apparatus every two minutes.

In the laboratory, each frame was converted to digital format, mostly .tif files, and saved on compact disks. With these digital images from photographs, it was possible to create a deep-sea photo database. Mr. Melnik showed a sample photograph depicting a disturber track about 10-12 cm high, with a holothurian (sea cucumber), probably 25-30 cm long, crossing the track (see figure 1 above).

Suggestions for environmental baseline studies

Outlining proposed guidelines for environmental baseline studies, Mr. Melnik said the study area should be a polygon about 4-5 $kilometres^2$ that resembled a mine site in its physical, chemical and biological characteristics, as determined by photo and television profiles and bathymetric and echo-sounder surveys. Russian researchers had always tried to select clear sediment areas with few or no manganese nodules, because the disturber device needed a clear area to create a big plume of sediment. Second, at least 30 sediment samples should be taken within the polygon to ascertain the number and taxonomic types of meiofauna and macrofauna and the chemical characteristics of pore water, and to perform geological and gravimetric analysis of the sediments. During the last Russian cruise there had been 30 stations, 12 using a multicorer and 18 using a box corer. As multicorers could not be used to collect macrofauna, a large number of box-core samplers were needed; perhaps 30 were not enough.

To collect macrofauna, he suggested the use of a 0.25m^2 box corer, with the resulting sediment core separated into three layers at the 0-2, 2-5 and 5-10 cm levels, then washed with an elutriation device and a 0.3-mm sieve, fixed using 4% formaldehyde and 80% alcohol, and stained with rose Bengal. The specimens should be sorted and initially classified according to the higher taxa – class, order and family. The sorted specimens should be stored in 80% alcohol as collection material, which could then be moved to other laboratories for study and possible species identification. The same procedures could be followed for the meiofauna, except that a 45-µm screen might be used for washing them.

It was important, in his view, to describe megafauna by using photo and television profiles entered into a central database. If possible, the profile data should be converted to digital format, using a film scanner or computer video card, and animal images obtained from a photo or television camera mounted on a microscope should be similarly converted. Digital files could be stored in a database along with animal counts, and maps of megafauna distribution could be made. Moreover, animal images in digital format could be exchanged with other scientists and used to create identification manuals. Some scientists had already shown photographs of small animals such as nematodes and harpacticoids that were sufficient to identify them, at least by genus.

SUMMARY OF DISCUSSION

One participant said the fact that Yuzhmorgeologia had used procedures similar to those employed by other deep-sea laboratories led to the conclusion that protocols for handling macrofauna and meiofauna could be standardised, at least in regard to sieve sizes. However, there were still too many differences in the way sediment samples were split into layers of varying thickness. On another point, she did not believe that a photographic database could produce good results without sampling the actual specimens, as it would lead to imprecise identification.

Another participant commented on data indicating that resedimented areas did not look significantly different from control areas in terms of recolonisation, whereas areas in the tracks showed reduced populations. He wondered whether this might suggest a procedure in which the mining vehicle would reclaim the surface by redepositing behind it the sediment it had stripped off while gathering the nodules, instead of leaving the area bare.

Mr. Melnik suggested that a regular dredge be used to recover manganese nodules in a disturbance experiment that would resemble actual mining. This could be done as an international project, since it would otherwise be difficult to cover a large area of about 500 by 500 miles. It should also be done in an area of high nodule density, where mining might eventually take place. The experimental results could be recorded in images that could be exchanged between countries and supplied to ISA for its database. He added that commercial mining might be 40-50 years in the future, since nobody had yet built a factory to process nodules and extract metals.

However, he described a complicating factor in estimating animal populations of areas densely covered with nodules. Some 80-90% of meiofauna lived in the top 1 cm of sediment, but when a nodule was removed, there might be no animals in the 2-3 cm depression it had occupied. Basing calculations on the number of specimens gathered by a multicorer from a clear area would lead to incorrect results unless the 30-40% of the area covered by nodules was taken into account.

PART III

Environmental Parameters Needing Assessment

INTRODUCTION

Having reviewed the data standards employed in recent exploratory research on the deep oceans, the Workshop turned its attention to specific scientific disciplines in which such standards are to be applied. These include chemical oceanography, physical oceanography (sediments, sedimentation and bioturbation) and biology. Biological aspects received special attention, in the form of papers and discussions on benthic fauna and the pelagic community in the upper waters.

Chemical oceanography was the topic presented by Dr. Gerald Matisoff, Chair of the Department of Geological Sciences, Case Western Reserve University, Cleveland, Ohio. He pointed to two reasons for monitoring the water column: protection of aquatic health and protection of human health.

He identified three factors related to mining that might raise concerns about aquatic health. These were: the possible reduction of oxygen in the deep ocean, due to the injection of mining wastes and organic material; the addition of nutrients from the bottom, affecting carbon productivity and the food web; and the return of sediment and other materials to the upper waters, affecting productivity there. The main human health issue concerned the release of metals and their accumulation in the food chain.

He suggested a number of specific measurements that could be used to monitor water chemistry, with special emphasis on oxygen and metal levels. These would be taken by recording and sampling instruments attached at different standard depths to four moorings located in each study area.

Some participants stressed the need to ensure, as one of them put it, that monitoring would be done for a reason rather than to collect information for its own sake. It was argued that more attention should be paid to how animal and human life might be affected. One speaker, believing that contractors should not be expected to provide much data until they started to test mining equipment, thought that a special study might be organized to gain a better understanding of the marine environment. Matisoff responded that the purpose of monitoring was to provide data that policy makers could use to decide whether intervention was needed for the sake of oceanic health. The Secretary-General stated that monitoring must begin right from the start of seabed activities, because the data were needed to see what kind of harm was occurring and to what extent.

Particular concern was voiced about the dangers of bioaccumulation of heavy metals in fish consumed by humans, though some participants doubted that mining would release significant quantities.

Dr. Craig R. Smith, Professor of Oceanography at the University of Hawaii, Honolulu, proposed procedures for baseline monitoring of sediment properties, particle flux (sedimentation) and bioturbation.

Explaining why these items should be measured, Dr. Smith pointed out that deep ocean sediments provided insight into the characteristics and heterogeneity of the ecosystem. Sedimentation – the descent through the water of particles containing organic carbon – was a major element governing the bottom fauna, including abundance, ecological rates and possibly species structure. Bioturbation – the churning of sediments by burrowing animals – was an index of animal activity that showed how deeply the sediment redeposited from mining activity would be mixed as the fauna recovered.

In the discussion, it became clear that more work would be needed before standards could be set for some of the proposed sediment measurements. When grain size, for example, was measured after raising it from the bottom, the results were not a good indicator of how the sediment would behave after it was resuspended from a mining plume. However, no standards existed for such measurements either on the bottom or onboard a vessel. Shear strength, an index of sediment cohesion, was measured differently by different groups, sometimes in place and sometimes after removal.

Standardization appeared closer in regard to sedimentation monitoring, however. Smith noted that a scientific group had approved a design for the traps that capture and measure sediment flux. The placement of traps was an issue, however, with some participants favouring a third trap beneath the two that had been suggested by the Legal and Technical Commission (LTC).

Regarding bioturbation, measured using radioactive lead, Smith recommended that it be assessed only to a depth of 5 centimetres, rather than the 15 cm suggested by the LTC, since studies in the Pacific Ocean indicated that it penetrated only about 2 cm. One participant pointed out that bioturbation could also be assessed from photographic records of animal traces and other seabed features, though another cautioned that the low sedimentation rate made it difficult to distinguish old traces from new.

Biodiversity in the benthos, and the sampling and analytical problems involved in assessing it, was the topic of Dr. Michael A. Rex, biology professor at the University of Massachusetts, Boston. He identified four ways of looking at diversity: genetic, or numbers and variety of species; population, concerned with dynamics, dispersal and total quantities of standing stock; community and ecosystem, relating to assemblages of coexisting animals, and landscape, or the variety of physical environments.

Dr. Rex stressed how little was known about animal life in the areas where mining would occur, compared to the bathyal depths along continental margins. It was known, however, that while the total amount of life declined exponentially with depth, species diversity remained high. This combination of few individuals and many species made it difficult to detect changes in community structure, including impacts that might result from mining, without taking a large number of box-core samples. Studies done so far in the Clarion-Clipperton Fracture Zone (CCFZ) of the Pacific Ocean had not collected enough samples to enable researchers to predict the probability of species extinction.

He made two suggestions to improve knowledge of deep-sea biodiversity. First, the specimens already collected from box cores by seabed contractors should be identified by species, so that species ranges could be ascertained. Second, one claim area should be thoroughly sampled, in the expectation that the data gathered could be generalized to other areas and help in developing more efficient sampling designs.

Diversity was known to vary on broad scales, he pointed out. For example, studies of isopods and molluscs had shown latitudinal gradients in species diversity, with fewer species living closer to the poles. He cited other studies indicating that local diversity – the kind that would be most affected by mining – was closely related to regional diversity and the ability of species to disperse. In other words, more species tended to live in a locality when there was a larger regional pool from which they could draw and/or when the animals could move about freely. In addition, the differing levels of diversity from place to place meant that the location of mining activity would have a strong bearing on the magnitude of its effects.

On the danger of species extinction, Rex observed that if a species had a restricted range there was a greater possibility that mining would cause extinction, whereas there would be less cause for worry if the range were broad. However, the sampling done so far did not give enough information on range and diversity to be able to determine the effect on population.

A participant asked about relationships between species at different ocean depths and how those higher up might be affected by extinction below. Rex responded by noting that the fauna was completely different at the top and bottom of the deep oceans, so it should not be thought that, if the abyssal fauna were extirpated, those above would provide a reservoir of species to repopulate the deep. Smith added that, while there were no strong linkages between the abyssal seafloor and the euphotic zone nearer the surface, many species had large vertical ranges. Moreover, one study of particle flux had shown that upward movement was about 40 percent of downward flow.

Among suggestions advanced to improve knowledge of deep-sea fauna, in addition to more sampling, were greater use of molecular genetic techniques to identify species and the use of epibenthic sleds to dredge up larger samples from the bottom. The latter technique was cited as a way of coping with the rarity of deep-sea species.

Dr. Gerd Schriever, head of the BIOLAB Research Institute, Hohenwestedt, Germany, described the history, methods and results of DISCOL, a German study focusing on an artificial disturbance of the deep seabed in the South Pacific Ocean off Peru and recolonisation of the area by benthic fauna. Based on lessons learned from this experiment, which lasted from 1989 to 1996 (under the name ECOBENT in its final year), he suggested several changes in approach and methods for a future investigation on a larger scale.

The DISCOL experiment centred on the effects produced when a specially designed "plough-harrow" device was used to dig into the surface of a nodule-strewn plain, picking up the nodules and burying them in its tracks. The aim was to recreate on a smaller scale – limited to a circular area of 11 square kilometres -- some of the impact that might be expected from a full-fledged mining vehicle.

Among the findings were that the fauna in the miner's path were likely to be destroyed and animals inhabiting the nodules themselves would be obliterated until new nodules reformed naturally at the rate of a few millimetres per million years. Many sediment dwellers were likely to recolonise from surrounding areas, but the researchers had found smaller populations of many species in the disturbed areas as much as seven years after the initial impact.

Explaining that DISCOL had terminated before all of the impacts could be thoroughly studied, Dr. Schriever advanced suggestions for a further project, which he hoped could be organized by international cooperation. This would involve disturbance of a larger area by a device more like those that would eventually be used for commercial mining. He stated that no study so far had operated on a scale large enough to gauge what would happen during mining.

Schriever's suggestion that a full study might take up to 12 years provoked comment. Speakers urged the international community to start such a project now, while enough time remained before the start of commercial mining. Another suggestion was that controlled experiments could yield valuable information about animal response to different levels of resedimentation.

Varying views were expressed about the likely extent of animal depopulation and the length of time needed for recovery. Some speakers pointed out that few animals could survive direct contact with a mining device that would range over many square kilometres of nodule-bearing surface. It was also noted that much of the area around a mine site would be made barren by burial beneath the sediment plume kicked up by mining activity. Others, noting that the rough bottom topography would leave many areas unmineable, said that such undisturbed places could be a reservoir for recolonising animals. A recurring question, unanswered by DISCOL, was this: If the fauna had not fully recovered seven years after a small disturbance, how long would the effects from full-scale mining endure?

Dr. P. John D. Lambshead, head of the Nematode Research Group at the Natural History Museum, London, dealt with meiofauna, particularly nematodes, in potential mining areas, and with new scientific techniques to aid in studying such animals in the deep ocean. He noted that these tiny roundworms and threadworms were considered the dominant metazoans (multicelled animals) in deep-sea communities and were used for environmental monitoring of European coasts and estuaries.

Knowledge about the distribution of abyssal meiofauna was extremely sparse, he observed. One scientist had estimated that only 1% of the nematode species he had found in the Venezuelan Basin were known to science. Yet their numbers were enormous – 100,000 individuals per square metre on the Central Pacific abyssal plain, for example.

Speculating on the possible impact of nodule exploration and exploitation, he said nematodes tended to resist the mechanical effects of natural physical processes but whether this would apply to mining was unclear. They might recover quickly from resettlement of the sediment plume but would be sensitive to any long-term change in the physical composition of sediment. The release of organic material when sediment was disturbed should increase productivity and cause a short-lived rise in local diversity.

Dr. Lambshead outlined the kinds of information needed for baseline studies of meiofauna and laid special emphasis on the standardization of taxonomy, in view of the technical difficulties involved in this work. He urged the establishment of a central taxonomic facility, preferably at a museum, where well-trained specialists could perform the laborious and expensive tasks required to identify species. Such a facility would also be the best repository for voucher collections of specimens gathered during scientific cruises such as those conducted by seabed contractors. Such collections, properly maintained by institutions with curatorial know-how, could be used by investigators as standards for species identification.

He held out a strong hope that the new technology of molecular genetics, in which species can be distinguished by reading the DNA in their chromosomes, would greatly speed taxonomic work. Analysis that had required a full month using the old techniques could be done in two days with the process called denaturing gradient gel electrophoresis (DGGE), using relatively inexpensive equipment. A project employing this technique with nematodes had started in June 2001 in the United Kingdom, and tests on bulk nematode samples from deep-sea areas affected by placement of mining tailings would take place in late 2002 or early 2003.

Possible impacts on the pelagic community of the open seas, and ways of assessing them, were discussed by Dr. J. Anthony Koslow, a research scientist with the Commonwealth Scientific and Industrial Research Organization (CSIRO), Hobart, Tasmania. While polymetallic nodule mining had the potential to affect vast areas, including the water column above the seabed, he said, there was little basis on which to project such impacts.

He summarized the current scientific understanding of how epipelagic ecosystems function in oceanic waters far from the coast, down to the depths where sunlight penetrates and photosynthesis is possible. Only in recent decades, he noted, had it become apparent that the food-production system in the open ocean differed markedly from that of coastal waters because it was based on relatively low levels of nutrient input. Coastal waters, with their high nutrient input from upwelling currents and coastal runoff, produced large phytoplankton on which larger zooplankton such as copepods grazed, and they in turn were eaten by fish. This classic pattern, with its short food chain, did not hold in the open ocean, however. The system there was based on a microbial loop that started with bacteria regenerating nutrients; tiny phytoplankton were the primary producers, and the chain was completed by zooplankton and fish. Since 85-90% of carbon was lost in each step of this chain, adding the additional step at the start meant that overall productivity was down about 90% in the open ocean.

If a large amount of deepwater heavily loaded with nutrient were to be discharged into the near-surface water by mining operations, he continued, one potential impact might be to shift the open ocean ecosystem toward the classic pattern. Whether good or bad, this was a possible outcome that warranted caution.

Discussing potential impacts on different groups of organisms, he said the release of sediment into the water could strip it of particulate carbon, reducing microbial activity and nutrient regeneration generally. Phytoplankton composition might be shifted toward species that thrived in high-nutrient environments, while adding trace metals could provide additional nutrients for some species and poison others. Among zooplankton, suspension-feeders, living off organic particles that filtered through the water, could be hurt by the release of mineral particulates. Micronekton such as copepods and nekton such as fish could be affected by trace metals or changes in food availability. These factors might also affect seabirds and marine mammals, which could be even more subject to the toxic effects of bioaccumulation of metals.

Dr. Koslow outlined various sampling procedures that could be used to assess these potential impacts, ranging from carbon and nitrogen measurements to observation of whales. He urged the adoption of standard protocols developed by international bodies, notably those devised for the Joint Global Ocean Flux Study (JGOFS) and by the International Council for the Exploration of the Sea (ICES) and the International Whaling Commission (IWC). He stated that the seasonal variability of the Central Pacific would make it necessary to conduct up to four cruises a year in order to obtain complete data.

Some participants questioned whether the volume of water discharged by a mining operation would have a significant impact in the vast ocean. It was observed, however, that a surface discharge would be visible from a satellite, so that the public would know of it. Several speakers said they assumed that the discharge would occur at around 1000 metres or more below the surface, though Koslow pointed out that nothing was known about that zone or about possible impacts. Smith favoured a release about 10 m above the bottom, near the area that would already have been disturbed by mining.

The view was expressed that data gathering and interpretation should focus more narrowly on factors that affected the food chain and other possible impacts from mining. Increase in knowledge was an objective of humankind, while evaluating impact was an objective of a company or the International Seabed Authority. Koslow responded that, with so many groups doing research in the few ocean areas of interest to potential miners, research efforts might be pooled so that it would be unnecessary for everyone to do everything. He added that, judging from their presentations to the Workshop, the companies already seemed to be doing most of the measurements he had described.

Chapter 12 Chemical Oceanography

Dr. Gerald Matisoff, Professor and Chair, Department of Geological Sciences, Case Western Reserve University, Cleveland, Ohio, United States of America

SUMMARY OF PRESENTATION

Dr. Matisoff began his talk by stating that the first question to be addressed in regard to the potential effects of seabed mining on the water column was: What was the objective of monitoring? Once this question was answered, a plan could be established to meet the objective and decisions could be taken about what parameters to monitor.

He saw two reasons for monitoring in the water column: protection of aquatic health and protection of human health. Nobody was concerned about leaving a scar on the ocean floor that might take a thousand years to cover up. What mattered was whether an activity would cause animal extinction, change food-web dynamics or bring about bioaccumulation of more metals into fish used for human consumption. Therefore, water-column monitoring should be designed to address those two criteria.

From the perspective of protection of aquatic health, there were a number of issues of concern. First was the possibility of generating anoxia: if a lot of reduced material was introduced or primary production was enhanced, ultimately resulting in higher oxygen demand somewhere in the water column, a conceivable result could be the significant removal of oxygen. If that happened in the oxygen-minimum zone, there was the potential for generating anoxia, by either the oxidation of reduced materials or the injection of organic material. As this was a concern especially in the oxygen-minimum zone, discharges must occur below that zone. However, there was still a danger that released material could move vertically in the water column or that the oxygen-minimum zone could move down.

Second, nutrients and metals rising from the bottom, as they always did, could affect bottom-water productivity and food web dynamics.

Third, the return of materials, by means of accidental spills or intentional surface discharge, would affect productivity at the surface or mid-water, depending on where it took place. Thus, there would again be a need to look at nutrients, metals, turbidity and the like, all of which affected productivity and bore consequences for aquatic health issues. One possibility might be to monitor the water being pumped in order to predict potential impacts on the water column.

For the protection of human health, metals were the main issue, not anthropogenic toxins such as DDT or PCBs, whose concentrations in surface layers at the bottom was sufficiently small that their remobilisation would probably be insignificant. The release of metals could be great enough to induce public concern about possible bioaccumulation. As there were already advisories about mercury in tuna, if the public heard that lead was being released into the water and getting into the fish, they might be quite concerned. Thus, monitoring for metals would be important, not that he expected dangerous concentrations but simply out of a desire to protect public health.

The monitoring scheme Dr. Matisoff favoured, as laid out in Craig Smith's background paper (chapter 3 above), called for four moorings spaced 50-100 km apart. One of the moorings would rise to within about 50 m from the surface, while the others, equipped also with current meters for physical oceanographic monitoring, could be at depths of 1-3, 5, 15, 50 and 200 metres off the bottom and at 1.2-2 times the highest topographic feature. Monitoring should occur in the oxygen-minimum zone as well.

Among the parameters to be monitored should be oxygen and total organic carbon. He was not sure whether oxygen demand should be examined, as it was not often studied in the marine world though it was measured in the terrestrial environment all the time. Monitoring oxygen demand would give a predictive capability by providing evidence of how much organic matter or reduced components could be put into the water column before driving the oxygen level down.

Frequency of sampling had to address seasonality problems. For that reason he recommended a minimum of twice a year, though others preferred four times.

Regarding sediment-water flux across the sediment/water interface, the idea was to measure the components coming out of the bottom and those resident in pore water. A Fickian diffusion calculation could be employed to gauge the outward flux; though not very accurate, it was easy to perform. Oxygen, nutrients and metals in the pore water should also be monitored.

To obtain quality data on metals in pore water and the water column, ultraclean techniques should be used for measurement and to permit calculation. Samples would have to be collected by trained technical staff before they were sent to laboratories capable of doing ultraclean measurements.

In addition, core depths would have to be specified. For example, a flux calculation theoretically required only the gradient at the sediment/water interface, including the bottom water and the 0-1 cm layer. However, if the rest of the core was discarded, some important part of the profile might be missed. Thus, sediment intervals must be specified, though not necessarily a large number.

Measurements would not have to be taken too often: before and after mining should be sufficient to assess the bottom flux, with no need for a time series. Flux measurements could be done near the mooring locations.

As to chemical parameters, he advocated the use of standard, commonly used methodologies. Oxygen could be measured by a Winkler system device or an electrode. Oxygen demand, if it were to be measured, was usually assessed by a time-series study. Oxygen reduction potential (ORP), suggested as a parameter in some literature, could be measured by electrode. Nitrate, nitrite, phosphate and silicate could be done by standard methods using colorimetry or a similar technique, and alkalinity by titration. The procedure for turbidity was straightforward. For metals, atomic absorption analysis (AAA) could be used, although ICP-MS (inductively coupled plasma - mass spectrometry) would probably be preferable, as it was cheap and accurate.

SUMMARY OF DISCUSSION ON CHEMICAL PARAMETERS

Placement of moorings

Professor Craig R. Smith raised a point about the location of moorings for monitoring instruments and the number of current meters they should hold. He noted that he had suggested a change in the recommendations made by physical oceanographers at the 1998 Sanya Workshop,[1] relating to the distribution of data collection that they saw as useful for understanding the current regime in a claim area of 150,000 km². That arrangement was intended for characterizing the baseline current conditions in an area, not necessarily for tracking a plume. For a pilot-mining experiment, the mooring distribution might be quite different and centred around the test site.

Asked whether a plume might slip between moorings if there were only four in such an area, Dr. Matisoff said that, since the plume got bigger as it moved away from the source, the moorings were less likely to miss it than if they were close.

Uses of data monitoring

Some participants urged that, beyond collecting data on chemical parameters, greater attention should be given to the impact of those parameters on the behaviour and survival of organisms. There was a need to link chemistry and biology, and to understand how they interacted. Monitoring must be done for a reason, rather than simply collecting information just for the sake of having it. More information was needed about how the biota reacted before a monitoring programme could be devised. One speaker thought that the regulatory requirements for monitoring should be minimized; contractors could not be asked to start a monitoring programme that belonged in the realm of scientists. Another, pointing to the expense of data collection, saw a need to define in advance what should be done with the acquired data, in terms of acceptable limits of variation and their impact on human and aquatic life.

Responding, Matisoff commented that the function of monitoring was not to say at what level cadmium, for instance, interfered with an organism's ability to function, but rather to demonstrate whether there was any accumulation of cadmium because of mining. It was up to somebody else to say that mining should stop because it was interfering with an animal's ability to function. A monitoring plan should not involve sending up a red flag warning that intervention was warranted. Rather, monitoring to protect aquatic or human health, whether for baseline conditions or mining impacts, should look at certain parameters and see whether they were changing. Determining the point at which intervention was needed was another problem – one for the International Seabed Authority to decide.

The Secretary-General remarked that the mining code obliged the Authority and the international community to protect and preserve the oceans from serious harm. Monitoring data were needed to see what kind of harm was occurring and to what extent. That was why monitoring must begin right from the start of the activities. Establishing the baseline information against which to evaluate future activities was not a matter of trying to impose something for the sake of science alone, but was a responsibility that had to be discharged. He found it difficult to understand the suggestion that there would be minimal harm and therefore no need to monitor, or that one would have to prove first that there was going to be harm before starting to monitor. Rather, the United Nations Convention on the Law of the Sea required a precautionary approach.

He recalled negotiations in Brussels on a sugar protocol between the European Community and the African, Caribbean and Pacific States, at which the sugar price had to be fixed each year. Good advisers in the field of sugar and sugar marketing were involved. The Prime Minister of Fiji had observed that, with the scientists and experts all saying different things, at some point a political decision was needed, after which the experts could be asked for reasons to justify it. Similarly in the case of the seabed, a political decision had been taken placing a general obligation on all States, whether or not they were mining, to protect and preserve the oceans from all sources of pollution. Those who were mining bore a specific responsibility to ensure that there was no serious harm. At some future date, with all the data available, the experts would be asked to evaluate whether in fact there had been serious harm.

Professor Smith expressed the view that the contractors were responsible for having competent scientists who could interpret the data they collected on baseline conditions and decide whether there was a potential for significant environmental harm. Probably the Authority would evaluate those interpretations objectively. The desire of scientists to know everything about the ocean might lead them to ask contractors to do more than was reasonable. On the other hand, scientists were also sensitive to the fact that it cost money to collect data, and that just enough information was needed to be able to predict the impact. The Workshop had to engage in this give and take. Another participant, agreeing, saw the need for a cost-benefit analysis, lest the cost of monitoring turn out to be higher than the revenues from mining.

A speaker remarked that contractors would normally have to make a baseline study only when they planned some activity that could harm the marine environment. During the exploration phase, that would probably occur when they started to test mining equipment. However, such testing would not happen until near the end of the exploration contract, perhaps 15 years hence. Thus, the pioneers should not be expected to provide much data during the present period. Instead, a special study could be organized to offer a better understanding of the marine environment.

Metal concentrations

A participant questioned why nickel, for example, would escape from manganese nodules into the water when that was precisely what the miner wanted to keep, not to expel. Matisoff replied that no one knew how much metal would be released into the water. Some of it could be in particulate form rather than dissolved and still get into the food chain through bioaccumulation, depending on where it was discharged and who ate it. That seemed unlikely, since metals had a tendency toward the particulate phase, which was why the nodules existed the in the first place. Nevertheless, the relevant parameters were of concern from a chemical perspective and should be looked at.

Another participant remarked that the issue of heavy metals in the food chain was a serious one. He cited the case of a fishery in which the natural concentration of mercury in the catch, taken at around 1000 metres deep, was sometimes above the limit permissible for human food. Naturally high levels of a number of heavy metals occurred in deep water, and by the time they moved into the upper levels of the food chain, the flesh of tuna or swordfish often had mercury concentrations near the highest level permissible for human consumption. If more heavy metals were mobilized into the water, they would create a potential problem that could not be ignored.

One speaker, while agreeing on the need to study heavy metals and especially their accumulation in biological cycles, pointed to problems that had arisen in collecting water samples, caused not by onboard laboratory processing but by difficulties with the winch, the cover or the ship. Standardisation or recommendations in this area might have to await further efforts to resolve such problems. Matisoff responded that, while he acknowledged the problems involved when non-technical personnel tried to apply clean techniques to sampling at sea, standards could be specified, based on procedures set out in scientific papers describing how researchers had managed to acquire quality data. It remained to be seen whether those standards were appropriately followed so that the resulting data would be useful. Many laboratories were available to provide analysis.

Another speaker questioned the need to analyse the metal concentration in pore water if most of the water taken up with the nodules was ambient water. The system tested by India, using a lifting device like a potato picker, did not disturb much pore water. An engineer would want equipment that would lift the nodules and nothing else. Matisoff replied that the answer depended on the technology used; if the top 20 cm of sediment was scooped up, the entire amount of pore water could be mixed into the water column.

Reference

1. International Seabed Authority (1999), *Deep-Seabed Polymetallic Nodule Exploration: Development of Environmental Guidelines:* Proceedings of the International Seabed Authority's Workshop held in Sanya, Hainan Island, People's Republic of China (1-5 June 1998), chapt. 9: Guidelines for the assessment of the environmental impacts from the exploration for polymetallic nodules in the area, pp. 219-239 (ISA, Kingston, Jamaica). Professor Craig's suggestions at the 2001 Workshop are in chapt. 3, sect. 2.1 above.

Chapter 13 Sediment Properties, Sedimentation and Bioturbation

Dr. Craig R. Smith, Professor, Department of Oceanography, University of Hawaii, Honolulu, United States of America

Dr. Michael Wiedicke-Hombach, Marine Geologist, Bundesanstalt für Geowissenschaften und Rohstoffe (BGR) Germany

1. Sediment Properties

Why measure them? The recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area, prepared by the Legal and Technical Commission (LTC) of the International Seabed Authority[1], call for contractors to do the following (paragraph 8(c)):

> "... determine the basic properties of the sediment, including measurement of soil mechanics, to adequately characterise the surficial sediment deposits and the potential source of deep-water plume; sample the sediment taking into account the variability of the sediment distribution".

As Dr. Wiedicke has pointed out (chapter 5 above), these also provide important insights into ecosystem characteristics and heterogeneity.

The explanatory commentary annexed to the LTC recommendations suggests that the following sediment parameters should be measured (paragraph 7):

> "... specific gravity, bulk density, shear strength and grain size as well as the sediment depth of change from oxic to suboxic conditions". (Additional chemical parameters were discussed earlier by Matisoff [chapter 12 above].)

The distribution of these measurements in space and time needs to be specified (possibly after designation of the test-mining site, technology and mining pattern).

"Disaggregated" grain size will not necessarily be useful for modelling plume behaviour. The grain-size distribution and settling characteristics of sediments in the mining plumes (both seafloor and tailing discharge) will depend on the mining technology used. When the technology is better known, a scheme should be developed for sampling sediments as they enter the plume and processing them with minimum modification of sediment aggregation.

2. Sedimentation (Particle Flux)

Why measure sedimentation? Particulate organic carbon (POC) flux is a basic parameter exerting major control on benthic community abundance, biomass, ecological rates and possibly species structure. The nature of flux (e.g., food quality) will be altered by resedimentation from the plumes. The LTC recommendations call for contractors to do the following (paragraph 8(f)):

> "... gather data of the flux of materials from the upper-water column into the deep sea."

The explanatory commentary annexed to the LTC recommendations suggests the following evaluation of sedimentation in each claim area (paragraph 10):

> Two sediment traps should be deployed on a mooring for at least 12 months. One trap should be below 2000 metres to characterize particle flux from the euphotic zone, and one trap about 500 m above the seafloor and beyond the influence of sediment resuspension to evaluate particle flux to the seafloor. Traps should sequentially sample at no longer than one-month intervals. Traps may be deployed on the current-meter moorings.

More detailed trap protocols and the measurements to be made on the collected material must be specified. We suggest adopting the protocols for deep sediment traps used by the Joint Global Ocean Flux Study (JGOFS)[2], and that variables measured include the fluxes of total mass, particulate organic carbon mass flux, calcium carbonate, biogenic silica and excess Pb-210 (again using JGOFS protocols). In addition, a two- to three-year baseline may be desirable to evaluate interannual variability.

3. Bioturbation

Why measure bioturbation rates and depths? Bioturbation is a readily measured index of community activity and indicates the depth scales over which redeposited sediment will be mixed during community recovery. The LTC recommendations call on contractors to do the following (paragraph 8(e)):

"... gather data of the mixing of sediment by organism[s]".

The explanatory commentary annexed to the LTC recommendations suggests the following evaluation of bioturbation in each claim area:

> Rates of bioturbation should be assessed using excess Pb-210 profiles, taking into account sediment spatial variability. Excess Pb-210 activity should be evaluated on at least five levels per core (suggested depths 0-1, 2-3, 4-5, 6-7, 9-10 and 14-15 centimetres), and mixing intensities evaluated from standard advection or direct diffusion models.

We recommend five replicate profiles per station with a minimum of four stations, corresponding in number and location to those recommended for seafloor-community studies. Because Pb-210 mixed layer depths appear to be shallow in the Clarion-Clipperton Fracture Zone (CCFZ), the depth levels within cores for Pb-210 assays should be concentrated nearer the sediment/water interface, i.e., at 0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.5 and 2.5-5 cm.

Change "standard advection or direct diffusion models" to "standard advection-diffusion models".

Because of the long characteristic time scale of excess Pb-210 activity (about 100 years), bioturbation intensities need to be evaluated only once at each station for baseline purposes.

However, time-series evaluation of excess Pb-210 profiles *is* recommended after test mining to elucidate the fate of the redeposition layer.

SUMMARY OF DISCUSSION ON SEDIMENT PROPERTIES, SEDIMENTATION AND BIOTURBATION

Dr. Smith spoke first of the recommendation by the Legal and Technical Commission (LTC) that baseline studies of physical sediment properties should include specific gravity, bulk density, shear strength and grain size as well as the depth of change in the sediment from oxic to suboxic conditions. Chemical sediment, he noted, had already been discussed by Dr. Gerald Matisoff (chapter 12 above). How these measurements should be distributed in space and time might be best considered after a mining site was identified and the technology and mining pattern were better known. Many of the parameters were geotechnical and would be useful in a mining engineering survey, and thus were likely to be measured independently of the environmental study.

Suboxic layer

One participant observed that the depth of the suboxic layer was highly variable. In the Peru Basin, it was about 10 centimetres below the seafloor, whereas in the western part of the Clarion-Clipperton Fracture Zone (CCFZ) it was at least 10 metres below. He wondered whether it was necessary to measure such thick sediments

Smith replied that he thought the intent was to determine whether mining would lift up reduced pore water that might contain dissolved metals. He suggested that the recommendation be reworded to conform with others that called for measuring redox conditions down to a depth of 10 cm or to the depth of the change from oxic to suboxic conditions, whichever was shallower.

Dr. Matisoff said the idea was that if the sediment was still oxic at 10 cm below the surface, there was no need to go deeper to look for reducing activity. The problem could be resolved by specifying the depth at which to measure pore water concentrations for flux and redox conditions.

One participant did not agree that measurement should be limited to the anoxic depth, since a mining operation might go deeper. Smith responded that the suggested depth of 10 cm was relevant to habitat characteristics, while 10 m was not.

Another participant suggested that an easy solution might be to use the 40-cm maximum depth of a box corer, one of the sampling instruments that would probably be used. Smith responded that 40 cm was deeper than one needed to go for redox conditions.

In situ measurement

A participant wondered whether in situ measurements should be recommended, given the uncertainties that might be introduced if measurement was done on board after cores were brought up. Smith replied that he did not think in situ measurements for specific gravity, bulk density and shear strength were necessary from an ecological perspective. Bearing strength was not too relevant to understanding the habitat, though it was certainly relevant to engineering the mining equipment.

Grain size

Smith suggested that the Workshop consider how to measure grain size. Bringing sediments up, disaggregating them and treating them with hydrogen peroxide would not reveal their behaviour at the seafloor when resuspended from a plume. The Workshop might recommend that thought be given to a possible protocol to measure native sediment or in situ grain size in a way that was relevant to plume prediction.

A participant expressed the view that grain size was an important parameter, even for impact assessment, and thus it would be proper at this stage to define how it should be measured rather than put it aside. Smith responded that he did not know whether there was a standard method for measuring in situ grain size. There were standards for bringing sediments up, disaggregating them and then measuring mineralogical grain size, but this was not done to assess environmental effects. The measurement was useful, but there was much more about grain size that was relevant to impact assessment.

A participant observed that, during the German DISCOL (Disturbance Recolonisation) project, grain size had been analysed onboard using multicorer samples. However, no protocols existed for that exceptional study. He had done many comparative studies on grain-size analysis but had found no method that gave unambiguous results. For example, using a Coulter counter, he had obtained completely different results when the samples were sieved in distilled water instead of seawater; he was sure that the Coulter counter with seawater gave a more correct answer.

Smith recounted his own experience with ecological studies of sediment communities in the deep sea, in which sediments had been taken just after recovery from box corers or multiple corers, immediately washed in a cold room on nested sieves, fractionated and weighed in the laboratory, giving a picture of what the sediments looked like in the field. Perhaps the Workshop could devise a recommendation on how to handle sediments.

Shear strength

Citing difficulties in measuring shear strength, a participant said he did not know how a protocol could be written since every group measured this parameter with different equipment and at different depths. Smith responded that shear strength was one of the less important measures for environmental purposes; he did not know many ecologists who used it in their studies.

Another participant suggested that shear strength be measured in situ, since more and more equipment was being developed to accomplish this. Such measurements during a dive by the submersible *Nautile*, made on a vein system, had shown greater shear strength than had been recorded using comparable samples from cores. Sediments should be measured before they were sampled by box corers, because samples were always modified as they were brought to the surface, invalidating the data. As measurement on the bottom seemed to be more adequate, he recommended the use of equipment in situ.

He added that the LTC recommendation on sediment properties did not specify what should be measured. It merely said that contractors should determine the basic properties of the sediment, including measurement of soil mechanics, to adequately characterise the surficial sediment deposit and the potential source of deep-water plume. He thought it better to establish a protocol for in situ measurements when an experiment was to be undertaken, using the best technology available at that time.

Observing that deep-sea biologists did not normally measure shear strength in situ, Smith questioned whether it was necessary to specify this parameter for environmental studies, since it would be measured in engineering studies. Another participant agreed, suggesting that the parameter be included in another category.

Water content

A participant expressed the view that the water content of sediment was an important parameter, since mixing a lot of water into the sediment changed the biology totally. Another participant, agreeing, recalled that a Polish group had published a study on vertical distribution of meiofauna in relation to water content and shear strength. Biologists might not look at it, but it was an important parameter, in that it controlled the movement of organisms through the sediment column. Its environmental importance might be unknown at present, but if sediment samples were to be collected, this parameter need not be excluded. People engaged in the study could decide what method was feasible.

Sedimentation measurements

Smith observed that the rate at which particulate organic carbon (POC) settled to the seafloor was a basic environmental parameter that, if it varied over time, was likely to alter community structure or at least the abundance of animals on some time scale. Other parameters such as the mixed layer depth -- the depth at which sediments were mixed by animals – were also controlled by or correlated with POC flux on a global scale. Their fundamental role in understanding the nature and variability of the ecosystem affirmed the importance of measuring sedimentation rates.

The LTC recommendations called on contractors to gather data on the flux of materials from the upper-water column into the deep sea. The Commission's explanatory commentary suggested that, within each claim area of 150,000 square kilometres, two sediment traps be deployed on a mooring for at least 12 months – one below 2000 m to characterize particle flux from the euphotic zone and the other at 500 m above the seafloor -- to be sampled sequentially at no longer than one-month intervals. This was a generic recommendation. Protocols had been developed by the Joint Global Ocean Flux Study (JGOFS)[3], which had deployed sediment-trap moorings all over the ocean following a standard technology and set of measurements, and he suggested that these protocols be adopted for sediment-trap measurements.

He mentioned a study on the North Atlantic Ocean, in oligotrophic waters similar in oceanographic climate to the CCFZ, which had examined a sampling area about 300 km in radius, called a statistical cone, where particles were collected in a trap at a depth of about 4000 m. One trap, properly placed, had provided an integrated view of a large part of the ocean surface. That provided a rationale for not having a multitude of traps; at least one trap mooring would indicate the general particle-flux climate. A trap mooring required a big capital investment but it was not that much more expensive to leave it out and turn it around each year during the exploratory studies. Thus, the Workshop might recommend that the trap be kept for a minimum of 12 months but that it would be useful, for an understanding of natural environmental variability, to operate the trap for two or three years.

Sediment traps

A participant asked whether a standard model of sediment trap should be recommended. She mentioned that the trap design used in the JGOFS French programme Eumeli, which complied with the JGOFS protocols, had been adopted by researchers concerned with benthic biology and the water column, in order to have the same sediment trap along the water column and near the bottom. She recalled that there had been much discussion, 10 or 15 years ago, about the shape of sediment traps and sequential sampling. Smith responded that JGOFS scientists had dealt with this issue in detail in an effort to look at flux in many different places in the ocean, and he suggested that the Workshop simply follow their recommendations.

Another participant questioned whether JGOFS-approved traps had been deployed in the CCFZ and whether they could collect enough particles in one month in such an oligotrophic zone. Smith replied that JGOFS traps at 9 and 10 degrees north latitude in the CCFZ, and at the Hawaii Ocean Time-series (HOT) station, which had an even lower flux, had obtained measurable samples for all the parameters.

Sediment-trap levels

The Workshop discussed a suggestion to add a sediment trap below the two proposed by LTC, the lower of which would be at 500 m above the bottom. One proponent of this idea noted that the depth of sediment and nodule separation was still unknown; while another urged deep placement – perhaps 10 m above the seabed -- in order to collect baseline data needed to assess mining impacts. Smith observed that a trap could not be used to track primary flux if it were put in the benthic boundary layer, 100-200 m above the seafloor; 500 m was a standard deployment to look at deep flux that was probably getting to the seafloor, without having the trap impacted by the benthic boundary layer. Another participant agreed that there must be a trap above this layer but argued that an additional trap near the bottom could provide information about resuspension material.

Smith countered that the transmissometer (nephelometer) suggested for physical oceanographic measurements in the benthic boundary layer might provide even more data about resuspension than a sediment trap. However, it was pointed out that a transmissometer recorded data on small particles whereas a sediment trap collected large particles. The French had combined nephelometry and the sediment trap for more than ten years, employing a trap at 10 m together with a transmissometer and another trap at 200 m from the bottom.

Bioturbation

Smith remarked that bioturbation was an easily measured index of one form of community activity that was useful in indicating the depths at which redeposited sediment would be mixed during community recovery from a redeposition event. The LTC recommendations called for contractors to gather data on the mixing of sediment by organisms. The Commission's explanatory commentary suggested that rates of bioturbation be assessed with profiles of Pb-210, a standard isotope. It also suggested depth intervals going from 0-1 down to 14-15 cm, a range that was probably not relevant in the CCFZ, according to studies showing that bioturbation penetrated only about 2 cm. He therefore recommended measurement over a depth of 0-5 cm, which he expected to be uncontroversial. He further recommended that five replicate profiles be taken at each station to give a statistically valid sample size.

Commenting on a suggestion to utilize Th-234, Smith agreed that that would be useful for shorter bioturbation rates. However, it might provide a level of detail that need not be specified. One problem with Th-234 was its short half-life of 24 days, so that, on a six-week exploration or monitoring cruise, samples would have to be measured at sea.

One participant drew a distinction between macrofaunal and meiofaunal bioturbation, which could be measured with the methods being discussed, and surface bioturbation by the megabenthos, which could be evaluated by a deep-sea profile recording animal traces and other seabed features. Smith agreed, adding that looking at the abundance of bioturbation features was not a rate measurement but might provide an index of the nature of the community before and after a disturbance -- for example, if bioturbation from megafauna could no longer be seen. Another participant, however, cautioned against mixing up old and recent bioturbation features, given the low sedimentation rate that did not cover surface traces, thus making it difficult to understand them in a quantitative way. Her laboratory combined these results with Pb-210 readings, but the latter gave a mean measurement and were not useful for bioturbation by large fauna.

Notes and References

1. International Seabed Authority, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area: prepared by the Legal and Technical Commission (ISBA/7/LTC/1), 10 April 2001; further revised and approved by the Commission as ISBA/7/LTC/1/Rev.1 of 10 July 2001. On 12 July 2001, the ISA Council deferred consideration of the recommendations until its eighth session (August 2002).

2. A. Knap et al. (eds.) (1996), *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements* (JGOFS Report No. 19), vi+170 pp. (reprint of *IOC Manuals and Guides No. 29 [*United Nations Educational, Scientific and Cultural Organization, 1994]), chapt. 24: JGOFS sediment trap methods.

3. *Ibid.*

Chapter 14 Biodiversity in the Deep-Sea Benthos: Pattern and Scale. Sampling and Analytical Problems Associated with Assessment in Abyssal Regions

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Since serious interest developed during the 1960s in commercially mining deep-sea polymetallic nodules, a great deal has been learned about patterns of biodiversity in the deep-sea benthos at local, regional and global scales. Biodiversity refers to the variety of living organisms. It involves all levels of organization including genetic, population-species, community-ecosystem and landscape, each with its own components of pattern and process[1]. The present Workshop has reviewed general patterns of biodiversity in the deep-sea benthos, and the special problems of measuring biodiversity and impact assessment in the abyss where mining is planned.

1. Pattern and Scale

1.1. Genetic Level

The Regulations of the International Seabed Authority[2] do not specifically address biodiversity at the genetic level but this could be included in a highly cost-effective way by using the same collections of benthos that are being used to measure community makeup. Genetic biodiversity is an essential part of understanding the effects of mining and other anthropogenic disturbances on deep-sea ecosystems, and developing sound conservation protocols.

The primary evidence used for conservation of biodiversity at the genetic level is genetic population structure, the spatial pattern of genetic diversity within and among populations[3]. It is a critical component of biodiversity for conservation efforts because the ability of species to adapt to changing environments depends directly on their genetic diversity. Loss and fragmentation of habitats reduce population size and erode genetic variation, making populations more vulnerable to local extinction. This, in turn, destabilizes biotic interactions within communities and depresses diversity at the community level. A diminished gene pool within species also limits the potential for future diversification. Genetic diversity is the ultimate source of biodiversity at community and landscape levels.

Measuring genetic population structure also has broad implications for understanding community organization. Local communities represent a balance between extinction rates driven by ecological interactions and migration from the regional species assemblage. Population genetic structure is the most accurate way to determine the extent of migration and gene flow among populations. It is also a key to understanding endemism. The degree of endemism in impacted regions is central to conservation efforts, because habitat destruction can result in permanent loss of geographically restricted species. In addition, many marine species, including those in the deep sea[4], while morphologically coherent, are comprised of genetically distinct sibling species. Without measuring the genetic population structure of species, it is impossible to assess the actual extinction potential of habitat alteration.

Until quite recently, investigating genetic population structure in deep-sea species has been a daunting prospect. Most organisms are minute and intensive sampling requires immediate preservation of bulk samples before they are sorted to species in the laboratory. However, techniques are now available for extracting, amplifying and sequencing DNA, even from small deep-sea individuals that were fixed in formalin decades ago and then preserved in alcohol[5]. Adding a genetic dimension to mining-assessment studies would add significantly to their potential for sustainable development and conservation of the deep-sea ecosystem. The cost would be modest because the material is already being collected for other purposes.

1.2. Population-Species Level

This level includes population dynamics, dispersal and standing stock. These topics have been reviewed extensively[6]. Of primary interest for the effects of deep-sea mining on the abyssal plain, standing stock of the benthos decreases exponentially with depth and reaches very low levels in the abyss (greater than 4000 metres) as a consequence of decreasing flux of particulate organic carbon (POC) to the seafloor. Standing stock of megafauna[7], macrofauna[8], meiofauna[9] and bacteria[10], as well as sediment-community respiration[11], all decrease with increasing depths. Standing stock can also show geographic variation across the abyssal plain[12].

1.3. Community-Ecosystem Level

Basic research and assessment work concerned with biodiversity has centred primarily on this level, which includes within-habitat variation in species diversity and species composition on local, regional and global scales. Most work has focused on the macrobenthos, which shows very high levels of local species coexistence and is amenable to taxonomic discrimination of species by using standard phenotypic and genetic methods. Less is known about the metazoan meiofauna, which are minute and less well known taxonomically[13]. The megafauna are better known taxonomically but exhibit considerably lower diversity and density than do the macrofauna[14], making them a more difficult functional group to use for impact assessment.

The macrofauna, dominated by polychaetes, molluscs and peracarid crustaceans, exhibit extraordinarily high local species diversity in the deep sea. The most intensive precision sampling study ever undertaken[15] found an average of 100 macrofaunal species per 0.09 m^2 at mid-bathyal depths in the western North Atlantic Ocean. Replicate box-core samples showed a very high level of variability in species diversity, indicating that a large number of samples is necessary to accurately discern geographic patterns of local diversity, to associate differences in diversity with environmental parameters[16] and presumably to detect anthropogenic effects such as mining. Macrofaunal diversity varies strongly with depth[17] and a wide variety of environmental factors[18]. It also varies at global scales, showing latitudinal gradients of diversity and strong interregional shifts[19]. Clearly, the magnitude of anthropogenic impacts on biodiversity depends on the scale of the impact as well as its depth and location in the world ocean.

A major difficulty in predicting the localized effects of impacts is that the species diversity on small scales remains poorly characterized. Species-accumulation curves of 18-20 replicate box-core samples taken at mid-bathyal depths in the western North Atlantic show no sign of reaching an asymptote because of the high number of rare species[20]. Diversity is so under-sampled that it is difficult to discern how much of the apparent geographical turnover in species makeup simply reflects sampling error – that is, additional sampling along a geographic gradient merely encountering different rare species that may pervade an entire region[21]. A second significant problem is that species' geographic ranges are very poorly known. This makes it impossible, in most cases, to determine the potential for permanent extinction of species that can be expected from human-induced impacts of different spatial scales and durations.

Stuart and Rex[22] have shown that local diversity of deep-sea molluscs is positively correlated with both diversity of the regional species pool and the proportion of species that have dispersing larvae. This suggests that local community diversity is maintained, in part, by continued dispersal from the regional pool. In other words, local community structure is related to regional-scale processes. Anthropogenic impacts will vary depending on regional diversity, the geographic distribution of species and the life-history characteristics of the regional fauna. The interaction of local and regional processes implies that mining in one part of a region may have broad consequences for communities elsewhere in the region that are not directly affected by mining.

1.4. Landscape Level

Once thought to be a relatively uniform environment throughout, the deep sea is now known to have a very high diversity of habitats and topographic complexity[23]. The deep-sea fauna are zoned with depth and show marked changes in diversity and composition with topographic features, current regimes, sediments and oxygen-minimum zones[24]. A great variety of chemosynthetic communities also exist[25]. It is clear that many soft-sediment, hard-substrate and chemosynthetic communities share some proportion of their faunas. However, the extent to which this is true and the importance of dispersal among habitats in the persistence of species remain unclear.

2. Abyssal Communities

Much less is known about community structure at abyssal depths far at sea, where mining is targeted, than at bathyal depths along continental margins. Standing stock declines exponentially with depth, reaching levels in the macrofauna on the order of 1 gram/m^2 and 100 individuals/m^2 below 4000 m[26]. Diversity, while somewhat lower than at bathyal depths in terms of the number of species per unit area at local scales, appears to remain fairly high. The circumstances of very low animal abundance and high diversity make it particularly difficult to detect spatial changes in community structure without taking a large number of box-core samples[27]. Comparisons between reserve and disturbed areas need to be carefully controlled in the sampling design, since abyssal communities now appear to experience natural cycles of food supply and demand on decadal time scales[28], which could compromise a simple before-and-after sampling approach to detect impacts. The present Workshop has proposed an appropriate sampling design (discussed by Dr. Ron J. Etter in chapter 18 below).

The abyssal fauna of the Clarion-Clipperton Fracture Zone (CCFZ) in the Pacific Ocean has been summarised elsewhere[29]. Collectively, what these studies show is that the abyssal fauna has been under sampled. Rarefaction curves (a re-sampling of species' relative abundance distributions to normalise samples to a common sample size) show no tendency for estimated diversity to reach an asymptote. This suggests that the faunas were not characterised well enough to compare diversity among sites or to detect disturbance effects. The most thorough study, at the Echo-1 site[30], was unable to reveal differences in community structure between mining and control sites, but it was unclear whether sampling intensity (eight box cores at control sites and six at test sites) was sufficient to show a statistical difference. Rarefaction curves for pooled samples at both test and control sites showed no asymptote. [Etter and Mullineaux[31] have shown that a more accurate way to compare species richness among sites in the deep sea is to use randomised species-accumulation curves for replicate box-core samples. However, even at mid-bathyal depths where animal density is several times higher, 18-20 replicate box cores did not produce species-accumulation curves that levelled off.]

Similarly, all of these studies conducted multivariate analyses of species makeup among sites that suggested spatial variation in community composition. However, again, since the fauna appears to be under-sampled, the extent to which apparent spatial change in composition reflects sampling error is unclear. It seems doubtful that the sampling intensity of these early studies (10-47 box cores per site[32]) is adequate to measure spatial variation in community structure at these depths or to accurately assess the effects of mining.

An additional problem is that the paucity of sampling in the CCFZ means that the geographic ranges of abyssal species are very poorly known, inside and outside of the region. This makes it impossible to know the probability of species extinction caused by mining operations on different spatial scales.

The present Workshop has discussed several ways to improve understanding of the potential impact of mining in the CCFZ. Contractors, during their exploration phase, have collected a large number of box-core samples. At the Workshop, they have presented data on standing stock of the fauna in these samples. If the samples could be sorted to species, this would very significantly increase the biodiversity database of the region. This could provide data on species ranges and adequate sampling efforts that potentially would be very useful in predicting the impact of mining. The data from the second Deep Ocean Mining Environmental Study (DOMES II), which have never been published or made available, would also be very helpful. Compiling species-abundance data (a list of species and the abundance of each species in each sample) from existing samples should increase the biodiversity database by at least several-fold.

Given the difficulty of sampling abyssal communities, the Workshop has also discussed the possibility of sampling one claim very thoroughly to establish a database that is adequate to measure effects of mining. It may be possible to generalise this to other claims and to use the results of a very thorough sampling programme to develop more efficient sampling designs for subsequent mining operations.

PRESENTATION AND DISCUSSION ON BIODIVERSITY IN THE DEEP-SEA BENTHOS

Levels of biodiversity

Dr. Rex began his oral presentation by describing the different levels of biodiversity, each with its own set of patterns and processes.

He said genetic biodiversity, though not on the agenda of the International Seabed Authority, should be considered. Much of the conservation movement for terrestrial environments was based on genetic population structure and the gene pool, because these factors provided much clearer insight into extinction potential and would be helpful in resolving taxonomic problems as well. Since material was being collected in the deep sea, it would be a shame not to do some research on its genetic population structure. The main expense was for collection, as the cost of sequencing the DNA was minor by comparison. Moreover, since genetic population structure was the origin of biodiversity on all the other levels, conserving it was important.

If the Authority was interested in pursuing standardization of research on abundant species, the Workshop should think about standardised methods of collection, of preservation for genetic work and of sequencing.

Regarding the population-species level of biodiversity, he said the population dynamics of dispersal was vital for recovery from disturbances and for standing stock. The small quantity of standing stock on the abyssal plain lay at the heart of the assessment problem there.

The community and ecosystem level was where species diversity came into play at different scales: alpha, beta and gamma or, more simply, local, regional and global scales of biodiversity. As Dr. Etter would discuss (chapter 18 below), among the challenging problems in the abyssal plains, where densities were so low, were to document patterns of species diversity on different scales and also to determine the scales of time and space at which various processes shaped these patterns.

Finally, the diversity of different habitats could be seen at the landscape level. The deep sea had a remarkably rich landscape of biodiversity. The fauna was zoned according to depth. There were important shifts in biodiversity between topographic structures such as canyons, mountain tops, trenches and other physiographic features -- for example, oxygen-minimum zones, current regimes, sedimentation and the turbidite situation in the Atlantic Ocean, as at the Madeira Abyssal Plain (MAP) site. There was a host of chemosynthetic communities that were quite different from one another. In the Gulf of Mexico, for example, there was a wide range of bizarre habitats including the Mississippi fan escarpments and other strange topographic features such as a salt knoll, brine pools, iron crusts and seeps of one kind or another. This surprising richness of landscape diversity had to be taken into account because it was now known that part of the fauna of these different habitats was shared but it was not known how the dispersal of populations from one habitat had an effect in supporting or preventing extinction of populations in other habitats.

Thus, biodiversity must be understood at all of these different levels, which demanded a much broader view. So far, the discussion had centred mostly on two levels.

As evidence of the rich landscape diversity of the deep sea, he showed a high-resolution sonar image covering about 100 by 175 kilometres at the Clipperton transform fault, at the eastern end of the Clipperton-Clarion Fracture Zone (CCFZ). This area, part of the ridge system rather than the abyssal plain, contained a wonderfully diverse environment, made up of mountain chains, faulting regions, complicated ridge and valley systems, small isolated deep basins and isolated mountain tops. Off to the west were the vast abyssal plains of the eastern Pacific Ocean, including the mining regions. It should be borne in mind that regions adjacent to the abyssal plain, which appeared to be quite different, might have an important impact on large-scale diversity in the neighbouring environment.

The high diversity of soft-sediment landscapes in the deep sea could be seen off the east coast of the United States, in a high-resolution sonar image measuring about 10x10 km from a little lease block off Cape Hatteras (North Carolina). In this surprisingly complex environment, the slope face was deeply incised by gullies that coalesced downslope into canyons. Intensive sampling had shown a fauna zoned with depth, which changed downslope and horizontally with such ecological factors as the amount of nutrient loading.

Sampling and analytical problems

Diversity was now known to vary on large scales, though Rex cautioned that not enough abyssal samples had been taken anywhere to look respectably at large scales of species diversity, even in the more accessible bathyal region. He cited a study of about 100 samples of isopods and gastropod and bivalve molluscs from the Atlantic Ocean, taken at bathyal depths between 500 and 4000 m[33]. Latitude gradients in diversity, like those in coastal and terrestrial environments, appeared in oceans of the Northern Hemisphere, but the situation in the Southern Hemisphere, with fewer samples and a more limited coverage of latitudes, was much messier – with no pattern evident in the case of isopods, for example. On the other hand, there was strong regional variation in the south -- for example, areas at all depths where there was high nutrient loading from upwelling tended to have depressed diversity.

Whether regional or latitudinal, variation in species diversity occurred on large scales in the deep sea. Thus, what kind of impact any anthropogenic activity would have depended greatly on location. A lot of variation in depth-related diversity existed within individual regions, even on the abyssal plain. Any search for a geographic pattern such as a latitudinal gradient would have to control for depth, to avoid finding an apparent pattern that was just a spurious consequence of difference in depth coverage with latitude. If, for example, diversity decreased with depth in the north, and most northern samples came from greater depths while most tropical ones came from shallower depths, there would be an apparent latitudinal diversity gradient that was just a spurious consequence of the difference in depth sampling.

When the data from the North and South Atlantic were statistically corrected to remove the effect of depth, using the residuals of the regression of diversity against depth and latitude against depth, large-scale horizontal patterns emerged.

Focussing on an area in the North Atlantic where the patterns were more obvious, he cited a study of more than 100 species of Turridae, the largest family of gastropods, collected over a century at 1300 stations in just the eastern North Atlantic. Rather than looking at the diversity of samples, he had documented the well-characterised latitudinal range of each species, examined where the ranges overlapped and summed the diversity. When averaged over large scales of time and space, the calculation showed the same sharp latitudinal decline in diversity. The implications for mining were that it made a difference where the deep sea was disturbed, in terms of the impact on biodiversity.

Meiofaunal data from foraminiferans in the North and South Atlantic also showed a decline in diversity toward the poles. However, John Lambshead[34], looking for large-scale patterns in the metazoan meiofauna, had found that they were not at all clear; there was either no pattern or, in some cases, evidence of a positive latitudinal gradient. Whatever the causes, on large scales there was variation in patterns of coexistence.

Many of the large-scale patterns had an historical component as well as an ecological one, as shown in an analysis by Thomas and Gooday of foraminiferal diversity between the Antarctic and Equatorial Pacific Oceans throughout much of the Cenozoic Era[35]. In the Eocene Epoch, when the Earth's climate changed from a greenhouse to an icehouse world, and polar ice caps developed in the South Atlantic and on Antarctica, the environment had become much more seasonal. Quantitative samples of deep-sea forams showed a divergence in diversity between the equator and the poles, similar to the latitudinal gradient displayed in the recent data, thus establishing that diversity remained high at the equator and headed south, as it were, toward Antarctica.

As another example of a lengthy historical component to these large-scale patterns, Rex had recalculated data from G.D.F. Wilson for typical deep-sea isopods of the suborder Asellota. They had invaded the deep sea early, apparently as far back as the Mesozoic Era, and had radiated extensively there in many endemic families. They had readily adapted to the deep sea, their only habitat. On the other hand, isopods of the suborder Flabellifera, which were not typical deep-sea forms but were in the process of invading the deep sea and had no endemic higher taxa, had arrived there only recently. They had apparently invaded the South Atlantic first, from the Indo-Pacific, and had since spread into the North Atlantic. When these two groups were added together, they demonstrated not just a decline in diversity in the North Atlantic but actually a pole-to-pole decline across the whole Atlantic, again showing an historical build up of these patterns over a long period, one that was not just ecologically controlled.

Other data, showing a decline in diversity of one group of molluscs in relation to latitude in the North Atlantic, highlighted the point that an important interaction of processes on various scales governed these large-scale patterns. According to one current concept, local diversity was often governed by regional enrichment. Put another way, local diversity represented a balance in an open system, particularly such as the ocean, between factors that caused local extinction – biological reactions such as competition, predation and so forth – and dispersal from a regional pool. The regional pool was developed over a long period through speciation and adaptive radiation. If that were true, and if local communities were fairly open, non-structured systems, then local and regional diversity should be positively correlated over a broad range of values, as local diversity evolved to reflect the amount of diversity available regionally to participate in local communities.

On the other hand, according to more traditional thinking -- a sort of ecological determinism -- local ecological circumstances controlled the amount of local diversity irrespective of how many species were around to participate. In that case, local diversity and regional diversity would be statistically independent or would level off as a kind of local saturation.

This issue had been investigated in a statistical analysis of a group of molluscs, both gastropods and bivalves, throughout the Atlantic Ocean, north and south. It showed a good positive relationship between regional and local species diversity, the implication being that the regional species pool over broad areas of the ocean had an important effect on local diversity -- the kind of diversity that would be affected by activities such as mining, petroleum exploration or dumping.

The idea that regional processes were important in governing local diversity had been tested by doing a multiple regression. In this calculation the dependent variable, what the analysis was trying to predict, was local species diversity, while the independent variable, the presumed governing factor, was regional diversity and the proportion of species that could disperse, since regional enrichment worked only by dispersal from the regional species pool into local environments. The analysis was controlled for depth, to avoid having that factor confuse the outcome. The resulting equation showed a significant relationship: local diversity was a positive and significant function of the number of species available to participate in local communities and the ability of those species to disperse. The conclusion pointed to the importance, in these circumstances, of understanding regional diversity on a large scale as well as the life histories of the species involved, in terms of their ability to move from place to place.

The relationship could be grasped more intuitively by looking at the residuals of a regression between local and regional diversity, as just described, against the variable of the percentage of species that dispersed. In regions like the North Atlantic, where local diversity was much higher than might be expected from the small size of its regional species pool, the many dispersing species could augment diversity by getting around. By contrast, in the Norwegian Sea, where local diversity was much greater than the size of the regional species pool might warrant, most species could not disperse well. Thus, the life histories of the population, and the size to which the local or the regional species pool had evolved, would have an important effect on the response to big impacts.

He cited a paper by Ron Etter[36] on species diversity against depth, based on box-core data for the entire macrofauna from the Atlantic continental slope and rise, collected in the course of petroleum exploration studies sponsored by the United States Minerals Management Service (MMS). Its hump-shaped statistical curve showed that species diversity was a positive function of sediment grain-size diversity. The study also demonstrated the huge amount of variation in diversity that could be found at any individual place, even with precision sampling and experienced people looking at the data. The lesson that could be drawn was that a lot of precision data were needed to detect large-scale patterns.

In addition to local diversity, there were also changes in the makeup of diversity from place to place. Branching diagrams called dendrograms showed similarities in species lists from one station to the next. Two places with almost the same species were said to have a high level of association, while others shared no species whatsoever. An almost classic ecotone between shelf and slope adjoined an area of tremendous change downslope, while the rise was completely different.

On the abyssal plain of the western North Atlantic, at or below 4000 metres, very low figures had been found for standing stock, about 1 gram or 100 individuals per m^2. A global analysis of metazoan fauna also showed a decline in density with depth, to a particularly low level on the abyssal plain. Such low-density levels made assessment difficult on the abyssal plain, because the ability to replicate was low and it was hard to detect differences from one place to the next, particularly when coupled with reasonably high diversity.

Gordon Paterson, in a worldwide analysis of the numerically most important group – polychaetes, or segmented worms – had also shown that abundance declined exponentially with depth. The only places with reasonably high density were locales where nutrient input was augmented around seamounts or where reactive sediments were exposed and there was more food.

Some of the most interesting figures in the deep-sea literature had been published by Fred Grassle and Nancy Maciolek[37], based on almost 170 box cores from an Atlantic continental slope and rise study, taken along 2100 m isobaths. They showed a huge range of diversity, along with relatively high abundance. The median diversity was high -- about 100 species for each of the nine central 10x10-centimetre sub-cores, or about 1 square foot. Data from the Echo-1 study in the Pacific Ocean showed much lower density. The data were not perfectly comparable because the first set covered all macrofauna while Echo-1 was limited to the principal groups – isopods, bivalves and polychaetes -- and its samples were much larger, a full $0.25m^2$. Though both density and diversity were lower at Echo-1, the finding of 40 species per $0.25m^2$ was still notable.

Pointing to the difficulties in making projections about the number of species in the deep sea, Rex said that Grassle had plotted the apparent accumulation of species over a distance of about 176 km along the 2100 m isobath and had used that rate of accumulation to make an estimate for the deep sea. The problem, however, laid in the number of singletons – that is, the number of species and samples represented by a single, rare individual. Data from Georges Bank, on the continental shelf, and Grassle's figures from the Atlantic continental slope and rise just south of there, showed no significant difference in the proportion of singletons, which seemed to be about 1:3 everywhere. In the deep sea, however, a huge number of species were each represented by a single individual. Thus, if a small sample of $0.25m^2$ contained a large number of species, and those species were more or less randomly distributed and extremely rare, it was difficult to know whether samples from other locales represented a geographical accumulation of species or simply indicated that more rare species existed everywhere in the sampling area. That was why the sampling problems at bathyal depths were exacerbated on the abyssal plains, where the density was even lower.

Rex observed that data from the second Deep Ocean Mining Environmental Study (DOMES II), a large sampling study, had never been published. They were in the hands of Eugene Gallagher at the University of Massachusetts. A student of Gallagher, Dwight Trueblood, who for a long time was in charge of the manganese-mining programme at the United States National Oceanic and Atmospheric Administration (NOAA), had convinced Kristian Fauchald of the Smithsonian Institution to identify the polychaetes but nothing from this large data set had been published.

He suggested that the amount of biodiversity information for the deep oceans would greatly increase, perhaps two- or threefold, if data and samples gathered by seabed investors could be examined and analysed, and their collections looked at and separated into species. Estimating biodiversity by using those samples would not be terribly expensive, and would help tremendously in interpreting the impacts and understanding the patterns of biodiversity in this area.

Referring to data from three sites in the Atlantic, he said they seemed to show much variation in species makeup, both among the samples from a particular place and certainly among the sites themselves. However, it was difficult to know how much this reflected real differences among the sites and how much was due to sampling error, as there were so few samples. Low abundance had also been recorded at the MAP site in the Atlantic, where a turbidite flow had occurred around 900-1000 years ago, and Adrian Glover and others[38] had speculated about whether the species impoverishment was due to the turbidite event or to low nutrient input. The scale of sampling and the number of samples would have to be increased to know how really different the sites were and to obtain data useful for interpreting an impact.

Rex showed a curve he had plotted using data from an old Echo-1 study in the Pacific, of individuals against numbers of species. The researchers had tried to discriminate between the test area, which had been mined some time before, and controls outside that area, but they had not been able to see a difference in this case. The length of the curve showed a large increase in the number of species from successive samples, but it was difficult to know whether a critical comparison could be made among the samples because they were so few, with so many rare species being encountered as more and more samples were taken. A cluster diagram of species makeup showed that the samples were quite different from one another. It was not known how meaningful these results were in reflecting real biological and ecological differences or whether they just derived from sampling error because the density was so low and the species so numerous.

Referring to a more recent equatorial Pacific (EqPac) study cited by Craig R. Smith (see the presentation summary in chapter 3 above), Rex noted that it showed a greater species diversity where equatorial upwelling produced a higher rate of nutrient input to the benthos, compared to the lower diversity in a more typically oligotrophic area to the north.

In conclusion, he reiterated the point made by Charles Morgan (chapter 4 above) that the abyss in this region was probably very under-sampled. The fauna of the CCFZ was probably not characterized well enough to detect impacts. Additional replicate samples were needed to assess the effects in the immediate neighbourhood of mining. Diversity had to be characterised on regional scales, including species ranges, to gauge the probability of extinction of individual species. It would help greatly to be able to examine the data collected by the pioneer investors and see what patterns of diversity they indicated.

SUMMARY OF DISCUSSION

Population dynamics

A participant wondered whether the small numbers of individuals combined with high diversity meant that the population had to be large but spread over a broad area. Otherwise, how would they multiply? If there were just a few individuals in a small area, was not the possibility of extinction rather large? On the other hand, if there was large diversity over the abyssal plain but few individuals, and a mining operation destroyed the population in a specific area, would not individuals further away come in and inhabit the area later?

Rex replied that understanding how species could live at such low densities had been one of the great challenges of deep-sea biology. However, there were many kinds of rarity. It was not necessarily true that something extraordinarily rare must be very widespread to avoid extinction. To answer such questions, the spatial ranges of species had to be documented. If something had a restricted range, there was an increased possibility that mining would cause extinction, whereas there would be less worry about extinction if the species were known to have a broad range. However, the sampling that had taken place so far did not provide enough information on range and diversity at different scales to be able to determine the effect on populations.

Protecting biodiversity

Another participant wondered if the act of sampling might cause extinction of a species having few individuals, whether it was done for scientific research or especially for bioprospecting, where more than one sample was probably taken. Should not the international community regulate such activities?

Rex replied that he supposed so, although such regulations were outside of the Workshop's scope. One reason to be concerned about species extinction was that rare organisms -- rare in the sense that their populations were localized or they were uncommon though they had a broader range – had often been found to be valuable for pharmaceutical reasons. That might well be true for deep-sea species, too.

Causes of diversity

Asked whether research was under way on the links between deep-sea biodiversity and environmental factors such as variations in topography and substrate, Rex said there was large literature on the causes of deep-sea species diversity, trying to relate patterns of biodiversity to ecological and even historical causes. In one of the best correlations, though it had been studied at bathyal depths, species diversity had been found to be a strong positive correlate of sediment grain-size heterogeneity. Another proposed correlate, out of a long list, was the amount of food available. However, sampling of the abyss had been so limited, and there had been so little effort or ability to relate the findings to environmental effects, that he did not think people would make claims about the abyss.

Another participant observed that his experience in diving with a submersible in the Central Pacific Ocean had made clear that the diversity of landscape was probably an important factor in the distribution of biotypes. Though there had been no opportunity to take measurements at that time, it looked as if he had been in the middle of the Alps, with flats that changed from place to place according to the presence of absence of nodules, bottoms and tops of cliffs, and so on. Because of this variety, much information would be lost if sampling took place without knowing where the samples had been taken.

Agreeing, Rex stressed that the wonderful diversity of environments, including chemosynthetic ones, corresponded to changes in biodiversity in the deep sea. Just a few years ago, these had been unimaginable, and even today most of the deep sea was still unexplored. As he had said when talking about the relationship between local and regional diversity, for many of the species that shared landscape habitats, their presence in one habitat might have important implications for their continued survival in others as well.

Depth comparisons and relationships

Asked about the comparative amounts of biomass at the surface and in the deep sea, Rex said biomass decreased exponentially with depth. One rule of thumb was that it dropped by about an order of magnitude every thousand metres, though with large variations from place to place. On this point, Craig R. Smith clarified that that was true when comparing shallow-water sediment to deep-sea sediment. However, in the water column of the CCFZ, there was more microbial biomass in the top metre of sediment at the bottom of the ocean than in the whole water column above.

A participant asked about relationships between species at different levels of the ocean and how those higher up would be affected by extinction below. Rex responded that there was a complete change of fauna from the upper bathyal zone -- at about 500 m -- to the abyss, though the depth ranges of some abyssal species varied in different parts of the ocean. Compared to the abyssal depths, the bathyal zone was a minute part of the ocean floor, just a little ribbon around the margin of the seas. The high species turnover with depth implied a long process during which tolerance to abyssal conditions had evolved. Thus, it should not be thought that, if the abyssal fauna were extirpated, the bathyal fauna would provide a reservoir of species to repopulate it. There had been a shift in thinking to the effect that the deep sea was an integral part of the biosphere.

If all the animals on the bottom were wiped out, would the fish care? Rex noted that at abyssal depths there were many fewer fish. To estimate the diversity of the fish megafauna in the abyss, he had had to lump together a huge number of trawl samples to get enough individuals. All food in the abyss, except for chemosynthetic communities, was extrinsic in origin, sinking from the surface in a variety of forms. The reason for the marked decline in standing stock with depth was that less food arrived there.

It could not be said, Smith observed, that the animals in the water column were independent of those on the seafloor. Though there were no strong linkages between the abyssal seafloor and the euphotic zone, many species that moved had large vertical ranges. For example, deep-sea amphipods that fed on the seafloor had been trapped 1 or 2 km above the seafloor in the water column, indicating that their life history and feeding biology were linked to the bottom. Citing another example of interaction, Rex recalled that the holotype of one large deep-sea crustacean was known from the stomach contents of a gull.

Smith cited a study by Ken Smith[39] in which upside-down sediment traps that captured rising particles had found an upward flux that was about 40 percent of the downward flux. There was also evidence that the amphipod mentioned by Rex that had been found in the gut of a sea gull stored its food energy in droplets of lipids that caused its body to float to the surface when it died. This had been a concern for people investigating radioactive waste in the deep sea, where even a little bit of material rising from the bottom might cause serious contamination. Though the euphotic zone would not die if life on the seafloor were wiped out, and the tuna and whales probably would not care, linkages did exist.

Species identification and sampling technology

Given the fact that science was far from knowing all the species in the deep sea, could just the macrofauna in the CCFZ be described before mining started? Otherwise, nobody would know whether a species had been made extinct and non-governmental organizations might take up this argument to oppose mining.

Rex replied that conducting a taxonomic synthesis of publications and/or a large biotic survey would be ambitious. He did not think that would be necessary to gauge the impact, however. Consistency in identifying species at various locations would suffice for that purpose. His point was that sampling difficulties made assessment difficult at this stage and that, in order for sampling to be useful, more of it had to take place.

Endorsing Rex's plea for molecular genetic studies of deep-sea organisms, Smith cited two arguments: (1) Many species might be identifiable only by using molecular techniques, which might cut the time required to differentiate species and understand distribution patterns. (2) By using population genetic models, estimates of population size could be made, based on genetic diversity within a population. Thus, some of the concerns that had been voiced could be addressed without exhaustive sampling, using population genetic techniques.

Rex added that this approach could also provide information about dispersal, which was a factor in recolonisation, and about the relationships between larger regional pools of species and local populations. As to how sampling might be improved, he said that researchers faced a dilemma. From what had been said about sampling in nodule fields, it seemed that box-core sampling worked well but the sample size was small. The way to learn more about the regional species pool would be to use epibenthic sleds and take a lot of samples. These would be bigger samples that could not be used to quantify by biomass and density but that would give a clearer indication of the species pool. That technique was difficult to employ in this environment, however, because the nodules tore up the material and would probably tear up the dredge. Thus, he guessed the answer lay in more box cores.

Smith observed that a lot of engineering expertise had gone into the design of mining heads to separate nodules from sediments. As using sleds to sample sediments without nodules raised the same problem in reverse, the Workshop might recommend that thought be given to developing a large-scale sampling device in the form of an epibenthic sled that would bring up sediment without having the nodules grind the animals to bits, thereby improving the analysis of distribution patterns.

Reinforcing this point, another participant said the problem he had found, when working on CCFZ polychaetes, was that there were never enough specimens in a box core, making it difficult to investigate biodiversity as opposed to ecology. Working with box cores was a nightmare when asking questions about regional ranges of species. A sled-type sampler was desperately needed.

Drawing a comparison with sampling for minerals, a participant said that, as the number of individuals and species diminished, sampling had to increase exponentially. Thus, to assess diversity in one area, the sample would have to be unmanageably large.

Rex replied that Dr. Ron Etter would talk more about the kind of sampling design that would work with these levels of density and species diversity (chapter 18 below). He did not think it would be impossible. Scientists were always saying they needed more information to demonstrate one thing or another, and it was correct that increasing sampling intensity would be an uphill struggle. He suggested that the International Seabed Authority think about an intensive programme in one abyssal track that might yield efficient sampling designs. Knowledge acquired in that way would pay off later for everyone, rather than conducting a super-intensive study just to identify the spatial scales needed for adequate sampling in all places.

Smith distinguished between two kinds of sampling for deep-sea animals. With quantitative or semi-quantitative sampling, using a box core or multiple core, it was difficult to get large numbers of organisms because of the low densities. A sled sampler dragged over the bottom could not provide quantitative data but it would collect a large number of animals at small cost. For analyses of species ranges, population genetic diversity or population genetic structure, quantitative samples were not needed; qualitative sampling devices such as the sled were easier and cheaper to use. To study dispersion of rare species with few individuals dispersed over a great distance was still a problem but a much smaller one with the sled sampler. As an example, in the abyssal Atlantic a single box core might bring up a couple of hundred individuals, while a single sled sample could bring up 10,000. With that many individuals it was much easier to look at the occurrence of rare species.

Another participant thought it should not be difficult for designers to deal with this problem. As people were building fishing nets that excluded turtles, one could easily imagine something that would keep out large nodules and allow the sediment into the nets. He did not think people had sufficiently put their heads to the problem

In a further comment on sampling gear, a participant reported good experience with equipping a multi-corer and a box corer with online video so that the researchers could see where their samples were taken. In addition, the multi-corer was being modified to take random samples without being brought up to the surface.

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Chapter 15 Seafloor Macrofauna in Potential Mining Areas: Parameters for Assessment, Recommended Techniques and Levels of Replication

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Paper by Dr. Gerd Schriever, Christian Borowski[?] and the DISCOL working group

The DISCOL project (*dis*turbance and re*col*onisation experiment in a manganese nodule area of the deep South Pacific Ocean) became the first large-scale impact assessment study. Originally, the DISCOL experiment was conducted by ecologists with the assistance of physicists measuring currents[1] in the experimental area. At a later stage, sedimentological and geochemical studies were implemented, and the succeeding ATESEPP (Impacts of potential technical interventions on the deep-sea ecosystem in the Southeast Pacific) programme combined research groups from various German institutions. During the DISCOL experiment in the South East Pacific (figure 1), the surface sediments of the DISCOL Experimental Area (DEA) were intensively treated with the "plough-harrow"[2], a specially constructed disturber (figure 2) designed for the simulation of some of the potential disturbance effects of a mineral-mining collector[3].

In February/March 1989, the 8-metre wide disturber was towed on 78 radial transects across DEA (see figure 1). The device penetrated 10-15 centimetres deep into the sediments and the resultant plough tracks (8 m wide by 10-15 cm deep) covered approximately 20 percent of the DEA. Video observations after the experimental treatment demonstrated heavily disturbed areas with high track densities alternating with lower impacted areas and undisturbed regions[4]. The semi-liquid surface material had been nearly eliminated from the tracks, where the disturber had left behind lighter-coloured and sharp-edge contoured clay ploughed up from deeper layers. Manganese nodules were ploughed under. Borowski and Thiel[5] described the reestablishment of the semi-liquid surface in the tracks over the subsequent three years. After this period, many tracks were filled with soft material and their surface contours were more or less smoothened.

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Nevertheless, the tracks were still recognizable in video observations and in box-core samples. Light-coloured patches at the surfaces still indicated the presence of sediments originating from deeper layers[6]. During the following four years, the shape of the tracks had hardly changed and the tracks continued to be distinguishable when the site was revisited during the ECOBENT programme in early 1996[7].

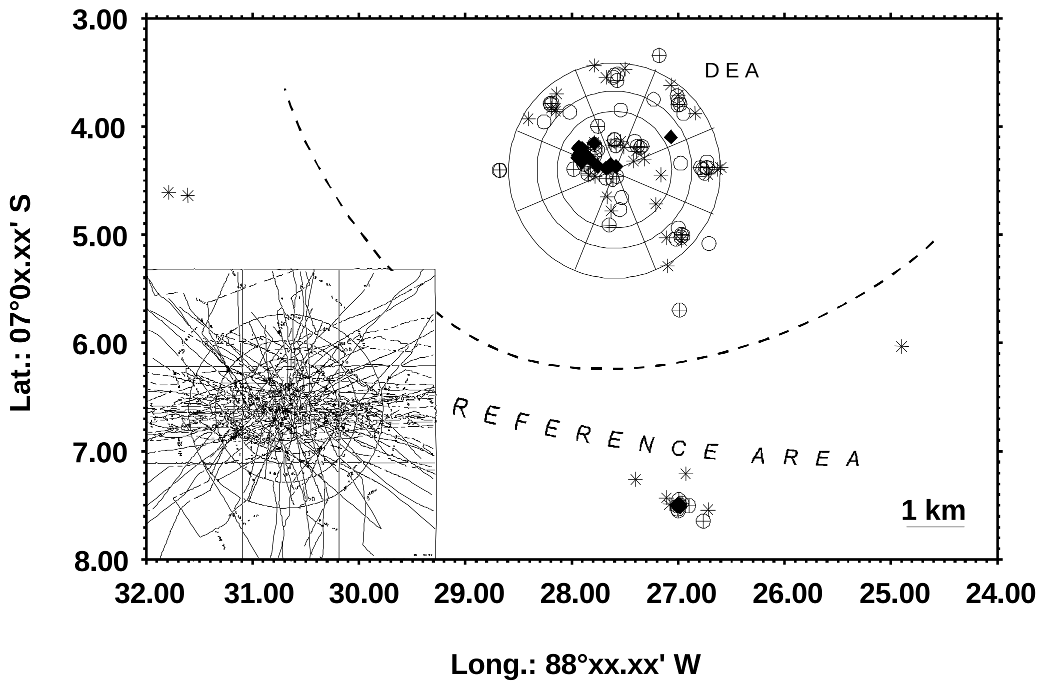

Figure 1 DISCOL Experimental Area (DEA)[8].

Figure 2 The plough-harrow.

1. Results from DISCOL as a basis for further impact studies

1.1. Assumed mining impacts

Various mining techniques have been developed and some were tested[9] in the 1970s. However, there was no decision when DISCOL was in its planning phase as to which type(s) might be used one day. We have assumed a vehicle carrying a collector at its front end, either towed by the mining ship or self-propelled, moving on chains. This assumption still seems to be the most probable. A design that moves the vehicle by two Archimedes screws and disturbs the sediment in two broad tracks more than 1 m deep seems to have no future, particularly in view of the environmental aspects. The vehicle envisaged for mining would move along the seafloor with a speed of about 1 m per second. This hybrid collector (combining mechanical and hydrodynamic principles for nodule take-up) would be 6 m or more in width and would gather nodules from the sediment surface layer by mechanical means and with the help of water jets[10]. An unknown percentage of the watery surface sediment, the semi-liquid layer, would be whirled up and partly entrapped during the collection process along with the nodules. Deeper sediment layers may be broken up into lumps, which would be transported in a conveyor-belt collection system. The vehicle, right behind and supporting the collector, would move with tank-like tracks along the seafloor, certainly penetrating the semi-liquid layer and most probably the upper stiff sediment layer. At least the track spines would penetrate this harder material and would break it up into lumps of various sizes. Behind the vehicle a disturbed field would remain, uneven due to an irregular distribution of the sediment lumps[11] and to some extent with aggregated sediment particles filling in the gaps and valleys between the lumps. Some of the sediment would also drift away, blanketing nearby regions[12].

For effective mining, the vehicle would meander up and down a mining block along roughly parallel tracks, probably leaving some small patches unmined. However, these should receive a strong cover from resedimentation of the plume, depending upon ambient current velocity and direction. We predicted that a typical mining block, covering between 10 and 100 square kilometres, would be nearly totally mined out, leaving only some small unmined but sediment-blanketed patches. These assumptions, upon which the DISCOL experiment was based, are still valid today.

1.2. Disturber and disturbance scheme

A disturber system had to be designed that would be able to:

?? Create disturbances similar to the assumed mining effects and

?? Remove the nodules from the sediment surface.

The design became the so-called “plough-harrow”[13], an 8-m wide system with small ploughs (two-sided shears, 35 cm) extending outward on both sides of the harrow to assure a ploughing effect on the seafloor irrespective of which side of the device engaged the sediment. Although this design is very different from any contemplated nodule mining system, it was suitable for purposes of this experiment and the effects achieved with this disturber seemed to be not too distant from our mining-effect assumptions:

?? Almost all nodules were removed from the sediment surface and buried in the plough tracks.

?? The sediment structure in the surface layer of the plough-harrow tracks became a patchy mosaic of clods from the harder, deeper sediment and soft, partly resettled material from the semi-liquid layer.

?? Alongside the tracks, untouched areas were blanketed by sediment.

Together with the similarity achieved, there is one dissimilarity of importance for the evaluation of the experiment: The circular DEA, two nautical miles in diameter, probably became entirely disturbed, but only about 20% of the circular field was directly ploughed, while the larger part received a sediment blanket up to 30 millimetres thick[14]

The disturbance effects were verified by photographic and video imaging[15]. The deeper, lighter, grey sediment ploughed up in clods was visible on the sediment surface between the dark brown material from the semi-liquid layer, and was still discernible after seven years[16]. Heavy resedimentation was indicated on some sediment-core X-ray images showing a dense sediment cover capping nodules and coating some of the holothurian megafauna. The resettled sediment blanket, however, could not be distinguished from the original surface sediment in photographic images and in most box- and multiple-corer sediment cores.

The idea of disturbing a circular area with radial disturbance tracks resulted in an expected difference between heavily disturbed central and less disturbed peripheral regions. The DEA was crossed 78 times with the plough-harrow, starting from various directions, dependent on the local wind field and surface currents. With this scheme, we were not able to achieve continuous disturbance of a large area (see above). In retrospect, it would have been more promising to choose a rectangular area for such study and tow the plough-harrow on numerous parallel tracks.

1.3. Sampling design

To arrive at a sampling scheme, the DEA was partitioned into eight sectors and three circular sub-areas, resulting in a central part with a diameter of 1000 m and a peripheral ring area with a width of 750 m, separated by another ring area of 500-m width which was not sampled (see figure 1).

For detecting differences in disturbance intensities, we assumed that five central and five peripheral stations would be sufficient. The sector fields were selected randomly from the eight possibilities available. During each cruise, one multiple-corer sample was collected for the study of meiofauna and three box-corer samples were gathered for investigating the abundance of macrofauna. Reference samples were collected 2 nautical miles up current from the DEA.

This sampling design appeared to be appropriate at the beginning of DISCOL, but initial species and abundance data demonstrated that the number of samples was too low. Additionally, throughout the study it was difficult to recognize disturbed samples when the degree of disturbance was not particularly heavy. Mounting cameras to the corers and imaging the seafloor just before bottom contact became a helpful method, but this was still a blind search for disturbed areas. Adding video control to the sampling systems during the last post-impact study allowed us to search and sample the disturbed areas successfully. Thus, the limitations introduced by the radial and non-continuous heavy disturbance created difficulties in unequivocal sampling of disturbed areas.

The macrofauna was defined to be larger than 500 microns during the first cruise, but we realized that this would not be sufficient for evaluation of this faunal component. During later cruises, sieves with 250-µm meshes were employed, limiting overall data comparability. Such errors could have been avoided with a separate pre-impact cruise into this specific area.

1.4. Sampling sequence

During the preparation phase for DISCOL, no information or prior experience was available on which we could base a suitable time sequence for revisiting and resampling the DEA. It is known that processes in the deep sea are slow, while recolonisation in shallow waters may be a matter of months. Small-scale experiments with defaunated sediments in the deep sea[17] have demonstrated the existence of opportunistic species and their fast colonisation potential in those small (less than 1 m^2) experimental sediment patches, but reestablishment of a community with natural successional changes appears to be a process extending over several years. Experimental and commercial large-scale disturbances will certainly last more than a decade.

Early in the planning process, we decided to return to the DEA after several months, and again after several years. The sampling schedule achieved was determined not only by scientific considerations, but also by ship-time availability (table 1).

Year No.	Year	Phase
0	1989	Baseline study
0	1989	Disturbance
0	1989	1st post-impact study
0.5	1989	2nd post-impact study
3	1992	3rd post-impact study
7	1996	4th post-impact study

Table 1 DISCOL/ATESEPP study phases.

Seasonal and interannual production and sedimentation cycles may be of significance in scheduling such long-term ecological studies. Only the second post-impact study is out of seasonal phase (September) with the three other cruises that occurred from January to March, with the main sampling periods during February.

However, the DEA, situated on the outskirts of a German mining claim, may be influenced by interannual variation in organic matter supply due to upwelling intensities off the coast of Peru and Chile, although it is 600 nautical miles from the coast. It is known today that fast-sinking aggregates of organic matter reach the deep seafloor within about six weeks, and they can create seasonal cycles even in high-oceanic regions[18]. An experiment like DISCOL should probably have been conducted in an oceanic polymetallic nodule region with relatively high predictability of production cycles.

1.5. Equipment used during DISCOL/ECOBENT

The benthos was sampled with the standard equipment previously used in other deep-sea studies in the Atlantic Ocean[19].

1.5.1. Megafauna

For the collection of megafauna an epibenthic trawl was employed twice. The trawl was equipped with 0.3-m wide skids alongside the 2.3-m broad opening of the net. The sediment in the DEA has a high water content and the skids sank into it, possibly gliding on the large manganese nodules. The trawl collected many of the large nodules (up to 13 cm in diameter).

Abrasion with nodules usually destroyed the fauna; therefore, further trawling was abandoned, in the knowledge that this would result in a gap of information desired for both its intrinsic value and for the determination of species.

1.5.1.1. Ocean Floor Observation System (OFOS)

1.5.1.1.1. General description

The Ocean Floor Observation System, built by Preussag Marine Technology, consists of an onboard unit and an underwater unit. By means of the onboard unit, different functions of the underwater unit can be controlled, and warning lamps indicate malfunctions, e.g. empty batteries or interruption of the data-transmission line. The underwater unit is a metal frame containing batteries, television and photographic cameras, lamps, flashes and a navigation transponder. The instrument is towed a few metres above the seafloor.

1.5.1.1.2. Photo system

The underwater flashes are activated by turning on the corresponding switches. Two control lamps serve as charging controls for the flashes. The red "Wait" lamp indicates that the flashes are being charged and the green "Ready" lamp is on when the flashes are ready for the next underwater photograph. Premature release of the flashes is possible, but then the flash energy is lower and consequently the photograph is darker. The flashes are released by pressing the "Actuate" button or using the hand-held trigger. A counter on the onboard unit shows the number of frames taken at a station or along a profile. Up to 800 exposures can be made during one operation, before the battery package has to be recharged and the camera reloaded. The lower left corner of each frame contains additional information on the distance to the bottom and the time the photograph was taken. Colour slides can be developed aboard the ship, employing the E6 process, and are available for evaluation only a few hours after the end of operation. The film used was Kodak Ektachrome 200 Professional.

1.5.1.1.3. TV system

Four spotlights and two floodlights are installed in the instrument housing of the underwater unit. They can be switched on and off separately, and the brightness can be varied by adjusting the dimmer buttons on the onboard unit so that optimum visibility of the deep-sea floor can be achieved on line. An underwater TV camera operating at low light levels transmits the black and white video signals via coaxial deep-sea cable to the laboratory onboard the ship, where all events are logged. Simultaneously, the video signals plus additional information (e. g. station number, date and time) can be inserted on a monitor and recorded on a VHS videotape recorder.

1.5.1.1.4. Navigation system

Horizontal distance and angle between ship and instrument housing are calculated by means of the Honeywell RS904 system so that the ship's track and the track of the towed underwater unit can be plotted on a chart. The ship's position is computed from satellite navigation (SatNav and/or Global Positioning System [GPS]) or from transponder navigation.

1.5.1.1.5. Data log

For each of the OFOS stations a separate data sheet was filled in. These sheets contain all essential data on the corresponding stations, e. g. cruise number, station number, date, names of the responsible operators, start and end of operation, functioning of lamps and flashes, number of photographs, time of videotape recording, time of visual seafloor observation, start of lowering and end of hoisting, and a summary of specific aims and/or noteworthy remarks.

1.5.1.2. Freefall Benthos Observation System (FBOS)

The Freefall Benthos Observation System is a stainless steel 2-m high tetrapod with 35-mm Benthos survey camera, strobe, battery pack, data chamber encoder, tandem-release transponders and glass vacuum spheres for buoyancy. The ballast weight (a railroad wheel) was placed below the tetrapod frame (figure 3). The camera was equipped with 30 to 90 m film length for 800-2400 pictures.

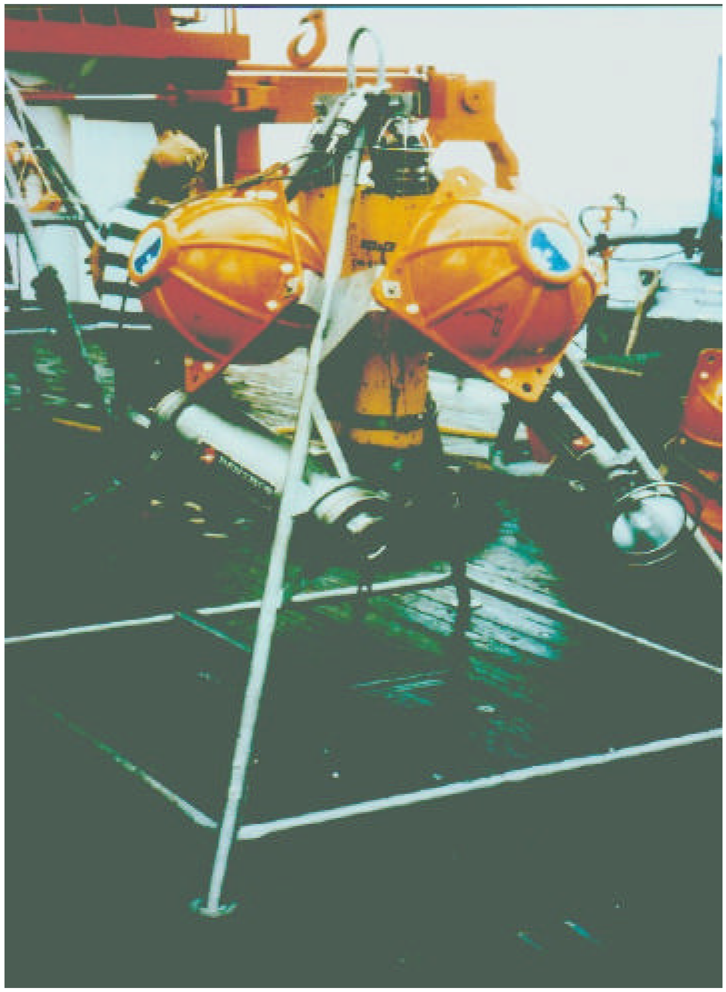

Figure 3 Free-Fall Benthos Observation System (FBOS).

After two deployments, the tetrapod was rigged with a pole, to which a fish had been attached within the still camera's field of view. Later the fish was put into a clear plastic trap to catch additional fish and crabs, and to learn about the behaviour of the organisms attracted to the bait.

1.5.1.3. Baited traps

The baited traps were made from plastic tubing 0.8 m long with an inner diameter of 0.3 m. Each trap consisted of two parts held together by a stainless steel collar with three hooks for easy opening and emptying of the caught animals. The traps were set at 100, 50, 30, 20, 10 and 5 m above the bottom, and one trap was mounted immediately above the bottom weight. For ballast-weight release, two tandem transponders were arranged in a metal frame support and connected with a chain looped through the release weight. To observe what species were attracted to the bait, dead fish were mounted in front of the FBOS camera system. In some cases, the bait was placed in a transparent trap made from a multiple-corer tube to learn about the behaviour of species at the traps and to test whether all species were captured equally well.

1.5.2. Macrofauna

For quantitative sampling of macrofauna, an USNEL box corer (figure 4) was used. The sampling area was 50 by 50 cm and several modifications were made. During the last cruise, the box corer was equipped with an online video system that allowed exact sampling of disturbed areas within the DEA.

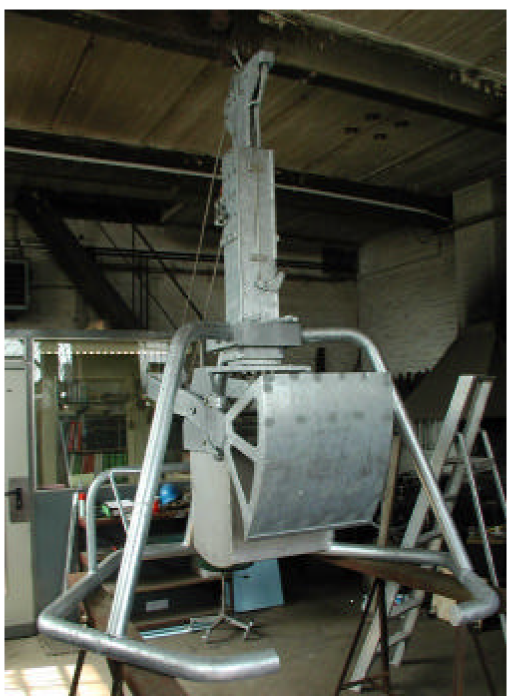

Figure 4 The USNEL box corer.

1.5.3. Meiofauna

Samples of meiofauna and bacteria, and for the determination of chemical components, were collected with a multiple corer[20] that deviated from the original type with its 12 narrower tubes. We modified the collection head to carry only 8 tubes (figure 5) with an inner diameter of 9.5 cm, i. e. 70.8 cm^2. This was thought necessary to increase the chance of coring undisturbed samples in a manganese nodule field. Only rarely was the coverage of polymetallic nodules so high that the core tubes were prevented from entering the sediment. Penetration of the tubes was 35-40 cm (core liner length 62 cm) and the water trapped above the sediment core remained clear in almost all instances.

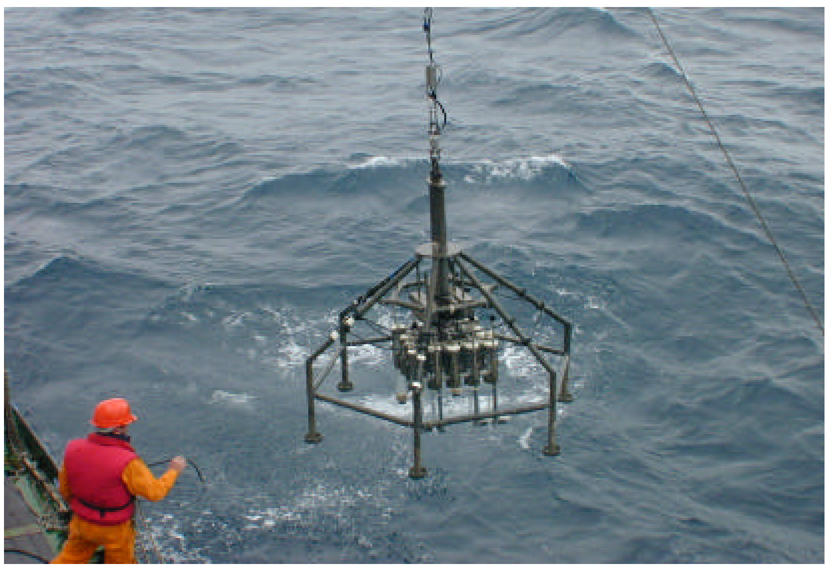

Figure 5 The multiple corer.

1.6. Sampling and processing of macrofauna

Macrofauna samples were collected with a 0.25-m^2 box corer during four cruises with RV *Sonne*. In the DISCOL programme, randomly chosen localities in the DEA were sampled during each expedition[21]. Because the plough tracks covered only parts of the DEA, only a small proportion of the DISCOL samples were obtained from the tracks ("disturbed" samples), while the majority of samples were obtained from between track areas ("undisturbed" samples). During ECOBENT, the sampling therefore concentrated on locations with considerable plough-track accumulations (identified from sidescan sonar mapping) instead of repeating the extensive DISCOL sampling pattern. Samples showing clear evidence of the plough impact (e.g., uneven surface, lack of the semi-liquid top layer, exposed lighter-coloured sediment originating from deeper layers) on at least parts of their surfaces were categorized as "disturbed". In samples from the areas between the plough tracks, the entire top sediment layer was smooth and semi-liquid. These samples were assigned to the "undisturbed" group[22]. Note that the disturbed samples included only disturbances caused directly by the ploughing in February 1989, not by artefacts that might have been created during the sampling procedure or later. Comparison of the sample surfaces with in-situ photographs of the seabed, taken with Preussag FBK 135 cameras during the sampling procedure, ensured clear categorization of the samples. During ECOBENT, a video camera mounted on the box-corer frame allowed additional in situ observation of the seabed and specific sampling of the plough tracks.

2. Effects on Fauna

2.1. Limits of predictability

The limited knowledge of the ecology of the deep-sea fauna, species densities and distributions, taxonomy, and genetic relationships within and between populations narrows the possibilities of predicting effects on the fauna. This is specifically true for the genetic impoverishment of populations and the loss of species that could make a case against deep-sea mining. Although ploughing the deep seafloor in the DISCOL project created impact configurations comparable to those expected from the miner, differences remain between the two types of disturbances that do not justify full extrapolation. Sediment compression, squeezing and the mobilization of the nodules by water jets were not simulated. However, these actions are likely to have negative influences on the fauna.

The DISCOL experiment investigated biocoenotic effects of physical disturbance; however, these cannot be related to single geochemical or sediment-structure alterations. Long-term shifts in the redox system and in shear strength of the upper sediment layer cannot be evaluated for their effects on the fauna.

Blanketing of sediment, nodules and fauna occurred in large areas, however, presumably in sub-lethal thickness. During post-impact studies, those effects were not adequately recorded. The benthic impact experiments (BIEs) of the United States, Japan (Japan Deep-Sea Impact Experiment [JET]), the Interoceanmetal Joint Organization (IOM) and India (Indian Deep-sea Environment Experiment [INDEX]) have so far not supplied suitable answers. It is not clear whether blanketing generally or a specific thickness of resedimentation results in the death of animals.

When attempting to make general statements on the effects of mining it is also important to remember that the total area experimentally impacted and the impact density within the area have not reached the extent expected in commercial mining. It also remains impossible to predict either the extent of impact when single mining units are combined into areas of up to 100 km^2 or the length of time benthic communities will require to regain their balance.

2.2. Effects

The fauna of the deep seafloor inhabits strata that will be the most impacted by nodule uptake. Most of the animals live on or in the semi-liquid layer or constitute the epifauna of the nodule surfaces protruding from the sediment into the water. This component of the fauna will be totally exported and destroyed unless at least a few nodules remain in place. Techniques for steering the miner, however, are so far advanced that almost the total area will be cleared. Should small plots remain unmined between the miner tracks, sediment may be shifted over them or they will probably be blanketed during the follow-up passes by the miner. The fauna inhabiting the hard substrate are likely to be destroyed. Most of the epifauna is bound to the nodule surface. Higher taxa found exclusively on nodules are the Bryozoa and the Brachiopoda. Other taxa having many species that rely on the nodules are the Xenophyophoria, Porifera, Polychaeta and Nematoda. For these species the environmental alteration caused by mining is irreversible in terms of human time scales, because nodule growth takes place over the span of a million years for a few millimetres of precipitation.

Whereas some demersal fish species, shrimps and swimming holothurians may be able to escape the miner system, towed at about 1 m/second, all other sediment-living fauna will be subjected to the mining process along with the nodules and the sediment. Faunal components whirled up into the plume may resettle and survive the immediate impacts. However, others may be damaged by the water jets or by their transport through the miner. Small individuals with a relatively stable cuticula, e.g. some nematodes, may pass through the system alive.

The hypothesis of the survival of some faunal components cannot be verified. The effects of the DISCOL ploughing, although much less intensive than during future commercial mining, allow the assumption that some animals should survive the mining torture. However, the community will be so extensively diminished that many species will have lost their food sources, and secondary mortality is likely, probably only after days or weeks. The same effect is likely to result from the destruction of the top few millimetres of the surface layer, where organic matter and feeding activities concentrate under natural conditions.

For the follow-up development of a new community, or rather the succession leading to a new community, observations are available from the DISCOL and ATESEPP studies, which made their final post-impact visit to the experimental area seven years after the ploughing. As in the case of the abovementioned BIEs, the fauna was not killed quantitatively.

For the mega- and macrofauna, it can be assumed that species recolonisation will occur by migration from the surrounding unimpacted areas. Larval transport with the currents and larval settlement will also supply new inhabitants, but permanent survival and metamorphosis from larva to juvenile will depend on the food source and a delicate balance of biotic and abiotic conditions. Scavengers, living on dead organic matter and bacteria, may have the best chance for settlement. The establishment of a stable population again depends on food sources and densities sufficient to assure sexual reproduction. Due to these various fine-tuned balances between community components and abiotic conditions, and because of the generally low pace of life at abyssal depths, the successional reestablishment of the fauna will take decades.

For the meiofauna without planktonic larval stages, the colonisation of free habitats is an even more time-consuming process. Directional migration is very slow, because individual ambits are small (on a scale of centimetres or decimetres) and merely result in a shift of populations. The passive drift of adult specimens may occur when currents result in erosion. However, even speeds of 10 cm/sec were rarely measured in the experimental area in the southeast Pacific and only for short periods[23].

DISCOL provided a few observations on the slow development of the faunal stock. Seven years after the experimental impact, community structure was still disturbed, as shown mainly by the irregular distribution of species and the differences in diversity patterns (figure 7), e.g. for polychaetes[24]. The megafauna has not re-established its original densities after this interval (figure 6).

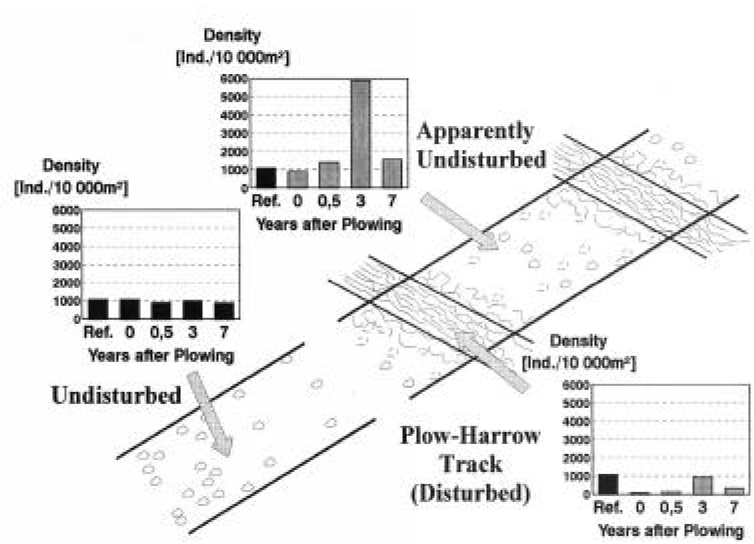

Fig. 6 Megafauna abundance change during DISCOL/ATESEPP[25].

When evaluating the effects of deep-sea mining the larger areas to be impacted and the higher impact intensity need to be considered. The topography of the seafloor, with its strong depth gradients and steep escarpments, is unsuitable for mining, and the heavy equipment will not touch areas with low nodule densities. Qualified plot sizes fall in the range of 20-100 km^2; the direct mining influences, however, will reach beyond these limits. Regions of similar or even larger size will remain between the mining plots, probably unimpacted except for resedimentation from the mining plume. They should serve as sources for the immigration of adult specimens and for the production of larvae.

It is correct to assume that recolonisation of species takes place over (long) periods and that the reestablishment of a balanced community will occur. This community, however, will be differently structured from the one existing before the nodules were mined. The epifauna has no chance to recover (see above) and the community is likely to resemble the soft-sediment fauna as it used to live between the nodules. Any interaction between the hard- and soft-bottom faunal components will have terminated at these localities, and this may affect the soft-bottom community permanently. Influences on the fauna and its composition due to the mosaic sediment structure of soft and more consolidated sediments are not known.

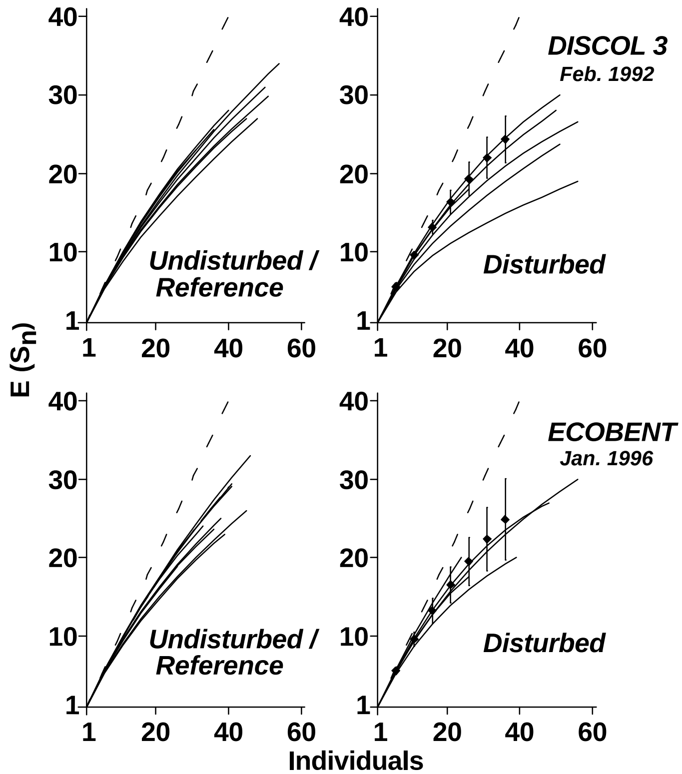

Figure 7 Hurlbert rarefaction curves for polychaete species richness of single box-core samples during DISCOL 3 and ECOBENT on the basis of 108 "species" (larger than 500 µm, 0-10-cm sediment depth). The dotted curves in the disturbed sections are the calculated means (with 95% confidence limits) for the undisturbed/reference groups of the respective expedition. The hatched lines represent theoretical maximum diversity[26]).

3. What did we learn from DISCOL?

3.1. Restrictions, number of samples and processing efforts

A critical point of a proposed experimental design is that the samples will be segregated in different physical locations and that it is impossible to randomise and intersperse samples receiving different treatment. Disregard of randomisation and interspersion results in uncontrolled conditions in an experimental design because differences between the localities of two samples may already have existed before the experiment. This may result in unrecognised locality effects that would bias the treatment effects. Such a design can lead to misinterpretation of the results and would be regarded as pseudoreplication[27].

Although interspersion in both impacted and unimpacted areas certainly would be preferred, this feature is difficult to achieve in the type of large-scale experiments we propose. The DISCOL experiment demonstrated that true replication could not be achieved within the experimental field because it was impossible to designate sub-areas not affected by resettlement of resuspended material that could serve as truly unimpacted control sites. Reliable interspersion of treatments would thus require a number of spatially well-separated experimental locations (at least four[28]) plus a corresponding number of reference areas. The resultant effort, both at sea and during data analyses over the entire programme, would be many times greater than under the proposed scheme and would go far beyond any reasonable or practical limits.

In the present case, there is only a limited risk of biasing effects due to the pre-existence or later intrusion of differences between locations, because of the relative homogeneity of deep ocean basin environments. The proposed treatment area of approximately 2 nmi^2 is relatively large, and dispersion of samples over that area should compensate for the potential of pseudoreplication. Accordingly, care should also be taken to have similar inter-sample distances at the two reference sites. However, a certain environmental variability within the entire proposed target area cannot be excluded a priori and should be properly evaluated in the pre-baseline and baseline studies. It is obvious that data analyses and interpretations of these studies must be completed before the start of the experiment, because they constitute the basis for selection of the three experimental and reference localities (out of five baseline localities), which should be as similar as possible.

Different methods have been proposed for the calculation of suitable sample-area sizes for given taxonomic compositions. Elliot's test for sampling efficiency[29] has already been used in deep-sea ecological studies[30]. This method calculates the number of sampling units necessary for representative collections of single taxa based on their densities and distributions in the samples. The test requires sufficient numbers of baseline samples and can serve to determine suitable reductions of sampling and sorting efforts in later collections. Appropriate sampling efficiencies can also be achieved by sampling the "minimal area" in the sense of Weinberg[31] and Pfeifer *et al.*[32], which is regarded as the "smallest" observation area for representative collections of the most abundant species or higher taxa. The approach of Pfeifer *et al.* calculates the minimal area for entire species or higher taxa compositions. By eliminating rare taxa from the analyses, it can be used for the identification of those taxa compositions that meet the minimal area requirements in a given collection of samples. Depending on the taxonomic level, this method does not necessarily require large sample numbers. However, it can help to prevent a priori exclusion of certain taxa that may gain statistical importance.

To obtain initial information about faunal composition and oceanographic data in a future large-scale environmental impact experimental area, and to be able to calculate the minimal area for the required number of samples, we suggest that a pre-baseline study be conducted. The numbers of photographs, videotapes and samples of the various organism size classes will require a long evaluation period, judging from our experience employing well-trained technicians and students (table 4). Certainly, one year is not sufficient for these tedious analyses, and the pre-impact study, experimental disturbance and post-impact study should follow in the third year according to the following scheme:

Year No.	Study phase
0	Pre-baseline study
1	Baseline study
3	Pre-impact study
3	Disturbance
3	1st post-impact study
4	2nd post-impact study
6	3rd post-impact study
8	4th post-impact study
10	5th post-impact study
12	Delivery of final report

Table 2 Proposed phases for a large-scale environmental impact experiment

The low density of animals in the deep sea precludes the sampling of specimens from many higher taxa sufficient for statistical analyses. To limit the time required for analyses, those taxa from which many specimens may be gathered with moderate effort[33] deserve special attention. In the DISCOL/ATESEPP project, it was decided to concentrate on:

- Megafauna: higher taxa;
- Macrofauna: total and Polychaeta on species and higher taxa level; and
- Meiofauna: Nematoda and Harpacticoidea on genus level.

These are the most abundant taxa in the deep sea and, together with the Foraminifera, should also be suitable candidates for later environmental assessment.

At the study sites of the DISCOL/ATESEPP project, a minimal area of approximately 10,000 m^2 to be recorded by video imaging was calculated for the most abundant higher megafaunal taxa[34] and for Holothuroidea, the most important taxon within the megafauna[35]. With respect to the macrofauna, minimal areas calculated for a selection of the most abundant higher taxa (Polychaeta, Tanaidacea, Isopoda, Cumacea, Bivalvia, Gastropoda, Scaphopoda, Echinoidea and Ophiuroidea) ranged from 0.5-1.5 m^2 of undisturbed seabed (equal to 2-6 box-core samples of 0.25-m^2 surface area) in the sample series of various expeditions to the DISCOL area[36]. As for the Polychaeta, minimal areas were calculated to be 0.8-1.7 m^2 of undisturbed seafloor for the 18 most abundant families and 0.9-1.7 m^2 for a selection of the 14 more abundant species.

Evaluation of the megafauna data confirmed that no true replicates were sampled[37]. Instead of single long photo/video transects, at least five shorter deployments of equal length should be planned for future megafauna studies to ensure statistical validity.

The number of eight box-core samples per station (i. e. 2 m^2) proposed for macrofauna analyses in environmental deep-sea studies lies beyond the minimal area calculations in the DISCOL/ATESEPP programme and leaves space for lower animal abundances in other deep-sea areas. It becomes evident that eight such samples should be sufficient even for analyses at the macrofaunal species level.

For the 12 most abundant families of Harpacticoida (selected from a total of 19 families), the minimal areas ranged between 142 and 355 cm^2 over the various DISCOL studies and stations. This is equivalent to two to five core samples with the 71-cm^2 tubes of the multiple corer[38] as shown in table 3. For nematodes, the area of five 71-cm^2 core samples was sufficiently large to meet the minimal requirements for the most abundant 43 and 38 out of a total of 68 nematode genera in undisturbed and disturbed sediments, respectively.

Baseline study	Towed video-photo system including side-scan sonar	5 x 5 transects, 2 nmi
	Box corer	5 x 8 samples
	Multiple corer	5 x 8 samples
	Trawl	3 deployments
Post-impact studies	Towed video-photo system including side-scan sonar	3 x 5 transects, 2 nmi
	Box corer	3 x 8 samples
	Multiple corer	3 x 8 samples

Table 3 *Imaging and sampling tasks during the baseline and post-impact studies.*

Further reduction of effort can be gained in meiofauna work by restricting sample sorting to the upper 3 cm of the sediment column. Previous studies[39] have demonstrated that more than 90% of the individuals of this size group live in the upper 3 cm of this sediment layer. Sorting of deeper horizons would not add much to the information already available.

The sampling scheme as proposed in table 4 suggests a smaller number of samples for the post-impact studies than for the baseline study because two of the five explored sites will be excluded from further investigations. Depending on the faunal composition and densities at a given site, and according to the target taxa selected and the respective minimal area requirements calculated from the baseline data, it is recommended that the scope for additional reduction of sample numbers and evaluation efforts in the post-impact studies be considered. Data from a previous cruise should be fully available before the subsequent one.

The time calculations given in table 4 are restricted to sample sorting and limited taxonomic analyses at genus level, but exclude all of the following tasks:

?? The total pre-baseline study,
?? All work at sea,
?? Data analyses,
?? Consideration of the Foraminifera,
?? Sedimentological and geochemical studies,
?? Project co-ordination,
?? Training of technical staff, and
?? Reporting and publication.

	Hours	**Per**	**Samples**
Megafauna	65	Nmi	Video and still recorded images
Macrofauna (>250 µm) includes processing of Polychaeta at family /important species level	90	Box corer	1/4 m² x 10cm
Meiofauna (>63 µm) includes processing of Nematoda and Harpacticoida at genus level	200	Tube of multiple corer	71cm² x 3 cm

Table 4 Calculation of minimum time required for biological sample and image processing.

The above calculation of work time is included in this paper because most projects -- including the DISCOL/ATESEPP investigations – eventually run short of time and funds, ultimately endangering some of the results hoped for or anticipated.

The calculations presented in the preceding paragraphs are based on the material and experience available from DISCOL/ATESEPP; thus, the recommendations on sample numbers are suitable only for this specific area in the southeast Pacific Ocean. Other studies need to calculate their own site-specific figures during the first phases of the project to make sure that enough samples are collected during the experimental phase. Nevertheless, the DISCOL/ATESEPP results indicate the approximate levels of effort required to be acceptable, and may serve as a preliminary order of magnitude for the planning phase and the submission of proposals for similar studies in the deep sea.

Additionally, one result from our investigation was that for the first time we established that recovery of such a large disturbed area had occurred and the recovery process was scientifically investigated. This result was contrary to most previous assumptions. According to these results, based on our experiment and on its scale, which was much smaller than possible impacts created by future mining, there should probably be no objections against mining.

4. Recommendations for the Standardization of Methods

We learnt during all our expeditions that it is very important not to alter any method during the course of sampling, even over years and when better methods become available, because otherwise you cannot compare your data. For sampling and analysis of benthos macrofauna and sediment, we recommend the following methods and procedures as applied during DISCOL/ECOBENT:

4.1. Gear for sampling macrofauna

USNEL box corer with a sampling area of 2500 cm².

Very important: After sampling, the top plates above the sampling area need to be closed very tight – take care to ensure good seals. The spade should have a seal as well so that the box is also very tightly closed at the bottom.

4.2. Sampling procedure

Depending on the capabilities of speed control for hoisting and lowering the winch, the box corer should touch the sea bottom at a speed of 0.3-0.5 m/sec. Use 0.3 m/sec only when the sea is absolutely calm. You can send down the box corer rapidly but you should reduce the speed before hitting the bottom. Several protocols have been published which can be applied. Please remember that they have to be adjusted, e.g. to the ships manoeuvrability.

4.3. Size of the sampling area

You have to sample the total 2500-cm² area of the box corer. Otherwise, you will have problems in complying with standard statistical requirements.

4.4. Sediment horizons

Suck up the top water with a flexible hose and sieve it with a 250-µm mesh. Any remaining water should be sucked up with, e.g., a turkey baster and passed through the same 250-µm mesh size used for the top water. Store this sample in a separate labelled container.

Three sediment horizons should then be separated, as follows:

a. Top sediment layer – depending on the sediment properties, take off the top 1-2 cm;

b. 1-5 cm (2-5 cm) horizon, and

c. 5-10 cm horizon.

Measure with a ruler from the upper sediment edges for b and c. Use a spoon or ladle to remove the sediment from the box carefully.

4.5. Mesh sizes of sieves

Use only 250-µm mesh-size sieves for all sediment horizons. In case you need different size classes, you can again sieve the residue from the 250-µm sieving according to your requirements. From our experience, we learned that 500 µm is too large and resulted in a loss of about 45% of the macrofauna[40].

4.6. Sediment treatment during sieving

Use a good stainless steel table for a proper stand, and filtered seawater. Use filters with changeable pore size so that they can be employed also for meiofauna or plankton samples. Macrofauna samples should be treated with a lot of water under low pressure, so use a large-diameter hose with some means of regulating the water pressure, perhaps with a valve. Most of the fauna, especially the polychaetes, are delicate and easily destroyed; so avoid a high-pressure stream that will break them during sieving.

Sieve immediately after recovering the samples; do not store them for long, even in a cool room. Macrofauna should be fixed with 4% buffered formalin in seawater. About 5-7 days later, change the fixative to 70% alcohol to prevent the destruction of calcareous shells, e.g. of molluscs.

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PRESENTATION AND DISCUSSION ON SEAFLOOR MACROFAUNA IN POTENTIAL MINING AREAS

Dr. Gerd Schriever described the German DISCOL/ECOBENT project in the southeast Pacific Ocean (1989-1996), discussing what had been learned as well as the sampling gear and procedures used. In addition, citing the final report on the investigation, he summarized suggestions and recommendations for another large-scale project in the same area, although he acknowledged that no follow-up study was expected.

History

The DISCOL project had been initiated by the German Ministry of Science and Technology in 1985, and it was to have been combined with a collector test in 1989, but that had been postponed. The aim had been to create an impact that could be compared to what a manganese nodule miner would create on the sediment surface in the deep sea. A political decision had been taken to conduct this experiment in the South Pacific, off the coast of Peru, at about 88 degrees west longitude and 7° south latitude. The researchers had divided the area into 10 pie-shaped segments and a peripheral zone. The central part occupied about 11 square kilometres and had a diameter of about 2 nautical miles. They had conducted four cruises through the area over the course of the project. As they knew little about the area at the start, they had carried out a SeaBeam survey to gather information about the topography and currents. They had decided to work at a location close to the German manganese nodule claim area, in a flat region with nodule coverage of about 5 to 10 kilograms/m² -- probably the lowest coverage suitable for commercial mining. They had chosen a low-coverage area for reasons related to the sampling equipment used. In an initial survey, they had located an appropriate area for baseline studies.

The name DISCOL -- derived from "disturbance and recolonisation experiment in a manganese nodule area of the deep South Pacific", had been funded by the Ministry of Science and Technology from June 1988 to December 1993. The fourth cruise had been called ECOBENT, short for "ecological investigation of the abyssal benthos of the deep South Pacific". The name had been changed because of funding regulations in Germany, where ministries did not finance projects longer than five years. The researchers were doing the same work as before but under a different name.

The 1996 investigations had been broader because geochemists, soil engineers and geologists had jumped in. ECOBENT's focus had been on station number 2, the DISCOL station. The researchers had chosen five stations in the peripheral area and another five at random in the central area.

Operations and findings

The SeaBeam survey in 1989 had shown a small hill in the north and a flat area in the south where the researchers had chosen the DISCOL area, at a mean water depth of 4140-4160 m. The standard gear included a multiple corer, a modified USNEL box corer, baited traps to get information about organisms migrating between the seabed and the water column up to 200 m above the seafloor, and a still photographic camera system called the Freefall Benthos Observation System (FBOS) to obtain information on migrating and demersal fish. This system, equipped with a back-up camera, had also housed small baited traps in front of the camera, permitting the researchers to spot unknown species.

The manganese nodules in the area had a cauliflower shape composed of many different small sub-nodules that differed from most of the nodules in the Clarion-Clipperton Fracture Zone (CCFZ). They had crevices and holes with a lot of mud inside. When this material was washed, special meiofauna had been found living within the nodules.

The researchers next had to think about how to produce an impact. They had always emphasized that they were unable to simulate mining because they did not have a miner and were unable to collect the nodules on the surface, but they had wanted to create a comparable impact. One September day, while Dr. Schriever and Professor Hjalmar Thiel had been motoring through the countryside seeing farmers plough their fields, the idea had struck them that they could do it the same way. They had wanted to get rid of the nodules from the bottom surface, so they thought of ploughing them under. They had then developed an instrument with ploughs on both sides of a frame, shaped like the big iron spheres that were used in fisheries. The entire device, 8 m wide and 2 m long, had been towed over the sea bottom. As both sides of the frame had been equipped with ploughs, it did not matter on which side it arrived at the sea bottom.

They had crossed the area 78 times. They had expected to find a more impacted area in the centre and a less impacted area in the peripheral grid. They had used the sidescan sonar system with a weight and camera, which had been towed about 3-5 m above the bottom to get images of the area behind the sonar device. A still camera and an online video camera, making up the Ocean Floor Observation System (OFOS), had also been towed over the area. They had regulated the impacts because the equipment had had to be picked up after about 10-12 runs to replace the ploughs. In the intervening periods, OFOS had been used to observe the impact and see whether the plough-harrow had been working properly. The impact had destroyed the top 10-15 centimetres of the sediment. Photographs showed that the nodules had been totally removed, leaving white calcareous structures that had been lying about 15 cm deep in the sediment. No organisms were visible on the sediment surface.

X-ray examination of multiple-corer tubes from the various stations showed differences in the resedimentation rate, which had been up to 2 cm at the station centre southwest and less than 1 millimetre at the centre northwest. These had been at different elevations. At 3 nmi north from the centre of the investigation area, in the direction of the main water current, the researchers had not been able to detect any resedimentation. Other benthic impact experiments (BIEs) had similarly observed that the sediment from the impact cloud had resettled faster than originally expected.

The researchers had carried out their investigations over the seven years following the impact in 1996. The first post-impact sampling had been done immediately after ploughing, the second half a year later, and the others three and seven years afterwards, respectively. During this entire time, the impacted area had been clearly visible in photographs and within the samples, although the structure of the plough-harrow tracks had become smoother, probably because of the water currents and the uptake of water into the sediment, which was harder than the top layer. Seven years after the impact, the sediment was still thoroughly disturbed and shear strength in the impacted area was low.

To observe the megafauna, OFOS had been towed over the area several times. The researchers had divided the area into reference zones, which had been completely undisturbed; the plough-harrow tracks, which they had called the disturbed area, and the area between the tracks, which they had called the "apparently undisturbed area". During the entire time, there had been no significant change in the density of individuals in the undisturbed area, whereas in the plough-harrow tracks there had been a decrease immediately after the impact. In the "apparently undisturbed area", the impact had been less, apparent only in the resedimentation, which had been partly visible and partly invisible. In total, they had disturbed about 24-25% of the total area, so that the "apparently undisturbed area" constituted a major portion. A steep increase in megafauna had been recorded in 1992, three years after the ploughing. There had also been an increase in nematodes and macrofauna that year. They still had no explanation for these population rises. There might have been a seasonal input of organic matter from the surface, originating in coastal waters off Peru, though that was 600 nmi away.

In analysing the macrofauna, the focus had been on polychaetes. Working with polychaetes was difficult; while this was also true for nematodes and harpacticoid copepods, the polychaetes needed special treatment because they were delicate and had to be sieved carefully. Data from the first two cruises showed a large standard deviation because the researcher, Christian Borowski, had used only 500 cm^2 of the box corer, sieving this through a 250-micron mesh, before the researchers had learned that they had to use the total area. An increase had been recorded in 1992 compared to 1989. Seven years after the disturbance, the rarefaction curves indicated that there were still differences in the polychaete community between the undisturbed reference area and the disturbed area.

The meiofauna had reacted immediately after the impact as well. The number of nematodes within the impacted area had declined along with harpacticoid copepods and foraminiferans, and a further decrease in the abundance of nematodes and harpacticoid copepods had occurred half a year later. This second decrease might have been a follow-up to the disturbance of the food chain, or else the higher number counted directly after the impact might have included healthy animals that subsequently died. However, the populations had recovered within three years. The foraminiferans had increased slightly, which might be an indication that protozoans reacted faster than metazoan meiofauna. The numbers of nematodes had increased tremendously by 1992 and the harpacticoids slightly, for reasons that were unexplained. Seven years after the start, the abundance of these two groups had returned to pre-impact levels, although in the case of the harpacticoid copepods there were still differences in diversity at the genus level when compared to the baseline study.

The researchers had learned during all their expeditions that it was important, especially for macrofauna sampling, to use a box corer. They had used a 2500-cm² corer with several modifications. They had changed the top plates, which were opened when the gear was lowered to permit a better flow of water and to reduce the bow wave. Additionally, they had installed special seals on the top plates and the spade so that the box would close properly after taking the sample and so that the sample could not escape during hoisting. Without the seal, a sample might be lost, especially in the nodule area, if there was a nodule between the spade and the edge of the box.

Procedures for future research

As Borowski had stated in the paper for the Workshop (section 4 above), no method should be altered during sampling, even over the course of years when better methods became available, because the data would no longer be comparable. To meet statistical standards, it was also advisable to avoid what Borowski had done in his initial sampling when he had used only 500 cm² instead of the total 2500 cm² of the box corer.

Concerning protocols for hoisting and lowering, Dr. Schriever said it was important to have a good winch operator, together with an experienced scientist to control the action. Another factor was the means of controlling the winch, which might vary from ship to ship, along with the experience of the scientists and the person at the winch. On the German research vessels, under proper conditions the winch was operated by experienced and trusted crewmembers who did nothing but assist the scientists at the winches and handle their equipment. The researchers had learnt that the box corer could be sent down quickly but its speed should be reduced to 0.3-0.5m/second before hitting the bottom so that the box corer would not produce too big a bow wave and could get a good sample. The low speed of 0.3m/sec should be used only when the sea was very calm.

In processing the samples, which had been taken to a depth of 10 cm, the DISCOL researchers had sucked up the top water with a flexible hose and sieved it with a 250-µm mesh. Then the remaining water should be sucked up, for example with a turkey baster, and sieved through the same 250-µm mesh size, after which it should be put in a bottle separate from the container for the top centimetre.

Only 250-µm mesh size sieves should be used for all horizons. If different size classes were being studied, the residue could be sieved from the 250-µm samples, according to the requirements of the study. DISCOL researchers had learnt that using 500-µm sieves resulted in a loss of about 45 percent of deep-sea macrofauna. The filter did not have to be stainless steel but a good standard of filtered seawater was needed to treat samples. Common filters of different pore size could be used for sieving meiofauna or plankton samples. Macrofauna samples should be treated with a lot of water under low pressure, using a large-diameter hose with a tap or other means of regulating the water pressure. This was necessary because polychaetes were especially delicate and could be destroyed; half of them were broken when sieved with high-pressure water. Macrofauna had been fixed with 4% formaldehyde and seawater for about 75 days, after which the solution had been changed to 70% alcohol to prevent the destruction of internal structures in animals such as molluscs.

The next question was how to establish the number of samples needed for the main taxa being investigated. Two methods had been proposed for calculating a suitable sample size for a given taxonomic composition. J.M. Elliot's test for sampling efficiency[41] had previously been used: it calculated the number of sampling units necessary for a representative collection of single taxa based on the density and distribution of the samples. Another approach, as described by S. Weinberg and D. Pfeifer[42], was sampling the so-called "minimal area", regarded as the smallest observation area for a representative collection of most of the abundant species of higher taxa. This approach calculated the minimal area but eliminated rare taxa from the analysis; depending on the taxonomy level, it did not require large sample numbers but it could help to prevent the exclusion of statistically important taxa. While this method encompassed the main abundant taxa, it excluded some minor taxa and thus probably did not meet the requirements of a diversity study. Using this approach in analysing their data, DISCOL researchers had calculated minimal sampling areas for future use in the same area. Such calculations required samples from the area to be investigated. The results were:

?? For the megafauna, a minimum area of 10,000 m^2 to be observed and evaluated, requiring an ocean-floor observation run at least 2 m wide and 5000 m long;

?? For the macrofauna, an area of 0.5-1.5 m^2, equivalent to 2-6 box-core samples of 0.25 m^2 each, and

?? For the meiofauna, an area of 142-355 cm^2, requiring 2-5 multiple-corer tubes of large size, 71 cm^2 each.

The programme for calculating the minimum area was available from Professor Dietmar Pfeifer of the University of Hamburg (Germany).

Suggestions for future experiments

Schriever then discussed how future experiments might differ from DISCOL, which had consisted of baseline studies, the disturbance and four post-impact studies. Based on their evaluation of data, DISCOL researchers suggested starting with a pre-baseline study to get information about currents and topography along with an initial sampling of megafauna, macrofauna and meiofauna, so that minimum sampling areas and the required replicates of gear could be calculated. This should take place about one year before the baseline study, to allow evaluation in the laboratory. The current-meter chain should remain in place for at least one year, with the data to be evaluated onboard at the beginning of the baseline study. Afterwards would come a pre-impact study, the disturbance, the first impact study directly after the disturbance and four more impact studies up to ten years after the impact. They suggested one more impact study because they had ascertained that the faunal composition was still different seven years after the baseline study. Perhaps further impact studies would be necessary, with the final report coming after 12 years.

Another result of DISCOL had been the finding, for the first time, that recovery of such a large disturbed area had occurred, contrary to most previous assumptions. Judging from the results of the experiment, while taking account of the fact that its scale was much smaller than possible impacts from future mining, Schriever concluded that there were probably no objections against mining.

SUMMARY OF DISCUSSION

Impact on nematodes

A biologist asked about the data showing a drop in the nematode population immediately after the impact experiment. This initial decline might be due to destruction or, he suggested, it might simply have been caused when things had been shoved up into the water column. Nematodes were vulnerable when they got into the water column because they had no ability to swim. Nematode abundance in the deep sea seemed to be closely linked to their food supply. After the physical reworking of sediment during the High Energy Benthic Boundary Layer Experiment (HEBBLE) in the North Atlantic Ocean, which according to Professor David Thistle had released food, there had been a surprisingly high abundance of nematodes. The effect in DISCOL could also have been due to a release of nematode food caused by physically reworking the sediment. On the other hand, data from the San Diego Trough and from some shallow waters, where there were many larger animals, suggested that certain types of larger megafauna were eating the nematodes, which would result in a lower abundance. As in the case of bacteria, abundance did not work well as a monitoring method with nematodes because the smaller the organism the less abundance served as a guide to productivity. However, he did not buy the explanation that damaged animals were being counted. In cultures, a damaged nematode disappeared rapidly. They were like balloons: if they were stuck with a pin, nothing would be left, and if damaged they would disappear within hours or days.

Schriever disagreed, saying that there had been a tremendous increase in the numbers of bacteria immediately after impact, by a magnitude of one or two, probably because they had been feeding on the destroyed and injured megafauna and macrofauna. The nematodes might have reacted similarly by becoming more numerous in the six months between the first and second post-impact studies, but they had not done so.

Responding, the biologist suggested that the nematode population might not have increased within six months because their lifespan was longer than that. Although the lifespan of deep-sea nematodes was unknown, shallow-water nematodes lived between 3 and 18 months, or an average of 9 months. In the deep, larger animals tended to live longer than their shallow-water counterparts did and the lower temperatures tended to lengthen life cycles. Thus, 9 months was likely to be a minimum figure for a deep-sea nematode. In studies of phytodetritus impacts, where bacteria and forams had shown before-and-after responses, the fact that the nematode population did not start to climb for almost a year had been attributed to their longer lifespan. This was speculative but it fit.

Asked whether mining might have the same effect of releasing food, thereby increasing the nematode population and invalidating any concern that they might become extinct, the biologist replied that such a response was possible, though there was also a smothering effect, so he was not sure. Looking beyond abundance to the ecological impact on diversity, however, he was willing to bet that, at the peak of abundance in 1992, diversity had dropped because opportunistic species would have reacted with a burst. He did not think any predictions could explain the loss of species, though it was possible that the release of opportunists could knock the "slow burners" out of the population locally. He cited a study of the top of a British beach in summer, where nematode abundance and diversity had fluctuated wildly and competitively in the hot weather before returning to normal in the autumn. Thus, an abundance rise could mean a diversity drop.

Schriever noted that an ecological study of this topic was being published by the Alfred Wegener Institute for Polar and Marine Research[43], based on the taxonomic work of Christian Bussau[44], who had sorted the nematodes from the DISCOL study into species.

Disturber device

Another participant asked about the farmer-inspired device developed for DISCOL, which, he said, seemed to be quite efficient in leaving no nodules behind and disturbing only 10-15 cm of sediment. He thought it could be a revolutionary, cheap and simple system for harvesting nodules.

Schriever replied that the device, which had been designed by the DISCOL team, had cost 30,000 German marks in 1988 (about $15,000 at the current rate) for four duplicate pieces kept onboard in case something was lost or went wrong. In mining, however, the nodules would have to be harvested, not ploughed under, so that a way had to be found to collect them. Moreover, the device was not environmentally friendly because it created a big plume that could be observed about 20 m above the seafloor, even six hours later. He had therefore been glad to hear the Indian approach in developing collectors that did not have such a big impact. He welcomed the efforts during the past nine or ten years to instil environmental consciousness into everyone who would be involved in mining, not only scientists and environmentalists but also engineers and politicians.

Another participant cited information from the proceedings of the 1998 Workshop of the International Seabed Authority[45] indicating that the plough-harrow system was much different from actual mining equipment because of the size of the area covered – a fact, he added, that had been recognized by Dr. Thiel.

Schriever agreed that the impact from the plough-harrow was different from that of a mining system. The DISCOL researchers had pointed out that they had not simulated mining; rather, they had created an impact that might be comparable to what a mining system might create. A mining system would probably not be able to avoid disturbing the sediment surface because even a 10-ton system like the Indian model described by Dr. M. Ravindran (chapter 7 above) would penetrate into the sediment and disturb the upper 10-15 cm. Because the sediment was soft, especially in its upper centimetres – though this differed from locality to locality in the CCFZ as well as in the South Pacific -- it would be disturbed and most of the megafauna within the tracks would probably be killed. Most or at least some of the macrofauna and meiofauna would survive, especially the nematodes.

Asked whether his group had ideas about the kind of disturber that could be designed for a future experiment, Schriever said no activity on this subject was under way in Germany. He thought it should be tackled after the results of the various BIEs had been correlated.

Another participant thought that the inputs to the Workshop could be useful in designing a mining system with a reduced environmental impact.

Standardization

Asked about his suggestions regarding minimum sampling areas, Schriever said he had advanced them as ideas for possible inclusion in a framework for standardization of methods, analysis and sampling, which could become part of the mining code or just something to be followed by each contractor so that the data collected in the various claim areas could be compared.

Recovery time

If it had taken seven years for the ecosystem to repair itself after the DISCOL experiment, a questioner asked, how many years would be needed after real mining? Second, had any new methodology been developed to reduce the restoration period?

Schriever responded that restoration of the area had not been completed after seven years. He did not have any more data because funding had stopped and the experiment had not proceeded. He would like very much to return to the area again to see its present condition.

The DISCOL researchers had discussed at length whether what had occurred was a recolonisation or a recreation of the community. Soft mining systems would probably have a low impact and not all the animals would be killed; some would be transported away by the current or they would return to the sediment in the mined area, where they might survive. He thought that recolonisation or recreation of the fauna would also depend on the size of the mined area. For example, if topography were to limit mining in the Korean claim area to 30-50 square kilometres, or 5 by 6-10 km, recolonisation from the surrounding unmined areas could occur quickly, as the distance to the centre of the mined areas would be just 3-5 km.

He cautioned, nevertheless, that neither DISCOL nor the other BIEs had operated on a scale large enough to justify predictions about future mining. Another speaker agreed, stating that extrapolation from the experiments was impossible mainly because nobody knew what sort of mining system would be employed.

A participant observed that, if only 30% of an area was mined in patches about 30-50 km wide, much of the area surrounding the highly disturbed portion might give organisms the chance to recolonise.

Craig Smith commented that 3-5 km did not sound far but it was a much greater distance than in the DISCOL area, which had taken seven years or more to recover. He did not think any macrofauna would survive after being picked up in a nodule harvester and blown up into the water column. When samples were washed, they had to be treated with a low flow rate on a screen to keep from destroying most of the polychaetes. Yet, the shear forces involved in washing sediments on a sieve were orders of magnitude lower than the shears produced in any kind of mining head to separate water from the nodules. Thus, while recolonisation of an area 5 km in diameter area would be fast when compared to an area 100 km across, it would still be slow. If the surface sediment were stripped from an area 5 km across, he would expect recovery to take at least two or three times longer than in the case of DISCOL. No information was available about rates of recovery in the middle of a large-scale, devastating disturbance. It could take 100 years or more.

A questioner, noting that in DISCOL the sediment had been shifted aside by up to 10 m compared to the 10-12 km that would be shifted by mining, asked whether the time required for recolonisation could be calculated by dividing 12 km by 10 m and multiplying the quotient by seven years. Schriever replied that the processes were non-linear.

Another questioner, citing data to the effect that meiofauna had reached a steady state by the time they were sampled three years after the impact, wondered whether a steady state would have been found if sampling had occurred two years after impact. Schriever responded that steady state in this case referred to abundance, not species composition. In any case, species composition and diversity were still different from the baseline. He added that the researchers had tried without success to find any correlation between these data and the shift from El Niño to La Niña conditions.

Asked whether the control sites had changed along with the impact site, Schriever replied that neither the nematodes nor the megafauna at the control sites had changed much. The tremendous change in abundance had occurred only within the DISCOL area.

Need for a large-scale experiment

A participant said that a large-scale experiment such as that suggested by Schriever would not be likely until future miners started work to prove the feasibility of their systems. However, at that point they would invest a lot of money that they would have to recover fast; they could not wait 12 years before they were authorized to start. It would therefore be difficult to decide far enough in advance how to deal with the problem of environmental protection. Yet, by the time mining technology was defined it would be too late for a representative experiment. While time was still available, an attempt should be made to get a better understanding of the ecosystem in order to make predictions. Even if the predictions were wrong, they would be useful in trying to find ways of reducing the environmental impact of the various systems.

Agreeing, Schriever said that was why his group, ever since 1992, had suggested that a large-scale experiment, well in advance of a pilot-mining operation or a mining test, should be carried out through international cooperation. This idea had been discussed two years ago at the Sanya Workshop. It could not be achieved by one country on its own, in view of the human resources, ship time and equipment required. A new experiment should be evaluated and designed by a committee of people or organizations.

Another participant expressed the view that people would know at least 10 or 12 years in advance when mining would take place. There was no mining system readily available that could start up even on a pilot scale; at least 10 years would be needed to put up such a plant. Thus, the lead-time should be available for what Schriever had suggested.

Supporting the kind of time frame Schriever had suggested, he said the Indian group, one of the last to do an impact experiment, had followed a similar schedule. It had helped in deciding the location of the test and reference sites, because 1.5 years of current-meter data had indicated which direction the plume might move and good information was available on the topography.

Another participant said it would be difficult to conduct good mining, imaging and impact studies without knowledge of the natural events in an environment. If mining would not occur for another 10-20 years or more, there was time for good scientific studies on temporal changes in natural events. It was important to understand environmental change and the ability of communities to remain in a steady state in the face of natural events.

Agreeing on the importance of environmental studies on natural variability, Smith put in a plea for controlled experimentation. While much had been learned from the BIEs, a great deal had not been learned due to such factors as lack of detailed knowledge about the redeposition thickness associated with these experiments. Though it was known that mining would create a large plume over broad areas and a significant amount of redeposition, there was still no good sense of how the community would respond. The comments about the size of the mined area had to be integrated into the thinking about environmental impacts. It was also important to keep in mind that the direct mining impact would probably affect a much smaller area than the plume and redeposition. Controlled experiments would give an idea of how the communities would respond to different levels of resedimentation, after which some kind of prediction could be made about the scale of the impact from the mining test or real mining without actually doing a test. Once pilot mining began, there would be a lot of economic pressure to do the real thing and make a profit. Lead-time was available now, but once pilot mining occurred, it might be too late to do the important environmental studies.

Schriever agreed, adding that Smith's proposal for critical dose experiments, which had been designed but never done, would be a step toward better understanding. Nevertheless, pilot mining should also be monitored to get an impression of the impact.

Another commentator expressed the view that, as pilot mining would mark the start of the commercial system, now was the time to prepare for that stage, because there would be no way to solve problems once it began. Pilot mining represented not a scientific approach, which was for knowledge, but a business approach, which was for profit.

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Chapter 16 Seafloor Meiofauna in Potential Mining Areas: Current State of Knowledge, Possible Impact of Exploration, Data Parameters to be Standardised and Gaps in Knowledge

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This paper deals specifically with the use of meiofauna – considered the dominant Metazoa in deep-sea communities and used for environmental monitoring of the European coasts and estuaries. Although practical problems have been associated with their use, new technology and research are constantly solving these issues.

With the development of new techniques and continuous deep-sea meiofauna research, any standardization recommended at this time must be also be able to incorporate future developments.

1. Current State of Knowledge of the Meiofauna of the CCFZ and the Central Indian Basin

Current knowledge of species distributions of abyssal meiofauna is extremely sparse. Lambshead[1] estimated that deep-sea meiofauna species distributions had been analysed from samples making up less than 5 square metres of deep-sea sediment. This figure is probably doubled or trebled now but is still a woefully inadequate sample from which to estimate diversity patterns in an environment that makes up half of the earth's surface. For this reason, I shall consider what is known in general about deep-sea meiofauna.

The most important meiofaunal taxon in deep-sea sediments is the marine Nematoda (roundworms or threadworms). These worms dominate the Metazoa[2]. Another important meiofauna taxon for monitoring is the benthic Copepoda. There are other ecologically important taxa, such as the Turbellaria, but for various reasons these are difficult to work with and unsuitable for monitoring. For the purpose of this document, mainly nematodes will be used as examples.

1.1. Meiofaunal abundance

Some examples of nematode abundance are given in table 1. The results for the Indian Ocean are probably unusual because these data are from a food-rich region. In general, copepods may be expected to be considerably less abundant than nematodes; the nematode/copepod ratio varies from 2:1 to 100 percent nematodes[3].

Biotope	Abundance
North Atlantic abyssal plain	0.3
Central Pacific abyssal plain	0.1
West European bathyal slope	0.6
Indian Ocean bathyal slope	0.9
Indian Ocean continental rise	0.5

Table 1 Examples of nematode abundance, as millions per m^2, from a variety of deep-sea sites.[4]

1.2. Taxonomy

Around 4000 species of marine nematodes have been described, mostly from coastal waters, and especially the coastal waters of northwestern Europe. Few deep-sea nematode species have ever been described and named. Tietjen[5] investigated the nematodes of the Venezuela Basin and found that only 1% was known to science. The nematode species of the Clarion-Clipperton Fracture Zone (CCFZ) and the Central Indian Basin will almost certainly be largely unknown to science. Some 358 nematodes from the CCFZ were examined as part of a provisional taxonomic study by Duane Hope of the Smithsonian Institution, and 216 of them were sorted into putative morphological species and identified down to the generic level[6]. This collection is at the Smithsonian and is a valuable resource for further work in this region.

Bussau[7] made a taxonomic study of the nematodes of the Peru-Beckens region as part of the Disturbance Recolonization (DISCOL) project. The animals were sorted into morphological species and drawn but not published. The collection probably still exists in Kiel, Germany, and may be useful for further work in the CCFZ. Brown[8] carried out a taxonomic and ecological analysis of the nematodes of the Central Equatorial Pacific; the results have just been published[9]. The ecological data and collections from this study are available in the National Collection of the Natural History

Museum, London. The only refereed publication analysing the taxonomy and ecology of deep-sea Pacific nematodes to species level is that of Lambshead[10] *et al.* (1994). This study analyses bathyal nematode populations from the San Diego Trough, and the ecological data and collections are available in the National Collection of the Natural History Museum, London.

The situation in the Central Indian Basin is even less satisfactory. There have been no ecological studies on nematodes to species level in this region and no comprehensive taxonomic collections exist to my knowledge. Cook[11] studied the ecology and taxonomy of the nematode communities of the nearby Arabian Sea. Again, publications are appearing[12] and ecological data and collections are available in the National Collection of the Natural History Museum, London; they may be useful to aid further studies in this region. Agnes Muthumbi has carried out some work at the University of Ghent (Belgium) on deep-sea nematode communities off the eastern African coast[13]; collections and data may be available. Ingole[14] *et al.* reported on the use of meiofauna for monitoring a disturbance in the Central Indian Ocean but only with abundance; their figures are unusually low.

Station	Depth (m)	Diversity index*	Species count	Number of individuals (cores/nematodes)
Norwegian Sea	1332	24.07	73	6/1629
Rockall Trough 545 m	545	28.72	81	3/304
Rockall Trough 835 m	835	31.08	83	3/292
Rockall Trough 1474 m	1474	27.39	93	3/334
Porcupine Abyssal Plain (1989)	4850	28.80	131	6/1256
Porcupine Abyssal Plain (1991)	4850	32.92	156	6/1428
HEBBLE Station 1	4626	24.94	133	8/1331
HEBBLE Station 2	4626	25.26	124	9/1152
Madeira Abyssal Plain	4950	25.39	78	6/578
Hatteras Abyssal Plain	5411	29.95	88	2/507
Puerto Rico Trench 1	7460	25.36	55	3/344
Puerto Rico Trench 2	8189	22.43	47	3/284
Puerto Rico Trench 3	8380	21.59	46	3/394
Puerto Rico Trench 5	2217	26.78	63	2/339
Venezuela Basin 1	3858	27.21	54	2/309
Venezuela Basin 2	5054	31.78	73	2/270
Venezuela Basin 3	3517	32.13	85	2/425
Central Equatorial Pacific 0° N	4309	34.34	124	5/477

Central Equatorial Pacific 2° N	4410	32.385	104	4/386
Central Equatorial Pacific 5° N	4411	32.176	118	5/498
CCFZ 9° N	4990	31.273	89	3/291
CCFZ 23° N	4879	28.185	81	4/407
CCFZ	4500	-	148	-
Arabian Sea	400	16.92	44	3/287
Arabian Sea	700	21.35	58	3/284
Arabian Sea	1250	30.63	95	3/248
Arabian Sea	3400	32.27	103	3/256

* Effect size (ES) = .51.

Table 2 nown species richness from a number of deep-sea sites, listed with the number of individuals and number of cores used for the analysis[15].

1.3. Deep-sea meiofauna species-diversity patterns

Nothing is known of the species-diversity patterns of the CCFZ or Central Indian Basin, although general information about nematode diversity patterns in the deep sea is starting to emerge. Sample diversity (or point diversity) shows a parabolic relationship with depth, diversity peaking in the bathyal zone[16]. Station diversity (alpha diversity) shows a different pattern, offshore species richness being higher than coastal species richness. It is not possible to make any observation about beta or gamma species richness because most deep-sea nematode species are undescribed.

Historical and ecological processes govern the species richness in any particular area. Little information exists on how nematode deep-sea species richness has been influenced by historical events but it has been suggested, for example, that the low diversity in the Arctic Ocean Basin is a product of the last ice age rather than current ecology[17]. Two linked ecological processes control diversity, namely disturbance and productivity. The relationship between these processes and diversity tends to be parabolic, diversity reaching a maximum at some intermediate level of disturbance and of productivity. The parabolic depth-diversity graph (see above) obtained for sample diversity is usually explained in these terms.

Two papers have investigated the relationship between diversity and productivity at abyssal depths, in the North Atlantic[18] and in the Central Pacific[19]. Both studies reported that in the food-limited abyss, in the absence of other ecological factors, diversity and species richness increased with productivity.

The impact of natural physical disturbance on diversity of deep-sea nematode communities has been recently investigated[20]. That paper reported the impact of benthic storms at the HEBBLE (High Energy Benthic Boundary Layer Experiment) site in the North Atlantic and of turbidite flows in the Venezuela Basin and Madeira Abyssal Plain. The results showed that deep-sea nematodes, like shallow-water nematodes, are resistant to physical disturbance, including smothering. Anecdotal evidence from a deep-sea tailing-placement site is consistent with this view.

A long-term change in the composition of the sediments can cause a change in meiofauna communities. There is some evidence for this at the Madeira Abyssal Plain and at a site subject to current flows in the northeast Pacific[21]. The sedimentation rate of pelagic material seems to be the important factor in the return of the meiofauna communities to baseline conditions[22].

The European DISCOL programme should yield useful additional information but the only paper yet published on the impact of disturbance on meiofauna deals only with abundance[23].

2. Possible Impact of Nodule Exploration and Exploitation

Nodule exploration and exploitation are likely to have four types of impact on the meiofauna communities: (i) the direct physical effect of the mining equipment, (ii) the settlement of the plume of sediment, (iii) any long-term change in sediment composition and (iv) productivity changes.

It is difficult to predict the effect of the machinery. Nematode communities tend to be resistant to the mechanical effects of natural physical processes that cause sediment disturbance but whether this will apply to the processes involved in nodule exploitation is unclear. Nematodes are resistant to plume effects and may tend to recover from such disturbances rather quickly. However, meiofauna communities will be sensitive to any long-term change in the physical composition of the sediment caused by exploitation. This may be a problem for some species. Sediment disturbance normally releases organic material, temporarily increasing productivity, and this causes a short-lived rise in local diversity.

Nematode ecological diversity is unlikely to be much affected as a whole by exploitation but the situation for individual species may be much less optimistic if for one reason or another they prove vulnerable.

3. Information And Data Needed For Baseline Studies

3.1. General meiofauna data

Data are needed on numbers of nematodes and copepods per standardised area. For nematodes, standardised measurements of a random sample need to be taken, from which biomass can be calculated.

3.2. Ecological diversity

The animals within a sample need to be sorted into putative species and counted for the estimation of ecological diversity indices. For nematodes, this involves difficult and slow sorting by well-trained taxonomists into nominal species on morphological criteria.

3.3. Multivariate analysis

This analysis requires the same data as in section 3.2 above, except that conspecificity across cores in an area needs to be established, significantly increasing the taxonomic challenge.

3.4. Species-richness assessment and species distributions

Species-richness and distribution analysis depends on reliable, consistent taxonomy over large spatial areas. This is problematical for meiofauna, especially nematodes, but is essential to determine whether species face extinction.

3.5. Standardisation of data

3.5.1. Sampling

Samples should be taken with a Bowers and Connelly Multiple Corer and it would be a good idea to standardise on a single core size. A minimum of six cores are required per station, each core coming from a single drop, the sediment being sectioned in 1-centimetre slices down to 5 cm (including 10 cm of overlying water in the 0-1 cm sediment horizon) and 5-cm slices thereafter. The 0-1 cm slice is the sediment horizon utilised for most analysis. A 45-micron mesh sieve is the maximum size that should be used for recovering meiofauna. It may be necessary to use a 32-µm mesh sieve if there is a high percentage of small nematodes.

3.5.2. Taxonomy

The standardisation of meiofauna taxonomy is absolutely critical. This cannot be overstated. Deep-sea meiofauna taxonomy is difficult. I strongly support the idea of setting up a central taxonomic facility at an institution (or institutions) that have a taxonomic collections-based "culture", i.e. a museum or museums. The criteria should be (i) concentration and critical mass of taxonomists used to the concept of taxonomic quality control and training, (ii) a culture of collections that can organise and curate voucher specimens, and (iii) a management culture capable of responding to commercial needs. As most deep-sea metazoans are undescribed and unnamed, voucher collections are critical for reliable taxonomy. The curation of voucher collections involves physical curation (proper preservation), databasing such that material can be retrieved as required and making specimens available as necessary. The taxonomy centre should also have appropriate geographic information system (GIS) software for analysing and displaying species distributions.

3.5.3. Knowledge gaps

The most important knowledge gap with regard to deep-sea meiofauna generally, and nematodes in particular, is the fact that most deep-sea species are undescribed. This leads to further knowledge gaps, e.g. we have no idea of the range of deep-sea meiofauna, which makes it difficult to assess whether individual species are threatened with extinction.

Similarly, we know nothing about the regional or oceanic diversity of most of these groups. This could be important because at any one site and any one time the number of reported species appears tractable (less than 200) but if these species are a constantly changing subset of a large regional species pool we could be facing a much more difficult problem.

A further taxonomic problem is that most marine invertebrate taxa display sibling species, where a single species turns out to be a cluster of discrete but morphologically similar species. This has not been investigated for marine nematodes but is highly likely to occur.

These taxonomic problems mean that only well-trained taxonomists can work at the species level with deep-sea meiofauna, and such work is laborious and expensive. A further problem is that the number of suitable taxonomic specialists is limited and falling. There are probably less than 20 marine nematode taxonomists in the world that could deal with the taxonomic problems arising from assessing species richness from deep-sea material. This also has implications for the training of new specialists.

3.5.4. New technology

The Natural History Museum is leading a consortium funded by the Natural Environment Research Council (NERC) of the United Kingdom and BHP Minerals to devise a new molecular system for identifying marine nematodes that is a fast, reliable approach to the taxonomy of this difficult group. The advantages of molecular biology are that the technique is inexpensive, the skills are widely available and easily taught, and it is fast. The specific objectives are:

(1) To define and validate the molecular method for identification of marine nematodes, and in particular to demonstrate that rapid identification is feasible;

(2) To relate “molecular signatures” to defined species with a view to developing and testing fast, cheap molecular methodology suitable for mass identification of nematodes in samples.

This system is based on sequencing informative segments of DNA and using them to define "molecular operational taxonomic units" (M-OTUs). To be useful, the segment of DNA must be known to be orthologous between species (as paralogues will define gene rather than organismal groups) and must encompass sufficient variability to allow discrimination between biological species. Species are identified through sequence identity.

Several genes are being investigated with respect to levels of sequence variation between and within species, as well as levels of variation arising from experimental error (generally low). Direct comparisons will be made between standard morphological and molecular classification systems to validate the M-OTU method.

Once the most useful DNA segment has been identified, single specimens can be sequenced from small pieces of tissue to avoid compromising morphological or biological studies of the animals. A cost-effective molecular technique is also proposed to identify nematodes from bulk ecological samples by extracting DNA from all specimens together, amplifying a segment of the gene best suited to identifying species and then separating amplicons by denaturing gradient gel electrophoresis (DGGE). Such methods are directly analogous to those utilised for research into marine microbiology. This has been revolutionised by the use of amplification of partial sequences of 16S ribosomal RNA from microorganisms in environmental samples and separation of amplicons through cloning or DGGE[24]. This will allow researchers without specialised taxonomic knowledge to use marine nematodes routinely in ecological and environmental research, revolutionising benthic ecology. In the long term, it will be useful to calibrate between known species and their M-OTUs for the majority of nematode species in taxonomically well-known habitats such as British estuaries. However, in the deep sea most nematode species will probably never be classically described and will simply be defined as M-OTUs.

This project started in June 2001. Tests on bulk ecological nematode samples from deep-sea areas affected by placement of mining tailings will take place in late 2002 or early 2003.

SUMMARY OF PRESENTATION AND DISCUSSION ON SEAFLOOR MEIOFAUNA IN POTENTIAL MINING AREAS

Dr. Lambshead, in his oral presentation, began by saying that "meiofauna" was a largely obsolete word. It had been originally invented as a size class for convenience; when certain silt or sand was put through a series of sieves, a more or less arbitrary decision had been made to call animals of one size macrofauna and those below that size meiofauna. These terms did not mean much in modern ecology or biodiversity studies because it could never be said that meiofauna *did* anything. They were made up of different taxa that had their own biodiversity and ecological characteristics. For example, in some ways nematodes were more like polychaetes than like copepods, the other meiofauna group. For purposes of monitoring, there were two important groups – nematodes and copepods. Nematodes were by far the most important simply in terms of numbers; in the deep sea, they made up 70-90 percent of the metazoan meiofauna. Other important meiofauna groups, such as flatworms, were too difficult to deal with and were of no use for monitoring. In using nematodes as an example, he was not implying that their behaviour was typical for meiofauna, since copepods behaved completely differently.

Research methods

Describing how biologists worked with these small, multicelled animals, he said samples were collected with a core sampler. Specimens not taken with a high quality meiofauna sampler were dubious, and even box cores were not good enough for meiofauna. Experiments had shown that an average of 60% of the meiofauna were lost with a box corer, the problem being that this proportion was variable. Next, using tube samples from a bionic multiple corer that had been brought back on the boat, the sediment was sectioned, usually at one-centimetre intervals. The only part of the sediment normally studied was the top 0-1 cm, because working with meiofauna was labour intensive and looking through the whole core would mean that fewer samples could be studied. Investigating this top centimetre probably gave a good idea of what was going on, because more organisms lived in that interface area than in any other segment. This might be a bad assumption but it had now become standard. Once sectioned, the cores were shoved into plastic bags with a preservative -- formalin for morphology or alcohol for genetic work. Nothing else could be done on the boat; the materials went into boxes and then back to the museum.

In the museum, the first step was to separate the animals from the sediment. This non-trivial process could not be automated; it was a technical rather than a scientific task but it was labour intensive and skilled. The technician performing this work took about one week per sample. Floatation methods were used to separate the animals from most of the muck, but finally each animal had to be picked out by hand on a titanium wire. Each worm, about 0.5 millimetres long on average, was then placed on a watch glass of glycerine alcohol (glycerol). The glycerine alcohol was put into a desiccator for a day or two, leaving a watch glass full of nematodes. These would have to be mounted on slides before any work could be done with them. With shallow water collections, all the animals could be put on one slide, but that did not work with deep-sea samples because their taxonomy was unknown. The animals had to be used as a voucher collection, because the species could not be identified from a book. Usually, about ten were mounted to each slide; one per slide would be better, but if a core contained 3000 animals, that many slides would be a bit much. Once mounted, they could be counted to derive an abundance figure.

As Dr. Michael Rex had pointed out (chapter 14 above), abundance was generally low in the deep sea. However, there were so many animals in a core that not all of them could be examined. Usually, 100-150 animals were taken out at random, using various ways of randomising. Each one had to be examined under a high-power microscope with an oil-immersion, 100-power lens, and each had to be drawn. Cameras could not be used because the high-power microscopes required thin optical slices. In shallow water studies, 10,000 animals might be looked at for a single dataset but for the deep sea the number might be 3,000, because the deep sea was more difficult to work with.

Current knowledge

Not much was known about meiofauna in the Clarion-Clipperton Fracture Zone (CCFZ) or the Central Indian Ocean, Lambshead stated. As far as he knew, no species-level paper had been published on the nematodes or any other meiofauna of the Indian Ocean mining zone. With regard to the Pacific, the situation was a bit better. More had been learned about deep-sea nematodes in the last 5 years than in the previous 50. He and his colleagues were pulling data together and doing correlative statistics, similar to the work done by Rex's predecessors for their animals 30 or 40 years ago. Thus, much of the information he was presenting was a bit tentative, because work on correlative statistics was in the early stages and hypotheses were being developed that still had to be tested.

In 1995, he and some colleagues had published the first table on species diversity in the Pacific Ocean, on the bathyal coast off California. This was not far from the CCFZ but it was probably not much use for that area because it dealt with a completely different depth at an unusual place in the San Diego Trough. The collection and all the drawings resided in the London Museum; they might be of limited taxonomical use. At the invitation of Craig R. Smith, he had just finished working on a study in the CCFZ at the EqPac (equatorial Pacific) stations and the HOT (Hawaii Ocean Time-series) station at 23 degrees north latitude. A species analysis of the data had been done, resulting in the only two ecologic datasets that existed for Pacific nematodes.

Speaking of taxonomic collections, he said one had come in 1987 from the Echo site, where Duane Hope, taxonomist at the Smithsonian

Institution, had collected 148 species, put them on slides, drawn them and incorporated them into the collections of the Smithsonian. Another collection had been made on the eastern side of the CCFZ around 1985-87. A taxonomic study from the DISCOL (Disturbance Recolonization) site by Christian Bussau had not been published but was available as a doctoral thesis[25], and the collection was at the Senckenberg Museum (Frankfurt am Main, Germany). Comparing these collections to the recent one should provide valuable insights into species ranges.

On nematode abundance, Lambshead cited data showing about 0.1 million nematodes per square metre on the central Pacific abyssal plain. This was an impoverished area compared to the North Atlantic, where the Porcupine Abyssal Plain (PAP) recorded a count three times higher. The Indian Ocean sites that had been studied were actually in the Arabian Sea, from an oxygen-minimum zone rich in food. Their figures of 0.9 and 0.5 nematodes/m^2 were proof that this unusual environment was nothing like the Indian mining zone, and he doubted that they would be useful for the Central Indian Ocean claim area.

Although no one knew how many species of nematodes there were, it was not difficult to estimate the number of individuals. According to his calculation, free-living nematodes numbered about 10^{19}.

Nematode abundance seemed to be controlled by food. It did not correlate well with particulate organic carbon (POC) because nematodes fed in the sediments, not on the surface. He cited calculations done with Adam Cook, his doctoral student, on data from the Arabian Sea[26]. Using a hydrogen index, employed by biochemists to measure food quality in the sediment, they had found a correlation of 98.9%, the best he had ever obtained on a data set. Looking at a graph of the data, one could not tell which of its points referred to the low-oxygen-minimum zone because, from the standpoint of abundance, the nematodes did not care that there was no oxygen.

The big problem was the taxonomy of the group. Out of 4000 described species, about 2000 descriptions were so old and so bad that one could not be sure of ever finding the species again. There were virtually no types because it had been traditional with these small animals to throw the types away.

As to estimates of species numbers, there had been a row with the terrestrial nematologists a couple of years ago about whether the oceans or the land had more species. The terrestrial people had compared their estimates for land species with the known number of marine species, which of course let them win easily. Fred Grassle had taken the statistics used by tropical rainforest researchers, based on 12 trees, and extrapolated them to the world. When this formula was applied to marine systems, it produced figures in the region of 10^6 to 10^8 nematode species worldwide. The message conveyed by these "political" figures was that applying the same sorts of dodgy statistics would yield the same sorts of telephone numbers for marine as for terrestrial systems. They would be big numbers – no one knew how many -- to be taken with a pinch of salt.

One of the problems with nematode taxonomy was the existence of sibling clusters. The standard of taxonomy for marine nematodes was well below the standard for terrestrial nematodes. Morphological taxonomy was still using 1930s technology. Moreover, of the 4000 described species, around half came from the beaches and estuaries of northwest Europe. Moving offshore from northwest Europe led rapidly to areas where all the nematodes were unknown. John Tietjen, the inventor of deep-sea nematology, attempting a taxonomic study of the Venezuela Basin, had estimated that he could fit only about 1% of the species to a name, assuming that they were not siblings – another unknown.

All nematode specimens from the deep sea were likely to be unknown. Once they were on a slide, they could probably be sorted into putative morphological species with a reasonable degree of assurance, because the sibling problem would probably not be too great at the core level. Thus, the next step, with the help of the drawings, would be to work out how many species the core contained. A single core from the abyss might be expected to have 40 or 50, which could be sorted into species reasonably well. It could also be assumed that, if animals in two cores from the same place looked the same, they probably were the same and could be so designated. Such was the taxonomy being employed at the museum level, the highest achievable. Perhaps only 20 people in the world could sort deep-sea nematodes into species at that level.

Biodiversity

Lambshead cited more or less comparable data on species diversity from around the world that he had collected with Guy Boucher, nematologist at the National Museum of Natural History in Paris. They had sorted the sources of the data into European estuaries, coral lagoons, sub-littoral, tropical, offshore Europe and the Mediterranean, bathyal (off

California and the Rockall Trough), abyssal (largely North Atlantic) and hadal (a single data set from the Puerto Rico Trench). They had been quite excited to obtain a parabolic curve, like the one mentioned by Rex for macrofauna (chapter 14 above), though the two were not quite the same because Rex's curve was based on a transect whereas this one plotted biotopes. Measuring biodiversity was not like measuring temperature or pressure; it was not real, it was a concept. Thus, there were various ways of doing it. He and Boucher had taken the number of species and created an ecological diversity index for a single point – namely, a core sample. As Rex had stated, different levels of diversity were recognised in the terrestrial sphere – alpha, diversity within a habitat, beta, diversity between habitats, and gamma, or regional diversity. Deep-sea samples showed a high level of point diversity for nematodes.

Speaking of another way to measure diversity, Lambshead said he had tried to investigate alpha diversity by using a series of cores from the same place and from what he had reason to believe were the same habitat, whatever habitat meant in this context. The resulting pattern was slightly different, illustrating the fact that biodiversity patterns depended to some degree on how one chose to measure them. Species richness, simply a count of the number of species, sounded much better than ecological diversity because it was something that could be grasped, a real number. It was meaningless, however, without specifying how many species in what area, because bigger samples had more species for purely mathematical reasons. In terrestrial work, species richness was usually plotted against area, whereas for the deep sea he had plotted against number of specimens. The data fell broadly into two blocks, quite different from the previous set: an offshore block, ranging from about 20 m offshore down into the abyss, and an intertidal block, including beaches and estuaries. At point-diversity level, the beaches were separate from deep sea and offshore, giving three habitats. In the case of alpha diversity, however, not only were there only two, but they also split in a different place.

By way of interpretation, he drew a comparison between species richness of nematodes at a Cameroonian rainforest site and in Loch Ness (Scotland), which supported the argument that the deep sea had the sort of diversity found in a rainforest. He suspected that the cause had something to do with the fragmentation of environments: lakes were contained and small, whereas the deep sea was effectively infinite from the viewpoint of a nematode 0.5 mm long and living in the sediment.

As to the processes producing these sorts of patterns, he said biodiversity scientists broadly saw three: history, and two ecological processes, disturbance and productivity. Whereas marine biologists in particular often looked for ecological solutions to problems, the answer lay often in history and not ecology. When monitoring in the deep sea, it should not be forgotten that natural patterns could vary from place to place for reasons now invisible that depended on the history of the area. For example, deep-sea species counts from the North Atlantic seemed to fit onto a nice line except for the Norwegian Sea, which was an outlier. He had spent some time arguing in the press with Rex about what that meant. There were many potential explanations: history, the fact that the sea was under ice only 8000 years ago; modern ecology, the odd nature of the Norwegian Sea, where cold water sank to the bottom and spread out; and something simple like geography, the peninsular effect that caused the environment to narrow on a peninsula, producing fewer species. Snakes in Europe were an example of the geographic effect: there were no snakes in Ireland, only two species in Britain and many more on the continent.

Lambshead then showed the same data plotted differently, using the latitudinal gradient approach pioneered by Rex in a paper published a few years ago in *Nature*[27] (see chapter 14 above). Where Rex had worked with molluscs -- one of the best-known groups -- and one or two others, Lambshead had used nematode data from the North Atlantic. He had not found the same pattern; in fact, he had obtained almost random variation. The explanation seemed to be that the North Atlantic, as far as nematodes were concerned, was not a good place to work because it was divided into a series of basins, each with its individual ecological character and different history. When he switched to species count plotted against latitude, a rising curve appeared, but the Norwegian Sea was still offline. He and Rex were still arguing about whether an adjustment for depth would destroy the significance.

In addition to the North Atlantic data, two more sets had been submitted to journals, from the CCFZ and the Arabian Sea. The Central Pacific was a better place for this sort of experiment, as it was not divided into basins and was all at the same depth. For the CCFZ, the data could be broken into two sets: where there was more productivity, there were more species. It seemed, certainly for deep-sea nematodes, that if more productivity were pumped to the abyss, more species would be found. The data from the Arabian Sea had come from a station at 3400 m that was the most productive he had ever seen as well as the most diverse. This pattern was based on just three datasets, and thus was very tentative.

Another factor supposed to influence biodiversity was disturbance. The Natural History Museum (TNHM), London, had been working on data from the turbidite site on the Madeira Abyssal Plain (MAP), a big area in the southern part of the North Atlantic affected by more than one turbidite flow -- most recently about 1000 years ago, according to geologists. In terms of ecological diversity (effect size [ES] = 0.51), the diversity index for the MAP site was 25.39 (see table 2 above). Compared to reference sites at the same latitude (sites at the same latitude had been used to take out the productivity effect) the MAP site was lower in diversity but not much lower, significant statistically but not that important biologically. The same pattern appeared in a comparison with reference sites at the same latitude from the High Energy Benthic Boundary Layer Experiment (HEBBLE), whose collection had been donated to TNHM by Professor David Thistle of Florida State University, Tallahassee. The HEBBLE data had been collected 4-5 weeks after a benthic storm, which had caused a somewhat significant lowering of diversity. These data referred to ecological diversity indices; he had no idea whether any of these effects had caused any species to disappear, because he could not tell whether the species in one place were the same as those in another, given the technology available. According to HEBBLE data from Kristian Fauchald, polychaetes there were much more depressed than the nematodes. The MAP site had the lowest diversity of any abyssal site because it was oligotrophic as well as disturbed. This fact reinforced Rex's comment that every place was not the same and that you had to have some idea of what you were looking at before you could look for a disturbance effect.

Possible impacts of exploration

Regarding the direct effect of mining equipment, Lambshead said that nematodes were very resistant to physical disturbance. This was known from shallow water work. Richard Warwick, of the Plymouth Marine Laboratory (England), who did shallow water studies, had said that the major difference between nematodes and most of the macrofaunal groups was that nematodes did not care much about physical disturbance. As to other effects, such as smothering by the plume or by the shoving aside of sediment, much work had been done in shallow water on dredge spoil. Broadly speaking, nematodes were resistant to this; they should be able to burrow their way out. A lot depended on how much was done and how quickly. Nematodes seemed to prefer chronic spoil -- a little bit at a time rather than a huge wedge all at once – though this might not be true for all groups. According to data from a mining company on tailings from land-based mines placed into the deep Pacific, the nematodes did not seem to mind too much; they seemed to colonise the tailings quickly.

Changes in sediment composition could have a long-term impact on the meiofauna, however. The difference in diversity at the Madeira site, where the turbidite was 1000 years old, seemed to be due to the fact that the turbidite flow had permanently changed the upper surface sediment. The MAP area had a low sedimentation rate from the surface. Interestingly, two samples from the Venezuela Basin turbidite, which was about 10,000 years old, had shown no evidence of any reduction in diversity. The differences were that, at the Venezuela Basin site, the nematodes had been living in pelagic sediment, the area had a much higher sedimentation rate and a longer period had passed since the disturbance. His conclusion was that the permanent change in sediment had probably caused the change in nematode diversity, because such an effect on meiofauna was known to occur in shallow water.

If a disturbance changed productivity in some way, which could easily happen if the larger animals were taken out, it could mean extra food dropping into the sediment for the nematodes. Work he had done off California some time ago indicated that, when there were many larger animals at a site, there were fewer nematodes. Taking out the larger animals would also remove competition. Moreover, larger animals presumably ate nematodes along with the sediment they took in; they were hardly likely to spit them out, given the food shortages at the deep-sea bottom. Still another way productivity might be changed was through the action of the mining machine in releasing organic material. In all of this discussion of possible impacts, he was not investigating processes, just correlative statistics.

He could say nothing about the possibility of extinction, because species ranges were unknown. To repeat what he had said before, the taxonomy was appalling, the species were not described, there was no assurance that species criteria were sorted out properly, it took forever to work on them and very few people could do the work.

Data parameters

Lambshead discussed various categories of data proposed for baseline studies, beginning with abundance and biomass. Abundance was assessed not by weighing nematodes but by measuring a few and then using a formula. In general, abundance and biomass were worthless in shallow water, where nematodes were often used for monitoring. Those factors changed unpredictably with all sorts of ecological factors and disturbances. When pollutants were introduced, sometimes the abundance went up and sometimes it went down. Bruce Coull, in a comprehensive paper on this topic that analysed other papers[28], had concluded that abundance and biomass were useless.

Various parameters influencing nematode size structure might be useful for monitoring. Information on species richness and distribution would be needed to ask questions about extinction. Ecological diversity indices could be calculated and analysed in the usual ways, but this was an expensive task that took a long time and required expertise that existed in very few places in the world. How could he recommend a method that, if enough people picked it up, could not be done anyway because there was no one to do it? Moreover, the expertise was not increasing.

Urging standardisation of sampling and extraction, he said that, although the techniques were known, 95% of all commercial monitoring data produced for legal reasons was worthless. Extraction was done by hand; people had to be taught how to do it. It was easy to teach as a technical skill but if it was not done right, the data would be useless. If the wrong sampling gear were used, the data would be useless. A few years ago, he and some colleagues who had been analysing data for ecological effects had not found the effect they expected. When the sample extraction was done by two highly reputable research institutes with good people, he had been able to tell from the results which labs had done the analysis. The point was that, if the data were to be at all useful, they had to be comparable.

Taxonomy and voucher collections

For taxonomy, and especially for nematode taxonomy, there was need for a central taxonomic facility, in the form of a museum, not a university. The culture of a museum was completely different from that of a university. Moreover, a museum would have a critical mass of taxonomists. That was important because it was difficult for people to do on their own what was essentially art rather than science; they needed someone to talk to, compare with and make sure that they were not drifting off into their own little world, that they were maintaining the criteria.

He added that voucher collections were needed because deep-sea animals could not just be looked up in a book. If he was working on British estuarine nematodes, he did not bother to draw them because 90% of them, drawn by his predecessor at the Natural History Museum, were covered in a work by Platt and Warwick[29]. The book described their characteristics and where they were found, and contained drawings and measurements. For the deep sea, nothing like that existed. Voucher collections were not used just for undescribed animals; they were used for described ones as well, because the description of an animal done with 1920s technology was not much use now. Researchers had to keep going back to check, redescribe and make sure their animals were the same. The 80 million scientific specimens at TNHM were not on dusty shelves, they were constantly being used. Huge trucks carried specimens to and from labs every day, and many visitors came with their collections to check them against the museum's, which were the equivalent of the standard metre rule. In chemistry, chlorine was much the same everywhere in the world and there were ways of testing to check its presence, but how would researchers know whether they were dealing with the right species?

To illustrate this point, Lambshead told a story about the elderly taxonomist who had trained him at the outset of his museum career. Once, at a scientific meeting, the taxonomist had been listening to a bright young man in the new field of biochemistry give a complicated explanation of why a nematode parasite in an experiment had produced two peaks on a graph. After hearing the explanation, his old boss had stood up and said, "Young man, are you aware that you've got two species in your culture?"

Collections could not simply be dumped in a cupboard. When the Natural History Museum recently incorporated the deep-sea collections of the Institute of Oceanographic Sciences (IOS) into the British National Collection, someone had to receive them, check that they were well preserved, put them in with the other 80 million specimens where they could be found again and enter them into a database. For the rest of its life, the collection would have to be checked periodically, the alcohol refreshed or changed, and even the glassware would have to be changed on a rotating basis. Of the museum's 400 scientists, 200 of them did nothing but look after the collections, as part of a culture of collection. If the entire nematode team went down in an aircraft, nothing would happen to the nematode collection. Someone else would be hired and sent off to the Smithsonian for training by their taxonomists, then come back and take it over; in the meantime, others among the 200 curators would be looking after it. Everything he had said about his museum applied to any of the great research museums. The British collections were widespread because of the Empire: the first collection had started in Jamaica and, broadly speaking, TNHM had the types for any bits of an old map that were coloured pink, including all the Australian types from the Great Barrier Reef. By contrast, at universities that hoarded collections, inevitably the lecturer interested in them died and eventually the collection was shovelled into a bin somewhere.

Museums were run by governments, not by universities. As part of the civil service, their culture was different. Some museums did not have a management culture that was interested in commerce. They were paid a set fee from the civil service. If the International Seabed Authority was looking for a central taxonomic facility, he recommended that it ask an institution for proof that it had done that kind of work before. There was a difference between a museum serving its scientists and a body serving a commercial need.

Regional species pools

Regarding the size of regional species pools, he said the problem could be described in this way: if a station in the CCFZ recorded an average of 130 species and a month later the number remained the same, were they the same or different species? No one knew, because no one had ever gone back to the same deep-sea area more than once to try to establish this. The problem would be addressed for the first time at a deep shelf site in the Antarctic Ocean, where a series of samples would be taken throughout the year to look for temporal variation.

The size of the regional pool was important. He had tried plotting for nematodes the kind of graph done by Rex for molluscs (see chapter 14 above), though he had not had the nerve to publish it because the data on molluscs gave a much better idea about their regional pool. His data suggested that the small group of species in the sample were a subset of a regional pool that was spitting species in, possibly more or less at random. If the regional pool in the CCFZ held 5000 species, for example, the problem was obvious. Of course, nothing could be said about whether a nematode species would be made extinct by mining operations, since there was no idea of their range. One of the difficulties was that there was almost certain to be a sibling-species problem; although this was not a great issue locally when sorting specimens from a core, it would really kick in when trying to look across big areas.

New analytical techniques

Morphological analysis was slow and expensive, and required scarce and dwindling high expertise. The solution lay in something he had been trying to set up for a long time, involving new technology -- "thinking outside the box". He had persuaded the National Environment Research Council (NERC) to put up some money for using molecular techniques to identify nematodes. Funds had been sought for this project for about ten years, on and off, but the truth was that the molecular technology had not really existed earlier, and now it did. The project was being funded by NERC, the Natural History Museum, the University of Southampton, the University of Edinburgh and the Plymouth Marine Laboratory. It also relied on a number of other laboratories, notably the Hawaii Undersea Research Laboratory, which had supplied many samples over the years. A collaborator in the project was BHP Mineral, not the company putting tailings into the deep sea but the one investigating the matter. BHP wanted to monitor the deep sea using nematodes but, in its own investigation, it had run into the problems he had been describing, whereupon it had offered to be a partner, supplying money, expertise, ships and samples. The new technology would be tried out first in British estuaries, where the species were reasonably well known, and then a field trial would be conducted in the Pacific.

The first request for money had gone to NERC about a year ago. Unknown to his group, other scientists had also asked NERC for money for the same sort of project involving terrestrial nematodes, because they had much the same problem. The terrestrial committee had funded them but the marine committee had initially deferred his group's request on the ground that it was untried technology. As a result, the terrestrial group was running one year ahead.

The aim was to do bulk identification of nematode samples. The advantages of this approach were that molecular work was cheap, it used widespread expertise, it was essentially technical work, it was easily taught, it did not require scarce taxonomic resources and, most importantly, it was incredibly quick. A run on a full sample using DGGE (denaturing gradient gel electrophoresis) took two days, compared to the whole month that a taxonomist would need to do a morphological analysis. Where the old technique used only 100 animals, many more could be handled with DGGE, making it potentially more accurate. Two DGGE machines could do two samples every two days. The equipment was not expensive, involving a separation of amplicons through electrophoresis.

The terrestrial people had already obtained results from some runs. They had worked with the 18S gene, which was good for phylogenetic rather than species analysis, because DNA work on terrestrial nematodes up to now had been phylogenetic and the gene was a known quantity. They had found that the 18S gene produced an underestimate of the nematodes in the samples, though this happened with complete consistency. In a field trial, using well-known British terrestrial species, the gene had worked perfectly, giving exactly the expected result, which was a slight underestimation. The 18S gene was fine except that it could not generally be used to distinguish between siblings or closely related species.

Now that this work had been accomplished, his group could jump a whole degree forward, using 18S and 16S genes. Work on designing probes for 16S was under way. Once this was done, researchers would be able to separate the animals automatically using floatation methods. They would not worry if extraction was no longer 100%, since they would not be doing counts. The procedure was to take a sample, split it in half, place half into formalin as a morphological record for voucher collections, store the other half in alcohol, extract the DNA and place it in the DGGE device. The DGGE gel sample could be cut up and sequenced to determine what nematodes were present. This would not just tell how many nematodes there were but for the first time nematodes could be tracked across the sea, through space and time.

All sorts of interesting information was emerging. From the new phylogenetic data, researchers were discovering that the existing nematode classification was complete rubbish, which showed how good morphological taxonomy was. Working with Craig R. Smith, he was looking at cold seeps, trying to see whether the populations of different types of ecosystems were identical or genetically different species. The first papers on this work should appear in about 12 months, easily in time to use as a method for monitoring nematodes in mining experiments. In his view, this was probably the only way effective monitoring at the species level could be conducted in the deep sea.

New thinking

Another approach, one that did not require new technology, was new thinking. Adam Cook, a postdoctoral student working with DGGE, had been doing some lateral thinking. While everybody measured the size of nematodes, he had asked a different question, connected with his work with low oxygen, about shape. It was known from shallow water studies that a nematode in a low-oxygen zone had to be slender because, lacking lungs, it exchanged gases through its surface. After determining that this rule involving the ratio of surface area to mass applied to deep-sea animals, the investigators had discovered that at the MAP site the animals were stouter, with a lower surface-to-mass area, than at the PAP site. The range of body sizes in the disturbed area had been compressed; mean size was unaltered but the variation around the mean was tighter. Mean body size, incidentally, depended on other factors that were starting to become known. Similar differences, described in a paper currently being written, had also appeared in comparisons between PAP and a deep-sea dumping ground for sludge. Broadly speaking, the shape of the animal seemed dependent on whether it had been disturbed, for reasons that were not understood. He was not recommending this as a method, because it was not known why physical disturbance or sewage sludge with metal contamination should have the same effect as low oxygen. He mentioned this solely as an example of the need to start thinking laterally. The tendency was to do the same things because they had always been done, but what was right to do with macrofauna might not be the right approach with meiofauna.

SUMMARY OF DISCUSSION

Nematode biology

Asked to describe a nematode, Dr. Lambshead said it was a simple tube with sensory equipment at one end, though it could be complicated in appearance. The thinking used to be that nematodes were simple and primitive but now they were thought to be simplified. According to the latest DNA evidence, they were closely related to arthropods, which had come as a bit of a shock. They used internal fertilization and did not have a dispersal stage, which should mean, according to zoological principles, that they were very endemic.

Their medical properties were negative ones – they parasitised everything. The parasitic ones infected all metazoans and all plants. Found in all sediments from Mount Everest down to the deepest trench, they were everywhere. Hookworms and bloodworms caused terrible diseases, especially in the tropics. They also attacked commercial crops. For every marine nematologist there were 10,000 plant nematologists and about 1,000 animal parasitologists, for commercial reasons. Nematocides were a big business. Nematodes were difficult to wipe out, they destroyed crops, killed animals and made people ill. The free-living ones did no harm; a person consumed hundreds per day, from tap water. Their ecological importance was unknown, but they must be important because numerically they constituted a huge wedge of biomass and the many things that fed at the surface of sediment were presumably feeding on nematodes. They were probably important in transferring energy out the system by feeding on bacteria and just about anything else. Some were predators, while many fed on bacteria, protists, foraminiferans or diatoms. It was thought that they helped in the breakdown of organic material because they scavenged into dead macrofauna and sometimes did not wait for an animal to die before feeding on it. Some of them released enzymes that broke down the organic material and some fed directly on the dissolved organic material. They probably kept bacteria in the growing phase because they were resistant to pollution, and they probably helped to dissipate oil and sewage. At the sewage-sludge dumping grounds off Britain, big shallow-water nematodes feeding on dissolved organics were so abundant they could be picked up in clumps the size of cricket balls; they were presumably converting sewage into biomass.

Nematodes did a lot of harm to people. They caused massive diseases in the tropics, and attacked animals and plants. The free-living ones, however, were on the side of the angels because they were important in keeping bacteria growing on organic material, breaking down organic material, keeping bacteria in the growth phase and generally passing organic material up through the food chain. Juvenile fish fed on them, in some cases coming along a beach and blowing on the sand to get the nematodes into the water column where they were helpless. Thus, they probably occupied an important intermediate position in the food chain.

Bioprospecting

Asked whether anyone was looking for useful genes amidst the diversity of nematodes, Lambshead said this was not happening now. His group had been approached by a consortium with a laboratory in southern Florida that was engaged in bioprospecting but the big problem had to do with who owned biodiversity. The Royal Botanic Gardens at Kew (London) had almost ended up in international court after starting to bioprospect in their living collections from various countries, when the Brazilian Government called for a halt, saying it owned the genes in Brazilian plants.

Kew had insisted that it was the owner of plants growing in its backyard. He understood that both sides had backed off. However, this was a current problem for museums that used to take specimens from all over the world; those specimens were drying up now that countries were afraid the museums were going to steal their genes. The problem had been the absence of a policy, though he believed that a set of rules was now in place.

As no one owned most of the deep sea, the answer was that bioprospecting could be done now but no one was doing it. The prospect was interesting because nematodes could be found everywhere, from hot water sulphur springs to the Skaggerak in the North Sea, where he had taken live ones from frozen coal dust. A German group in Bremerhaven had taken live nematodes from the Arctic pack ice and was working on the biodiversity of Antarctic terrestrial nematodes. Nematodes had an amazing ability to survive environmental conditions, and their enzymes worked.

Collection techniques

Asked about the procedure for estimating the abundance of nematodes in box cores, Lambshead replied that all the nematodes in a sub-core were mounted, on the false assumption that they represented the whole core, and the numbers were then multiplied. An analysis of box cores versus meiofauna cores from the same area, published by Vincx *et al.,* had shown that, as a mean, box cores were 40% as efficient as meiofauna cores. That percentage was misleading, however, because much depended on such factors as the nature of the sediment and the skill of the box-core operator, which used to be very important. When Adam Cook had tried to compare nematode abundances from around the world and the first graph did not look good, he had adjusted the box-core numbers by 40% and produced a better curve.

Box cores should not be used for meiofauna, though they were regarded as tolerably acceptable, depending on how the data were being used. As the box core tended to blow away the surface, it did not collect the same species at the same depth in the sediment. Moreover, besides the reduction in numbers, it collected slightly different fauna than a random sub-sample of a meiofauna core. The problem did not always arise, however. In certain CCFZ data from both meiofauna cores and box cores, an analysis of both abundance and diversity had shown no difference between the devices; the box cores seemed adequate, probably thanks to a skilled crane operator. Another factor might be the sediment: one geologist had told the Workshop that the sediment was coarse in situ, so that the box core might have worked because the sediment had not been blown away by the corer's bow wave.

Craig R. Smith observed that the effect had to do with the lowering protocol. The winch operator had not decided how the core went in; rather, the scientist had given instructions. The samples collected in the EqPac (equatorial Pacific) transect happened to have been collected under good sea-state conditions and with a good winch operator.

Nematodes as a study topic

Lambshead was asked why he was concentrating on nematodes when there were so many other species. He explained that, about 13 years ago, after he had received a doctorate in pollution ecology and was trying to use nematodes in pollution monitoring, his far-sighted department head had decided that, as the deep sea would eventually be used for dumping and mining, he wanted to have a deep-sea group. Under the 1980s reorganization of the Natural History Museum under Prime Minister Margaret Thatcher, a decision had been taken to target the groups that mattered taxonomically. Before that complete reorganization, Gordon Paterson, for example, had been an echinoderm specialist, but as echinoderms did not raise any taxonomic problem, he had been sent to the Smithsonian Institution and retrained under Kristian Fauchald as a deep-sea polychaete taxonomist. Since the museum was trying to focus on fields where its customer base wanted it to concentrate, the feeling had been that polychaetes and nematodes, as the biggest taxonomic problem in the deep sea, should be the focus of a taxonomic organization.

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Chapter 17 Pelagic Community Impacts and their Assessment

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The mining of polymetallic nodules on the high seas has the potential to impact vast areas, both on the seafloor and in the water column. Potentially exploitable deposits of polymetallic nodules are found over large expanses of the abyssal Pacific and Indian Oceans[1]. A key area of commercial interest, the Clarion-Clipperton Fracture Zone (CCFZ), is situated in the North Pacific Ocean between Mexico and Hawaii, in a region that appears to lie between the highly oligotrophic North Pacific tropical gyre and the more productive North Pacific Equatorial Countercurrent / eastern tropical Pacific regions[2]. The plankton in this region, particularly of the tropical gyre, is characterized as having high diversity and stability and being remote from terrestrial influences[3]. Weak seasonality is observed in both regions. Interannual variability may be as great or greater than seasonal variability, as seen from the Hawaii Ocean Time-series (HOT) investigations[4]. Seasonality in the two regions differs: higher productivity is observed in winter in the central gyre but in spring and autumn in the countercurrent region[5]. The zooplankton communities are considered "climax" communities, based on the considerable age of these mid-ocean ecosystems, their stability and lack of disturbance. There is little basis on which to project the likely impact of mining operations.

Deep-sea nodule mining may be anticipated to transport considerable sediment and deep water to the surface mining vessel: an estimated 7,400 tons of sediment and 34,560 cubic metres of water per day[6]. If discharged at the surface, this would likely have a substantial impact on the pelagic ecosystem, based on the flux of nutrient into oligotrophic water and the influence of sediment on light penetration, trace-metal concentrations and the feeding of planktonic suspension feeders[7]. It was therefore agreed at the 1998 Workshop of the International Seabed Authority in Sanya, China, on environmental guidelines for deep-seabed polymetallic exploration, that discharge should be below 200 m, the approximate depth of the epipelagic zone, and if possible, deeper than 1000 m, below the oxygen-minimum zone and the depth of vertical migration for much of the fauna within the upper pelagic zone[8]. I assume in this paper that this deep-discharge recommendation will be followed to minimise impacts on the fauna of the upper waters. However, some near-surface discharge may be anticipated, so potential impacts will be examined throughout the water column. Recent iron-enrichment experiments demonstrate that such nutrient enhancement can have substantial impacts on plankton productivity and species composition[9]. However the impacts of deep-sea mining could extend over a considerable period and involve far larger perturbations, and cannot be predicted with any confidence from the results of short-term experiments.

Assessment of water-column impacts is complicated by the extensive size range of organisms to be considered -- literally, from bacteria to whales -- and the range of depth zones (pelagic, meso- and bathypelagic), each containing potentially distinct communities. The approximate depth limits of these zones are: pelagic zone, 0-200 m; mesopelagic zone, 200-1000 m; bathypelagic zone, 1000 m to near bottom. Temporal variability -- variability on seasonal, interannual and decadal time scales -- is also greater for pelagic than for abyssal communities, with the potential for aliasing and the need to distinguish seasonal and interannual variability from the potential impacts of mining activity.

Standardised sampling tools and protocols are essential to enable comparison between mining-impact sites and across different periods. This is probably nowhere more important than in working with pelagic communities, given the wide range of sampling tools available and where each choice of, say, net type and mesh size yields a somewhat different "community".

1. Potential Water Column Impacts

1.1. Potential microbial impacts

Large amounts of sediment released into the water column and sedimenting through it have the potential to strip the water column of aggregates and other sources of particulate carbon, thereby stripping it of a principal source of its productivity. This would potentially reduce microbial activity and nutrient regeneration generally. Some oceanic ecosystems, particularly those in the central gyres, are based largely on the "microbial loop". These impacts could therefore fundamentally alter pelagic community ecosystem structure and functioning.

1.2. Potential phytoplankton impacts

Transport of nutrient-rich deep water into the euphotic zone could significantly enhance productivity and alter community composition from nitrogen fixers and species associated with low nutrient to those with higher nutrient preferences.

Trace metal release into the euphotic zone could have a positive or negative impact on productivity, by either providing necessary micronutrients (e.g. iron) or poisoning sensitive species, thereby altering community composition.

Release of particulates into the euphotic zone may reduce water clarity, decreasing euphotic zone depth. This would be expected to particularly impact phytoplankton in the deep chlorophyll maximum.

1.3. Potential zooplankton impacts

Release of particulates may reduce feeding efficiency of suspension feeders. This will particularly impact species in the zone of sediment and mine-tailings discharge, and zooplankton in the near-bottom layer most impacted by mining activity. Little is known about the productivity of deepwater zooplankton but they are presumably food limited; reduced feeding efficiency may significantly impact growth and reproductive efficiency.

Enhanced (decreased) productivity at lower trophic levels will enhance (decrease) secondary productivity and potentially alter community composition and food web pathways. Changes to the microbial loop and phytoplankton community structure may have fundamental implications for the size structure of the zooplankton community.

Enhanced trace metal concentrations within the sediment plume or sediment discharge, and mobilization of trace metals in the oxygen minimum, could all have potentially toxic effects on zooplankton groups.

1.4. Potential micronekton impacts

Potentially there are both direct and indirect impacts of mining on the micronekton. The discharge may directly impact the micronekton in the region of discharge through elevated trace metal contamination. Indirect impacts of mining activity on the micronekton may flow from changes in primary and secondary production and/or in the size-frequency distribution of their prey field. Heavy metal contamination of the food chain may lead to bioaccumulation of toxins up the food chain.

1.5. Potential seabird and marine mammal impacts

The potential impacts of deep seabed mining include toxic effects of bioaccumulation of heavy metals through the food chain and the potential effects on feeding of altered prey availability / food-chain productivity. The size distribution of prey fields, as well as their productivity, may be altered.

2. Standardized Environmental Impact Assessment

2.1. Monitoring objectives

Monitoring baselines are to be established for the following:

?? Bacterioplankton biomass and productivity throughout the water column;

?? Phytoplankton biomass, composition and productivity;

?? Zooplankton composition and biomass throughout the water column;

?? Micronekton composition and biomass throughout the water column, and

?? Marine mammal abundance and, so far as possible, behaviour.

2.2. Overall survey design

Key issues in the overall design of a monitoring programme are the spatial and temporal scales of variability. Although spatial gradients are reduced in the open ocean, the size of the claim areas (150,000 square kilometres) and their position (e.g. CCFZ being between the North Pacific central gyre and eastern tropical Pacific / North Pacific Equatorial Countercurrent region) suggest that there will potentially be significant spatial variability. Sampling should therefore be carried out along a series of stations orthogonal to that gradient, presumably latitudinally. Given the size of the claim areas (387 km on a side), sampling might be based on a series of four stations, each representing about 100 km, as suggested by Smith (chapter 3 above, section 3.1).

Control and impact sites also must be determined, based on the constraints that they need to be as similar as possible oceanographically but that the control site must be beyond the area of impact. The impact of mining activity on the water column -- the extent of drift of the discharge plume -- will presumably affect a very large area.

Seasonal variability needs to be assessed. However, given the different seasonality at the different biomes, this cannot be achieved with less than four cruises a year during the period of baseline monitoring, combined with a mooring for continuous sampling at a central site.

Zooplankton and micronekton often carry out extensive vertical migrations. Estimates of their abundance also often vary considerably between day and night due to net avoidance. It is therefore recommended that sampling for these groups be replicated day and night.

A range of sampling tools needs to be utilized to assess impacts on the water column community:

?? Microbiology, phytoplankton, microzooplankton: water samples at discrete depths throughout the water column;

?? Zooplankton and micronekton: depth-stratified net sampling through the water column; and

?? Marine mammals: observer transects between stations.

As far as possible, sampling protocols should follow standard procedures developed for JGOFS (Joint Global Ocean Flux Study)[10].

2.3. Particulate organic carbon and nitrogen

Sampling is carried out at standard depths: 0, 25, 50, 75, 100 m, chlorophyll maximum, 150, 200, 300, 400, 500, 750, 1000 m, oxygen minimum, 1500, 2000, 2500, 3000, 3500, 4000 m, 10 m above bottom.

Presumably oxygen, CO_2, salinity and nutrient samples will be obtained from all or most of these depths. Samples for particulate organic carbon (POC) and particulate organic nitrogen (PON) are obtained from each bottle following JGOFS protocols, based on filtration of water samples onto GF/F (glass-fibre) filters and analysis with the CEC (Control Equipment Corporation) 240-XA elemental analyser[11].

2.4. Microbiology

Bacterial abundance, biomass and productivity should be measured at all standard depths. The standard method for assessment of microbial biomass and abundance is based on counts of bacterial numbers from samples fixed in glutaraldehyde, stored in the dark at 4 degrees Celsius, filtered onto a 0.2-micron Irgalan Black stained Nuclepore polycarbonate filter, stained with acridine orange or DAPI and examined under an epifluorescence microscope[12]. Counts must be made within several days of fixation. The estimated volume of randomly selected bacteria and use of carbon/volume estimates provides an estimate of bacterial biomass[13]. Microbial productivity is assessed from measurements of the incorporation of tritiated methyl thymidine[14].

2.5. Phytoplankton

Phytoplankton biomass is assessed based on measurement of chlorophyll *a* and phaeopigments by fluorometric analysis.[15] Community composition is assessed both from high-performance liquid chromatography (HPLC) analysis of algal pigments and cell counts, using the samples and procedures as per bacterial cell counts based on epifluorescent microscopy[16]. Biovolumes are based on measurements of a sub-sample of different phytoplankton cell types and estimates of the third dimension[17]. Sampling is carried out at standard depths within the pelagic zone: 0, 25, 50, 75, 100 m, chlorophyll maximum, 150, 200 m. Phytoplankton productivity is assessed based on the incorporation into organic matter of inorganic radioactive C-14, following 12-hour incubations under as realistic light conditions as possible[18]. New production, relative to primary production based on recycled nitrogen, should be measured based on the incorporation of NO_3 labelled with N-15 into phytoplankton during incubation experiments, similar to the incorporation of C-14[19]. New production may prove an important parameter, if there is significant flux of deepwater into the euphotic zone.

2.6. Zooplankton

Depth-stratified sampling over the water column can be carried out most efficiently with a BIONESS (Biological Net and Environmental Sampling System) or MOCNESS (Multiple Opening and Closing Net and Environmental Sensing System) with nine or ten nets, mouth opening 1 m^2 and mesh size 200 ?m. The sampler is lowered while underway to within 25 m of the bottom and then towed obliquely upward so that nets sample the following depth horizons:

Net 1: Surface – bottom-25 m
2: Bottom – 25-2000 m
3: 2000-1000 m (or base of O_2 minimum layer)
4: 1000-500 m
5: 500-200 m
6: 200-0 m.

Two tow series will be carried out in daylight hours at each station and two at night.

Zooplankton sampling procedures follow the *Zooplankton Methodology Manual* published by the International Council for the Exploration of the Sea (ICES)[20]. A flow meter, calibrated before and after each cruise, is placed in the mouth of the net. Larger gelatinous zooplankton are removed, identified, enumerated and their volume measured prior to sample fixation. Samples are fixed in 4 percent buffered formaldehyde. In the laboratory, displacement volume is measured and aliquots counted so that at least 300 organisms are enumerated, by genus where possible.

Microzooplankton, defined as organisms less than 200 ?m in length, are sampled from the Niskin bottles during the standard rosette sample casts and at the standard depths. One-litre samples are fixed with Lugol's solution and examined after allowing the organisms to settle on a settling chamber so that they can be enumerated with an inverted microscope.

2.7. Micronekton

The micronekton can be sampled using a MOCNESS-10, a system with six nets, a 10-m^2 mouth opening and a 3-millimetre mesh. The same depth horizons and replication will be used as for the zooplankton sampling. Gelatinous organisms are identified, enumerated and weighed prior to preservation; other organisms are fixed as per the zooplankton. In the lab, they are identified to species, enumerated and weighed by group.

2.8. Marine mammals

Observations of marine mammals (species and behaviour, where possible) will be carried out along the cruise track between each station, from entry into the claim area to the first station and from the last station to the point of exit from the claim area. Observation protocols will be based on a single trained observer, who should make observations of numbers by species and behaviour. Observations should follow the protocols of the International Whaling Commission[21], based on a constant watch by the trained observer with the assistance of crew or other scientists during daylight hours along a preset cruise track. The vessel is diverted to approach sighted animals to identify species and count all animals (so-called "closing mode"). Only primary sightings are included in the abundance estimates, when full searching effort is applied. Search effort is recorded whenever there is a change in effort and environmental conditions are recorded hourly.

2.9. Remote sensing

Satellite ocean colour images of the claim area will be archived and potential differences in ocean colour between reference and impact sites analysed.

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SUMMARY OF PRESENTATION AND DISCUSSION ON PELAGIC COMMUNITY IMPACTS AND THEIR ASSESSMENT

Introducing his paper, Dr. Koslow said his role was not to impose standards but rather to set up a framework for looking at pelagic community impacts, pointing to areas that needed standardisation and then helping to achieve consensus among participants in the Workshop. As Myriam Sibuet had stated (chapter 9 above), standardisation was needed in certain areas; in the case of plankton, for example, a range of mesh sizes were being used, some of which might be so coarse that important parts of the community were completely missed.

His presentation would deal with three aspects: (1) a conceptual framework for looking at ecosystem structure and function throughout the water column, as a basis for seeing what had to be sampled and why; (2) potential impacts of deep-seabed mining on the water column, and (3) sampling protocols for assessing potential impacts. He would attempt to cover everything from microbes to whales.

Ecosystem structure and function

He began by discussing pelagic communities, their structure and composition, from two dimensions – vertical and horizontal. Pelagic communities had typically been divided vertically into three layers: (1) an epipelagic zone down to about 200 metres, which was more or less the depth limit of vertical migration of most epipelagic zooplankton; (2) a mesopelagic zone from 200 m down typically to about 1000 m, although in the eastern Pacific Ocean it might be more relevant to define its lower margin at the level of the oxygen-minimum zone, and (3) a bathypelagic zone, the deepest. Among the fish populations, flying fishes, tuna and the like stayed in the upper waters, while many mesopelagic fishes migrated into the upper waters at night and most of those in the bathypelagic zone resided there permanently.

The horizontal spatial dimension concerned biogeography. In this regard, far more was known about pelagic communities than about benthic ones. For a number of the major groups, scientists had a handle on what species were present and how they were distributed. John McGowan and his co-workers had described the zooplankton provinces of the Pacific[22], while a recent book by Longhurst on ecological geography used satellite oceanography and a review of the literature to synthesize what was known about the production regimes and phytoplankton provinces of the world's oceans[23]. It was heartening to realize that the results from the various works were fairly consistent.

Looking at the size distribution of organisms in the water column, he said that while these distinctions had been defined partly for operational reasons in terms of the mesh sizes people used, it did have some correspondence with reality in that the size categories were composed of very different groups. The picoplankton, measuring just a micron or a few microns, were very small photosynthetic cells. The nanoplankton, up to about 20 µm, were fairly small phytoplankton cells, some of which were heterotrophic, feeding on each other. The 20-200-µm range was usually considered the realm of the microplankton, including both larger phytoplankton cells and small zooplankton, mostly protistan groups. Between about 200 µm and 2 millimetres were macroplankton or mesoplankton, of which copepods were the dominant group among a number of other things. Above 2 mm were a host of larger plankton such as krill, euphausids, gelatinous plankton and so on.

Epipelagic ecosystems

He turned next the trophodynamics of epipelagic ecosystems, or how these systems functioned. Well into the 1960s and 1970s, people thought that what had been termed the classic ecosystem structure was fairly universal. However, it turned out to apply primarily to coastal areas, upwelling zones and regions with high nutrient input. In such places, a substantial supply of nutrients led to the production of relatively large phytoplankton that were grazed predominantly by macrozooplankton such as copepods, and these were then grazed directly by fish such as clupeids, herrings and anchovies. This was a fairly efficient and short food chain, dominated by what was called new production. New production was, basically, production with new nutrients that had entered the system. Increasingly, however, it had come to be realised that, particularly in areas such as the open ocean with low nutrient input, this was not the real structure of the production system. Those areas tended to incorporate what was known as a microbial loop, in which bacteria regenerated nutrients, small phytoplankton cells in the pico- to nanoplankton range were the predominant primary producers, microzooplankton grazed on both the small phytoplankton and the bacteria, and they in turn were grazed by macrozooplankton and fish.

If production at the primary level amounted to 100 grams of carbon, for example, typically about 10-15 g would be produced at the secondary level, with a loss of about 85-90 percent in going from one step to the next. Adding a further step below the fish level meant that overall productivity at that higher level was down by about 90%. This was the system that existed in the open ocean, which depended predominantly on regenerated nutrients.

One potential impact of discharging into the near-surface water a large amount of deepwater heavily loaded with nutrient might be to shift the ecosystem more toward the classic food chain. One might ask if that was such a bad thing. However, whether good or bad, changing the functioning of a large ecosystem was obviously something that warranted caution.

Looking at how the phytoplankton functioned in the epipelagic ecosystem, he recalled that the Japanese and Korean investor groups, in presenting their data to the Workshop (chapters 8 and 10 above), had described the typical profile of low chlorophyll in the near-surface waters and a chlorophyll maximum at about 75-125 m. This was typical of open ocean systems, where the near-surface layers, above 50 m, had high light but low nutrient levels and very low chlorophyll. The phytoplankton in that region might be working by nitrogen fixation or they might simply be predominantly very small cells, whereas down in the chlorophyll maximum the low light conditions were at the boundary where nutrient was high. As Sibuet had mentioned in regard to bacteria (chapter 9 above), one could not directly relate chlorophyll, whether high or low, to productivity. Perhaps the cells in the upper water were turning over quickly while the others were turning over slowly. In any case, it was vital to sample the two regions to see both community composition and productivity.

As for zooplankton, one of the key issues was which group, microzooplankton or macrozooplankton, were the dominant herbivores at this level of the food chain. Standard dilution experiments to measure microzooplankton grazing, like those reported by the Korean research group (chapter 10 above, section 3.3.2), might be incorporated into the impact assessment to measure the relative importance of the two groups.

An important feature of the macrozooplankton was that many of them carried out diel vertical migrations down to 100-200 m, which was important in designing the sampling. With a single oblique haul from 200 m to the surface, for example, there was no way to know where the plankton were in the water column, the near-surface layer or down in the chlorophyll maximum. It might be important to carry out sampling both day and night, and to conduct depth-stratified sampling, in order to tell where the zooplankton were in the water column.

Among the fish groups were a combination of epipelagic planktivores and mesopelagic migrating planktivores such as mictophids. There were a number of deep-water planktivores, of which the mictophids were probably the best known. These groups migrated down to several hundred or a thousand metres on a daily basis. The diel movements and feeding of these fish were probably one of the key links between the mesopelagic layer and the epipelagic zone.

Meso- and bathypelagic ecosystems

The meso- and bathypelagic systems were based predominantly on detritus in different forms, particulate or in aggregates such as marine snow. The detritus was colonised by bacteria, which were being grazed by microzooplankton that in turn served as the food of macrozooplankton. While no one understood what the impact of discharge would be, one possible impact might be dilution: though it was not clear to what extent macrozooplankton were filtering out particulates as they moved through the water, if there was a lot of discharge material it could dilute what was already a very dilute food source. Another possibility was that, as the sediment sank rapidly through the water column, it might strip the water of organics.

Biogeography of the CCFZ

Describing some features of the Clarion-Clipperton Fracture Zone (CCFZ), Koslow said it seemed to straddle two biogeographic provinces and had the characteristics of both. According to work by John McGowan[24], who had looked at the dominant copepod communities of the Pacific Ocean, the two provinces corresponded to the dominant water masses and current systems of the central tropical gyre region and the tropical equatorial Pacific region.

Alan Longhurst[25], looking at seasonal cycles of productivity in the region, had seen only slight seasonality in the mixed-layer depth of the central gyre, although there seemed to be some increase in the summer. As Craig Smith had pointed out (chapter 3 above), this was a low productivity system, producing about 5 grams of carbon per m^2 each month, which translated to about 60 g per year. A productive zone such as the upwelling regions of the California or Peru currents produced hundreds or even 1000 g per year, greater by a factor of 10 or more. In the North Pacific Equatorial Countercurrent area, the mixed-layer depth again showed little seasonality, though with some indication of both a spring and an autumn bloom. Thus, that the seasonality in these two regions was quite different -- potentially a spring and autumn bloom on one side and potentially a summer bloom on the other.

Consequently, in sampling these regions there would be a danger in having only one cruise per year, as a particular cruise could pick up the bloom in one period but not in another. He therefore recommended several cruises, perhaps four in a year. He also endorsed Smith's suggestion for a mooring site so that the region could be studied continuously over a year. He noted that many of the classical studies on which these data were based had been carried out quite early, in the 1960s and 1970s, before the importance of the microbial loop had been recognized and before the roles of microzooplankton and very small phytoplankton had been examined, so that much of this work needed to be revised. Moreover, methodologies had changed; trace metal clean techniques had often shown higher productivity in areas that had appeared to have low productivity, an effect that might prove particularly true for the very small phytoplankton cells predominant in the upper layers.

Both of these biogeographic provinces with different dynamics were high in diversity. While probably not as diverse as some of the benthic areas that had thousands and thousands of species, they were among the most diverse pelagic systems in the world's oceans, with hundreds of species of copepods alone. Even though productivity was low, there was probably a latitudinal gradient in production, making it important to sample along a latitudinal gradient as the Japanese and Korean teams had been doing. Another important factor was that interannual variability might be greater than seasonal variability. That fact had emerged from the Korean work, where sampling across the El Niño / La Niña cycle had shown clear impacts. Hence the need to resolve this seasonal variability question with either a number of cruises or a mooring.

Potential impacts of mining

Koslow recalled the consensus at the 1998 ISA Workshop in Sanya, China, that the discharge of deep water and tailings from a mining operation should take place at fairly deep levels[26]. It was unclear to him whether such a rule would be put into effect or how much leakage might occur. In his discussion, he assumed that there would be at least some discharge in the surface waters, but clearly, it was desirable to minimise the amount.

Among the potential impacts on microbiology, mining discharges might strip the water column of aggregates and particulates, and reduce the roles of nutrient recycling and the microbial loop. For the phytoplankton, transport of nutrient-rich deepwater into the euphotic zone would enhance productivity and could profoundly alter community composition, and species and size structure. Speaking facetiously, Koslow said that if discharges visible from satellites took place totally into the surface water, they might impact the global carbon budget, enabling the mining companies to obtain carbon credits. Recent iron-enrichment experiments in the equatorial current in the South Pacific had shown that a single enrichment in surface water had had a measurable impact on both production and species composition. Therefore, in a chronic, long-term operation continually pumping deepwater up to the surface could have a substantial impact.

Other possible impacts might result from the release of trace metals into the euphotic zone. It was unclear whether the effects would be positive or negative. Some trace metals such as iron had been shown to be limiting; since the nitrogen fixation taking place in surface waters had a strong need for iron, trace metals would enhance that kind of productivity. They might also have a negative impact by poisoning some cells, thereby altering community composition.

The release of particulates such as sediments or tailings into the euphotic zone would affect light penetration and decrease the depth of the zone, which would presumably have a large impact on the deep chlorophyll maximum at the base of the zone. For zooplankton, the release of particulates would presumably reduce the feeding efficiency of suspension feeders. Enhanced or decreased productivity at lower trophic levels would enhance or decrease secondary production. Any change in the size structure and species composition of the phytoplankton would presumably affect the zooplankton. Again, there was the potentially toxic effect of sediment plumes and trace metals.

Moving on to the micronekton and nekton, he said flow-on effects would again result from changes in primary and secondary productivity, size and frequency distribution. There might also be bioaccumulation of toxins, probably not a trivial issue since a number of commercial species, such as tuna and swordfish, already had fairly high levels of heavy metals in their tissue naturally and one would not want to increase them. As to potential impacts on larval fish, there might well be a number of tunas in both the Indian Ocean area and in the Pacific, since several tuna species typically spawned in the open ocean.

Speaking finally of seabirds, he mentioned a dumping site off Tasmania where jarosite, a waste product of zinc mining, was being dumped and where testing of a small seabird had raised concern about elevated levels of cadmium. It might therefore be worthwhile for seabirds to be examined if bioaccumulation of toxins became an issue. Altered prey availability and food chain productivity would presumably affect these species at the high end of the food chain.

Sampling protocols for impact assessment

Koslow next discussed the dominant components to be sampled, the depths for sampling and some of the standard methods. His basic proposal was that some of the standard protocols in the literature should be followed, since a great deal of thought had gone into sampling methods for the various groups and a number of leading researchers in these areas had agreed on that approach. For instance, everything from particulate organic carbon (POC) and particulate organic nitrogen (PON) to bacterioplankton and phytoplankton were covered in the protocols developed for the Joint Global Ocean Flux Study (JGOFS), which were available on the World Wide Web[27]. For the zooplankton and microzooplankton, an excellent zooplankton methodology manual prepared recently by the International Council for the Exploration of the Sea (ICES)[28] was recommended for any groups involved in zooplankton sampling. For marine mammal observations, the International Whaling Commission (IWC) had worked out protocols over the years.[29]

He proposed that primary sampling for bacteria, phytoplankton and microzooplankton be carried out by obtaining water samples at standard depths. It might be felt that these were too many or the Workshop might want to change them but he thought it desirable to sample in the upper epipelagic zone, the chlorophyll maximum, and the mesopelagic and bathypelagic zones. Whatever standard depths were agreed, he suggested that the following components be studied:

?? *POC and PON*.

?? *Bacterial abundance, biomass and productivity*: The standard method for abundance involved counting under an epifluorescence microscope. Biomass was assessed largely by volume and dimension estimates, while tritiated methyl thymidine was used to examine bacterial productivity.

?? *Phytoplankton biomass, community composition and production*: There were problems with using chlorophyll *a* as a standard measure for biomass, but in conjunction with analysis of pigments by high-performance liquid chromatography (HPLC) and epifluorescence cell counts, a good idea could be obtained of what was present and how much. Phytoplankton work would be done only in the upper 200 m, while microscope counts and C-14 productivity studies would probably be done at least at two depths in the surface layer and in the chlorophyll maximum.

?? *Microzooplankton*, defined as plankton smaller than 200 µm: An agreed mesh size of 200 µm should be chosen. Zooplankton workers had used a range of sizes from 200-500 µm; however, particularly in open ocean regions where the zooplankton tended to be quite small, a coarse mesh would miss a great deal of it, hence the proposal to standardize on 200 µm. The standard method was to use an inverted microscope for examining several water samples. Biomass was typically looked at by estimating volume. Standard dilution experiments would be useful to examine the role of the microzooplankton in grazing the phytoplankton.

?? *Mesozooplankton*: Agreement should be reached on a standard set of sampling depths to look at the zooplankton, consisting of surface-200 m, 200-500 m, 500 m-oxygen minimum and two tows in the bathypelagic zone. While a simple opening/closing net could be employed, to carry out a set of stratified tows it would be easiest and most efficient to use a device such as a Multiple Opening and Closing Net and Environmental Sensing System (MOCNESS) or a Biological Net and Environmental Sampling System (BIONESS), which were standard in a number of areas. Biomass could be looked at either through displacement volume or dry weight, while abundance was typically assessed through microscope counts.

?? *Micronekton*: The same depths should be sampled as for plankton. Again, there was a wide range of samplers, but one possibility was something like the MOCNESS-10, an opening/closing net system that had a 10-m² mouth opening, enabling it to sample the depths quickly and efficiently. The standard treatment of micronekton was to sort the catch into species groups and then carry out counts and weights by species.

?? *Marine mammals and seabirds*: The most realistic approach would be to have visual transects between stations. Typically, under the IWC protocols, when a marine mammal was spotted the observation vessel would divert from its course to try to identify the mammal or get a better idea of the count and then go back to the track. Obviously, that would not be done for seabirds, but a well-trained person could readily identify seabirds.

SUMMARY OF DISCUSSION

Use of existing standards

At the start of the discussion, Craig Smith observed that a number of accepted techniques and standards for different types of sample collection and analysis existed either in protocol manuals, like that of JGOFS, or in scientific papers. One efficient approach to standardisation would be to say that, in sampling macrofauna, for example, the techniques of Sibuet *et al.* (1975) were recommended. Every scientific paper described its methods, and identifying from the literature a few papers that described the methods adequately would be an easy way to set standards. For much deep-sea research, no protocol manuals were available, so that a landmark paper might be used instead.

Koslow stated that that was what he was proposing also. A decision could be taken, for a particular component, to use a specified method from a particular paper such as the JGOFS protocols or the ICES manual. The more advanced state of water-column research, and the greater amounts of money available for it, had led to the manuals and protocols in that area. So many groups around the world were carrying out cruises that it had become necessary to reach an agreement about methods. In the absence of a strong reason to the contrary, it made sense simply to adopt, say, the JGOFS protocols for measuring bacteria, phytoplankton and so on, which everybody could then follow, making things a lot simpler. The JGOFS and IWC protocols and the ICES manual were quite specific, amounting to cookbooks.

Magnitude of mining impacts

Asked about the size of an area likely to be influenced by a mining operation and the probability of a negative impact on the ecosystem, Koslow mentioned a recent paper about environmental impact assessments in the marine versus terrestrial realms. The paper had pointed out that in the terrestrial realm, when there was talk about clearing a forest, it seemed clear how the landscape would be changed and what the negative versus positive arguments were. In a marine situation such as the water column, those elements were not always clear. What mattered was not so much whether a change might be negative or positive but the fact that there would be a change and an impact. Scientists, conservationists and policy makers had to decide what level of change they found acceptable. If, for example, a large discharge of deepwater enhanced nutrient and increased productivity, it might be thought of as either positive or negative, but the point was that there would be an impact, even one that could be seen from space.

As to the potential diameter of the impacted area and the magnitude of the impact, eventually a number of claim areas might be mined and several ships might be discharging. Hjalmar Thiel had estimated that something like 34,000 m^3 of deep water might be discharged each day in a single mining operation[30]. Trace elements and pore water would come up with the sediment, and he was not sure what the whole mix would be. Recent iron-enrichment experiments with a single dumping of iron into a small patch of water had shown dramatic changes in productivity and species composition. Therefore, several vessels working for 10 or 20 years could produce a substantial impact.

The participant who asked this question remarked that environmentalists and quite a few biologists raised scare scenarios about tremendous devastation, even though the volume of material lifted up from the deep ocean in a mining activity would be negligible compared to the volume of the ocean and would affect only a limited area. When trying to design a code for future ocean mining, the question arose as to whether this type of activity should or should not be allowed.

Koslow responded that the current question involved trying to assess what the impact would be, not setting policy. It would be easy to estimate how much new productivity and carbon might result from the discharge of a specified amount of surface discharge. With a chronic effect occurring 300 days a year over 10 or 20 years, the global community would want to assess the impact. That should not be done just by saying that it would be trivial or significant. An evaluation would be needed and, because the circumstances of discharge were unclear, some monitoring of the water column was required.

Asked whether the impact would be different if the discharge occurred in deep water rather than at the surface, he said he thought the consensus at the Sanya Workshop had been that releases should be below 1000 m, in other words below the oxygen-minimum layer and the whole mesopelagic level. In that case, surface effects would be limited to some accidental discharges and overflows, while the primary impacts would hit the bathypelagic plankton as the sediment went down through the water column. Presumably, the impact would affect an area of the ocean that was a lot less sensitive to human concerns. While he recommended minimising the impact on the surface ocean, some discharge would be almost certain, hence the need at least to consider what the potential impacts could be and look at them in relation to the amount of discharge.

The participant who raised this question remarked that, if the International Seabed Authority were to set a tailing discharge depth at perhaps 1000-1200 m from the surface, the consortia could save a lot of money by not having to provide information about the plankton community in the upper 1200 m or to monitor that area during mining. He acknowledged that some information might still be needed on unavoidable impacts from the mining ship or platform – for example, noise in the water that might affect mammals. Another participant thought this might be a good idea for impact monitoring but baseline monitoring should cover the entire water column.

One participant said he had made a fast computation according to which a collector 16 m wide, travelling at 2 kilometres an hour at a depth of 4500 m, would move between 1000 and 2000 m^3 of water an hour, which would be diluted in 15 million m^3. (Another speaker observed that the amount of discharged water would be about equal to the volume of the mining vessel.) As an engineer rather than a scientist, it seemed to him that 2 parts out of 15,000 implied a very diluted effect in the water column. On the bottom, the collector would kill everything; there was no way to be gentle with the bottom. However, because energy use for the collection process was one of the major problems faced by engineers, the aim was to avoid moving what was not useful. Most of the sediment debris would be washed away at the bottom, so that mostly water and nodules would be brought up. If it were possible, only nodules, pure and clean, would be lifted.

Koslow was asked how disturbances and mortality at the bottom would affect animals in the water column or at the surface. He replied that the tendency was to think of the system as working primarily from the top down, with most of the organisms in the mesopelagic and bathypelagic realms deriving their primary food source from the particulates and detritus sinking through the water column. However, while most of the food came from the surface rather than from the bottom up, Smith had pointed out research that had identified releases, reproductive products and other things rising from the seabed up to the surface. The question deserved further examination, as little work had been done on it

Smith said his gut feeling was that the surface water impacts would probably not lead to species extinction, at least not on the same scale as at the bottom. However, the volume of water to be discharged would not stay as a cube and sink to the bottom of the ocean. It would mix in the upper ocean and it was qualitatively much different from surface waters. According to the earlier modelling efforts that Charles Morgan had cited (see chapter 4 above), it would generate a standing plume of 85 by 20 km. It was reasonable to expect enhanced productivity and altered food web dynamics in that plume. This was not a large part of the ocean and there would probably not be a devastating impact, but there would be some impact and it almost certainly would be visible from a satellite, so that the public would be aware of it. Whether or not that was acceptable was another issue.

Nevertheless, the discharge would be into the deep water at a depth to be defined, not on the surface, a participant countered. No current design contemplated discharging at the surface.

Smith acknowledged that he had presented a worst-case scenario with discharge at the surface. He thought that, for minimal impact, the best idea might be to discharge at 10 m above the bottom, into the environment that was already disturbed.

Koslow reiterated his view that the project would be much more acceptable to everybody if the deepwater and sediment tailings were put back into deep water.

Asked whether enough was known to make reasonable predictions about the bathypelagic zone (4000-5000 m) where the discharge might occur, Koslow said nothing was known about that zone. All the work he knew about had been carried out mostly in the epipelagic zone, with some in the mesopelagic. There was some knowledge about the distribution of copepods, euphausids and other planktonic groups, and people had worked on some of the mesopelagic fishes. However, only a handful of researchers had made tows deeper than 1000 m.

Purposes of monitoring

A participant remarked that making so many measurements at multiple depths would be good science but terribly expensive. Measurements should be limited to those that would answer such questions as the impact on the food chain and related factors. When experiments were planned, there should also be interpretation procedures that would relate the data to the answers being sought about impact.

Koslow responded that, with so many groups -- French, Russian, Indian, Korean, Japanese and others -- conducting research, he did not think it necessary for each one to carry out the whole programme. As only a few areas in the world's oceans were involved, it would be sensible to think about pooling research efforts so that one or two groups would focus on the water column in the CCFZ, for example. He had been impressed by the presentations made by the Japanese and Korean groups, which seemed to be making virtually all of the measurements under discussion. Their activities showed that the programme was within the realm of feasibility and that it corresponded to what people were actually doing. The aim was not to tell every group what they needed to do but to reach a consensus on what was important. The purpose of his talk was to provide a conceptual framework of how the system seemed to work, because to understand the impacts one had to see how the food chain operated at the various levels and to grasp the role of the bacteria, phytoplankton, macrozooplankton and others. There were standard measurements for making such assessments but he did not think it necessary that everybody do all of them.

A participant stressed the need to distinguish between impact assessment and increase in scientific knowledge. Increasing knowledge was an objective of humankind, while evaluating impact was an objective of a company or the Authority. The two were quite different and must not be confused.

Smith suggested that, when the Workshop broke up into working groups, participants should try to identify critical issues that needed to be addressed and might be best addressed by cooperative programmes. However, they might also recommend standardizing other kinds of studies so that the data would be comparable. The idea would not be to say that people had to do certain things; rather, if they performed certain measurements they should do so in a manner comparable to other oceanographic programmes and efforts.

Sampling parameters and depths

A participant remarked that, in deciding what parameters should be monitored, it was first necessary to know which ones would be sensitive to the impacts of deep-sea mining. Further, in selecting depths for sampling, the level of the oxygen-minimum zone had to be known. In the western part of the CCFZ, for example, that zone was generally at about 800-1000 m, but sometimes it was at 300-400 m or deeper than 1200 m. Koslow responded that, where the oxygen minimum varied dramatically, it was not a good reference point.

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PART IV

Sampling, Database and Standardization Strategies

INTRODUCTION

The Workshop examined two specialized aspects of information gathering and dissemination, relating to sampling design and database development. It then held an open discussion on standardization strategies and heard a presentation on this topic outlining many of the basic issues involved in collecting and analyzing information.

A general sampling design for baseline studies, aimed at deriving statistically valid results from research into potential mining impacts, was offered by Dr. Ron J. Etter, professor in the Biology Department of the University of Massachusetts, Boston.

He explained that the design would have to distinguish between an impact from mining and the naturally occurring variations from place to place and from time to time on the ocean bottom. The design took the classic form of an impact site – the mining locale – and control sites distant from the impact. Because so many environmental changes might conceal the results of such a comparison, the design relied on replicates – repeated samplings at several locations – to enable statisticians to separate anthropogenic from natural causes.

In his scheme, data would be gathered by collecting sediment-filled box cores from the seabed and counting or otherwise measuring their animal communities. An impact site and two control sites would be designated, and three samples would be taken at each of three stations within each site, in a process repeated eight times over a period of some eight years, for a total of 216 box cores. Additional samples would be needed if researchers wanted to distinguish between the torn-up area of a mine site and the adjacent area affected by the mining plume. On the other hand, investigators could get away with fewer samples if they had a better idea, gained from other experiments, of precisely how a mining operation affected the environment. Less-rigorous sampling strategies could be employed if investigators simply wanted to find out what was present at different locales on the seabed.

When a participant questioned the need for so many samples, Etter explained that the statistical device known as power analysis could be used to determine how much sampling was needed to attain a given level of probability. For example, if the size of the impact were known in advance, fewer samples would be required. Such information could be obtained from dose-response experiments and other measurements.

Dr. Michael A. Rex, the biology professor at the University of Massachusetts who had spoken earlier of biodiversity, presented a framework for the contents and functioning of a computerized and integrated ISA database covering seabed exploration, mining and assessment. Data to be included would cover such fields as:

- *Benthic ecology*: sieve size, species identification, number of individuals per species, sediment depth in box-core samples, density, biomass, seafloor and megabenthos images;

- *Water-column components*: conductivity-temperature-depth profiles, light levels, chlorophyll-*a* concentration, dissolved oxygen, nutrient levels, salinity, productivity, pelagic community structure, observations of marine mammals and seabirds;

- *Chemistry and physics*: grain size, sediment distribution and mixing depth, organic and inorganic carbon, trace metals, pore-water fluids, alkalinity.

Linked to these variables would be basic station data such as when and where they were gathered, sampling circumstances and the storage location of samples. In addition to new material, the database should include information from earlier baseline studies.

The database should be flexible in enabling researchers to retrieve just the information they needed, and should be usable with existing analytical tools for statistics, mapping and modeling.

Rex suggested that existing databases created by other organizations, of which he gave examples, should be examined by those who would develop the new one. The Authority should establish a team of database managers who could interact with oceanographers and seabed contractors. It should consider putting the database on its Web site to make it more widely available.

In the discussion, one participant stressed the need to make the database friendly to scientists, as had been done in the development of Biocean, the database of the Institut français de recherche pour l'exploitation de la mer (IFREMER). Another thought it more logical to develop cataloguing and metadata standards that would promote interaction between existing databases of the contractors.

Rex estimated that two or three programmers would be needed to maintain the database. The cost of contractual services for Biocean was put at about 30,000 United States dollars a year, not including IFREMER staff. An ISA official said the Authority had recently begun work on establishing a central data repository on manganese nodules, sulfide deposits and crusts, and would approach the Finance Committee about whatever needs arose in connection with the proposed new database.

Rex believed that information collected in past years, including results from impact-assessment studies sponsored by governments, should be incorporated. However, a participant cautioned that some older material was not comparable to newer data. The Secretary-General reported that ISA had had good responses from several non-contractors who had offered data and would be in touch with others to see what it could get on a selective basis.

The Secretary-General commented that the Authority's emphasis on the environment, while mandated by its objectives, was also motivated in part by the notion that it would be better for ISA to develop its own standards than have them imposed from outside by those who might question its status as a responsible actor in the oceans if it did not act.

Dr. Craig R. Smith, professor at the University of Hawaii, moderated an open discussion on standardization strategies, designed in part to guide the working groups that were to prepare detailed recommendations. Two topics, taxonomy and field sampling, were the focus of much of the discussion.

On taxonomy, participants generally agreed on the need for coordination in this highly specialized domain of species identification, but several speakers warned against excessive centralization. Dr. Smith began by suggesting that one museum be identified as a centre to which all contractors could send specimens for identification. Others, however, saw a need to divide the work among experts on different animal groups, who could be contacted through a centrally maintained list. Several participants urged greater emphasis on cooperative endeavours such as workshops to train taxonomists from various countries. In general, the approach of coordination won out over central management.

Another idea that gained support was to have one or more voucher collections of type specimens, either located in one place or circulating, against which contractors could compare their own finds.

The discussion of field sampling touched on several issues, notably the usefulness of advisory teams that would go along on research cruises to help contractors collect and process samples. Smith cited as an example the need to standardize techniques for lowering box corers to collect sediment and fauna samples on the seabed, a process that could produce different and therefore non-comparable results if not done properly. There was broad support for the exchange of scientists on research cruises, though the idea of seagoing advisory teams met with a mixed response: a contractor stressed that individual groups should be left to decide whether they wanted such help, while another contractor doubted that there would be room aboard research vessels for an international team. The latter speaker favoured having the Authority establish its own research team or cooperative programme.

One participant pointed out that oceanic exploration by individual scientists or groups was different from seabed exploration, where contractors working in the same region had a common goal of assessing the environmental impact of a proposed activity. A degree of comparability was needed in the latter situation.

Smith asked for views on the idea of using a central laboratory for chemical analysis and sample processing, as was often done in the United States. Three contractors objected to such an approach, however, saying that they could handle such work on their own and that they wanted to build up their own capabilities to do so. Another idea, to have a single monitoring firm, received no support.

Dr. Rahul Sharma, scientist at the National Institute of Oceanography, Goa, India, reviewed in a paper the reasons for collecting baseline environmental data and listed the kinds of data required, from atmosphere to seafloor. The paper went on to discuss studies of mining impacts, stating that none of the results of impact experiments so far could be used to predict the effects of large-scale mining, because the tests had covered too small an area and had not lasted long enough, and because the test equipment did not match what miners could be expected to use.

The paper went on to make recommendations for future benthic disturbance experiments that would overcome some of these shortcomings. The recommendations call for greater sediment discharge, discharge at a higher point above the bottom to assess the effects of dispersion of the mining plume, a towing pattern that would move the disturber (simulated mining vehicle) over a greater seabed area during a longer time period, an autonomous disturber in the form of a remotely operated vehicle rather than one tethered to the control vessel, and real-time assessment of impact through live television and other devices.

Also included in the paper are design suggestions to limit the environmental impact from mining. These are: minimizing sediment penetration by the collector and mining vehicle, avoiding the disturbance of the more solid layer below the surface, reducing the mass of sediment swirled up into the water near the bottom, laying more of the churned-up sediment immediately behind the mining vehicle, minimizing the transport of sediment to the ocean surface, reducing the discharge of tailings (mining wastes) into lower waters, and reducing the drift of tailings by increasing their sedimentation rate.

In his oral presentation, Dr. Sharma said that, when collecting environmental data, the needs of mining engineers and planners should be borne in mind, since the data could also be useful for designing systems for mining and environmental conservation. On the seafloor, for example, engineers could use such data for mine-site selection, coping with topographical obstructions and the design of mining-system components.

He described how the five previous benthic impact experiments had differed in ways that made comparison of the results difficult, including observation periods of different lengths, inconsistent sampling of sediment-core slices, and the use of different techniques to measure water content and density of sediments.

The discussion highlighted the difficulty in trying to assess mining impacts from the limited tests performed so far. One participant also expressed surprise at the number of parameters that Sharma had listed for measurement, stating that if the costs of environmental studies were too high, investors would turn to less costly operations elsewhere. Smith observed that a balance had to be struck between what people would like to know and what they needed to know about the ocean and the impacts.

Chapter 18 General Sampling Design for Baseline Studies

Dr. Ron J. Etter, Professor, Biology Department, University of Massachusetts, Boston, United States of America

How should we sample to establish a baseline for the potential environmental impact of polymetallic nodule mining in the deep sea? The sampling programme will depend critically on exactly what information is required. One may simply want to know what organisms exist within these environments and what their natural spatial and temporal patterns of variation are. On the other hand, the goal may be to detect how mining operations change deep-sea communities.

I shall describe a sampling programme that will accomplish both goals, although it is designed primarily to test statistically for a change in the ambient abyssal communities due to mining. I shall then discuss several other sampling strategies that will quantify the spatial and temporal patterns of variation in deep-sea communities, providing a baseline, but will not allow one to test for mining impacts.

The sampling programmes I describe are very general. More efficient sampling programmes could be designed if we had basic information on the nature and scale of mining, the type and magnitude of environmental changes due to mining operations, the spatial and temporal variability of the organisms that inhabit nodule provinces and, most importantly, how organisms might respond to mining operations.

I shall describe a sampling programme to detect changes in benthic macrofaunal communities, although with slight modifications similar strategies could be used for other faunal components. I shall begin by noting some specific challenges for developing a baseline-monitoring programme; then describe various sampling strategies that have been used for detecting environmental impacts from anthropogenic activities, noting their deficiencies, and conclude by proposing an appropriate strategy that is statistically rigorous.

1. Challenges for Developing a Baseline to Detect Environmental Impacts

Organisms naturally exhibit both spatial and temporal variation. For example, if we measure the abundance of a particular species at two different stations, population size would very likely be different, as indicated by the dots marked *1* in figure 1. This spatial variability exists naturally because of environmental heterogeneity, sampling error and potentially because of independent temporal cycles. In addition, if these stations are resampled later (dots marked *2* in figure 1), the size of the population at each location will very likely have changed due to natural temporal fluctuations. In fact, because population sizes at each station may vary independently, it is possible that they switch their rank order. All of these changes in both space and time can occur quite naturally. The challenge in environmental impact studies is to separate out natural spatial and temporal changes from those caused by anthropogenic activities.

Another challenge is to decide exactly what is meant by an environmental impact. How much of a change is necessary before we decide that an impact has occurred? Benthic communities are spatially and temporally dynamic, and thus some differences will develop among control and impact locations simply due to these natural changes. What level of change is acceptable? This will need to be decided and will have important ramifications for sampling protocols, statistical tests and potential mitigating strategies.

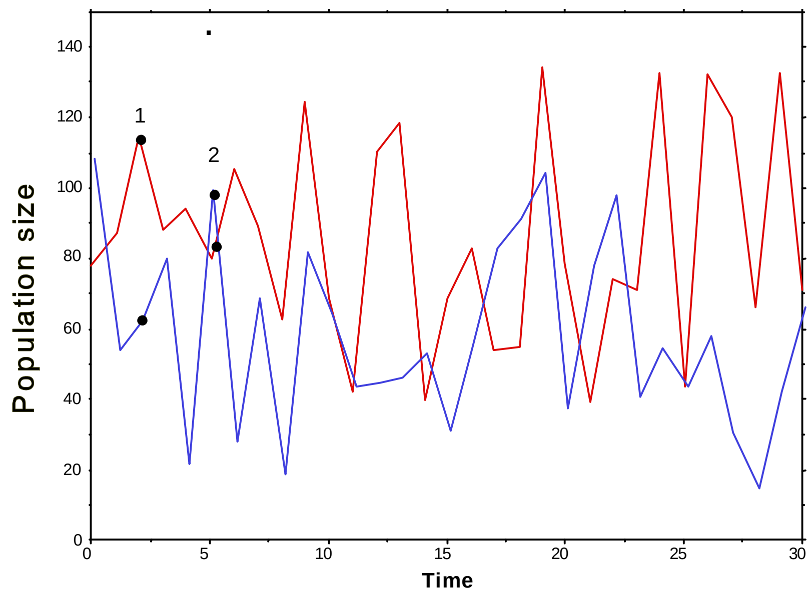

Figure 1 *Temporal variation in the population size of a hypothetical species at two stations (blue and red lines represent the different stations). The dots marked 1 and 2 represent two times each station was sampled with three replicate box cores. See text for explanation.*

Finally, we need to determine what the response variable(s) will be for detecting an impact. Potential response variables could be macrofaunal abundance; biomass; the relative abundance, diversity or composition of species (functional groups, trophic modes, etc.) within communities; local extinctions, or global extinctions. Because each of these variables has different natural spatial and temporal patterns of variation and different sensitivities to environmental changes, these decisions will also have important implications for the sampling strategies, amount of work involved, technical expertise necessary to conduct the work, ability to detect change and the nature of what is considered an impact.

2. Sampling Strategies to Detect Anthropogenic Impacts

Early studies of environmental impacts from anthropogenic activities (e.g. sewage outfalls, nuclear power plant effluents, oil spills) used a very simple sampling design – a series of replicate samples (e.g. box cores) were taken from a potential impact site and compared to a series of samples from a reference (control) site (e.g. figure 2). Any differences between the reference and impact sites were attributed to the anthropogenic activities. However, this is not an appropriate statistical design. The major deficiency is that there is only a single impact site and a single control site. The replicate samples taken at each site are therefore pseudoreplicates[1]. Consequently, any differences between the samples taken at these two locations may be due to initial spatial variation, different temporal cycles or differential responses to natural environmental changes that are independent of the anthropogenic effects.

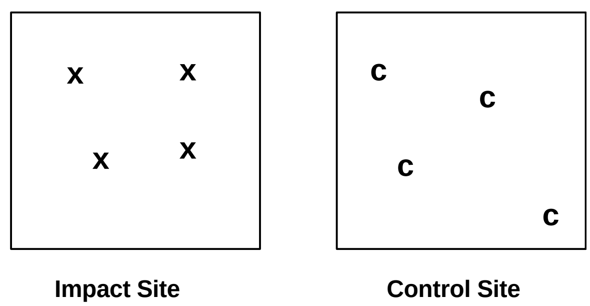

Figure 2 An impact site (receiving an anthropogenic effect) and a control site. Each site has four stations (represented by the X or C) positioned at random within the site. At each station, three replicate box cores would be taken.

An appropriate statistical design would have multiple impact and reference sites (figure 3), which could then be compared. Any differences among these multiple control and impact sites could then be attributed to the anthropogenic effects. Of course, no one is suggesting that we encourage more mining operations (build more nuclear power plants or sewage treatment facilities or create more oil spills) just to improve the statistical rigour of testing for environmental impacts. However, without replication at the appropriate scale, other sampling and statistical procedures are necessary.

Green[2] suggested the first solution when there is a single impact site. He suggested that replicate samples be taken in both reference and impact sites before a potential impact and again after the anthropogenic activities had begun (figure 4). In an ANOVA (analysis of variance), an anthropogenic influence could be detected by a significant interaction term between location (control vs. impact) and time (before vs. after the onset of anthropogenic activities). Locations may show differences simply due to natural spatial heterogeneity. Similarly, natural temporal cycles may cause differences between times. However, if anthropogenic activities caused changes in community structure at impact sites, impact sites should respond differently to time than control sites, producing an interaction between location and time.

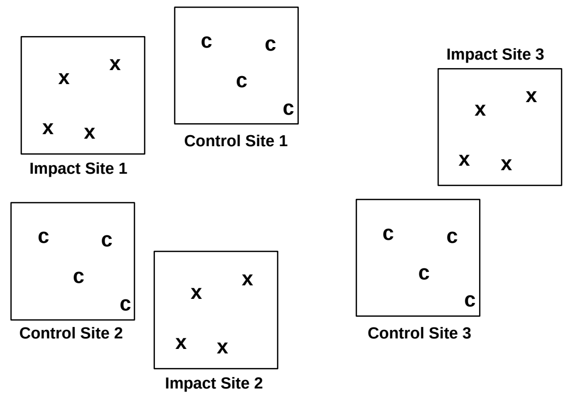

Figure 3 *Three impact sites (receiving an anthropogenic effect) and control sites. Each site has four stations (represented by the X or C) positioned at random within the site. At each station, three replicate box cores would be taken.*

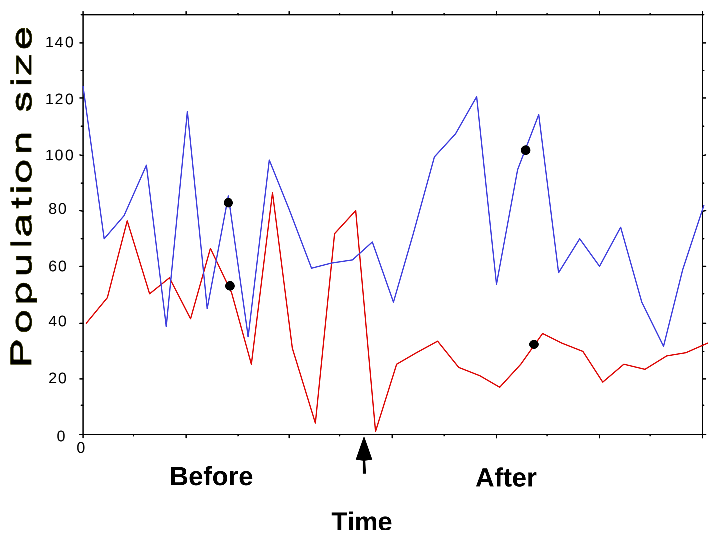

Figure 4 *Time series in the population size of a hypothetical species at an impact (red line) and control (blue line) site. Before and After represent prior to and following the onset of anthropogenic activities at the impact site. The dots represent sampling times where each of four stations within each site (control vs. impact) was sampled with three replicate box cores. See figure 2.*

Although this initially seems to be a reasonable solution, numerous authors pointed out that it does not eliminate the possibility that any differential response of the community at the impact site may be due to natural cycles that vary spatially[3]. That is, any differences between the impact site before as compared to after the anthropogenic activities could not be interpreted as a consequence of these activities.

Bernstein and Zalinski[4] and Stewart-Oaten *et al.*[5] suggested an improved sampling design referred to as BACI (Before-After-Control-Impact). They argued that replicate samples should be taken several times before the onset of anthropogenic activities and several times after, at both the impact and control sites. This would provide temporal replication and reduce the likelihood that any observed interaction was due to chance environmental variation. However, this does not deal with the main problem – that the two sites can have different temporal patterns of variation that have nothing to do with anthropogenic activities.

In a series of papers, Underwood[6] described sampling and analytical solutions to these design flaws in environmental impact studies. First, one should use multiple control sites. It is often impossible or impractical to have multiple impact sites, but there is no reason not to replicate control sites. The multiple control sites will provide insight into natural patterns of spatial and temporal variation in the target communities. The basic idea is that an impact would cause a change in the response variable (e.g. population size) before compared to after the onset of anthropogenic activities that exceeded the average change in the controls over the same period. Second, each station should be sampled several times before the potential impact and several times after, providing temporal replication. Finally, an impact can be identified from a comparison of various interaction terms in an Asymmetrical ANOVA[7]. Basically, the interaction in time between the impacted and control sites should be different from the naturally occurring interactions in time among the control sites.

3. Proposed Sampling Design

Based on these studies, I describe a sampling programme with an appropriate design for statistically detecting an impact from polymetallic nodule mining operations in the deep sea. The design I propose represents a bare minimum sampling programme. Appropriate levels of replication will need to be determined from a power analysis[8] once the response variables have been chosen, levels of acceptable change are determined and some estimate of the natural variability has been made.

After an area has been selected for mining, two other areas as similar as possible should be selected as control areas. These should be at a sufficient distance from the mining operations that they will not be influenced by the plume produced from collecting nodules or other mining activities. They should also be similar in scale to the mining area (e.g. figure 5). In each area, three stations should be selected at random for sampling (e.g. figure 5), providing nine permanent stations that will be followed through time. Each station should be sampled four times before the onset of mining operations and four times after mining begins. This is essential to provide temporal replication. The time scales will need to be decided, but a reasonable approach might be to use some sort of log series (4, 2, 1, 0.5 years before and 0.5, 2, 4, 8 yrs after). At each sampling (cruise), three 0.25-square-metre box cores should be taken at each station. This produces 27 box cores per year, with 216 over the entire 12 years. Although this may seem excessive, keep in mind that these are abyssal samples and, at least for the macrofauna, they will have on average about 100 individuals per box core. These cores should not take as long to sort as the bathyal cores most deep-sea biologists are familiar with.

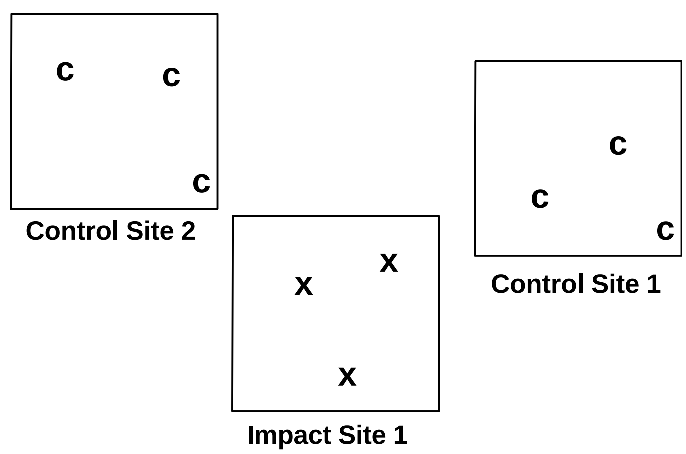

Figure 5 One impact site (receiving an anthropogenic effect) and two control sites. Each site has three stations (represented by the X or C) positioned at random within the site. At each station, three replicate box cores would be taken during each cruise.

Several important factors will need to be considered. First, it may be desirable to have more stations within the impact area. For instance, one may want to have a series of stations different distances from mining operations to better assess the spatial extent of any potential impact. It may also be important to have stations stratified between the area actually cleared of nodules and areas affected only by the plume. It would not be possible to examine these effects without adding more stations to the impact area. Second, it may be possible to reduce the amount of temporal sampling, especially before mining operations. This will depend to some extent on the amount of natural temporal variation in the ambient communities. Third, the levels of replication used in these studies will need to be determined from a power analysis[9]. As alluded to earlier, a power analysis will need basic information on the temporal and spatial variation in the response variable, the acceptable levels of change (i.e. what magnitude difference would be considered an impact), and levels of type I and type II errors. Finally, I suggest that at least one epibenthic sled sample be taken at each station before and after mining begins. This will provide a very good estimate of the number and type of species within each community, and be critical for any genetic studies of changes in biodiversity. For example, mining may not cause any immediate extinction but may so severely deplete the genetic diversity in some species that they will eventually become extinct.

If this sampling design is implemented, it will allow us to develop a good baseline on abyssal communities and, more importantly, allow us to test rigorously for any effects of the mining on natural assemblages. A number of specific results would obtain:

1. The 24 box cores (and 2 epibenthic sleds) that would be taken at each station over the course of the study would provide an excellent characterisation of the communities.

2. We would be able to quantify spatial and temporal variation on a variety of scales both within and among stations. This information will be critical for developing more efficient sampling procedures in the future and for interpreting any putative impacts from mining.

3. We would be able to quantify the time scale of recovery.

4. This is the only design that will provide a rigorous test for mining impacts.

4. Sampling Designs for Establishing a Baseline Independent of Impact Assessment

If the goal is to establish a baseline of natural spatial and temporal variation in abyssal assemblages independent of testing for mining impacts, sampling strategies of a more general kind could be employed. These are discussed in greater detail elsewhere[10]. For example, if there is no information available on habitat variation within a claim area before the onset of a sampling programme, a simple strategy is to randomise the samples in space. That is, one could simply use random geographic coordinates within the claim area to select stations to be sampled through time. Each station should be sampled by taking three replicate box cores during each cruise. Temporal sampling could be annual, seasonal or some sort of log series (e.g. 6, 12, 24, 48... months after the first sample). If environmental data (sediment type, geochemistry, currents, topography, etc.) are taken simultaneously, this design would allow us to quantify spatial and temporal variation in abyssal communities and search for any environmental correlates potentially influencing community structure. Alternatively, one could use a systematic sampling procedure where stations and sampling times are regularly spaced within the claim area and during the time over which one establishes the baseline. The weakness of this approach is that it may miss or emphasise specific periodic spatial or temporal cycles.

A somewhat more sophisticated design, if there were no a priori information on habitats, would be to use a nested sampling strategy. For example, one might choose three large areas (30 by 30 kilometres) at random within the claim area, then in each of those three areas choose three somewhat smaller areas (10x10 km) and within each of those nine areas select three stations to be sampled through time (figure 6). The advantage of this design is that specific statistical tests[11] can be used to identify whether processes are operating at different scales in shaping any spatial or temporal variation in abyssal communities. In addition, one can usually quantify variation on more scales than from either a random or a systematic sampling design.

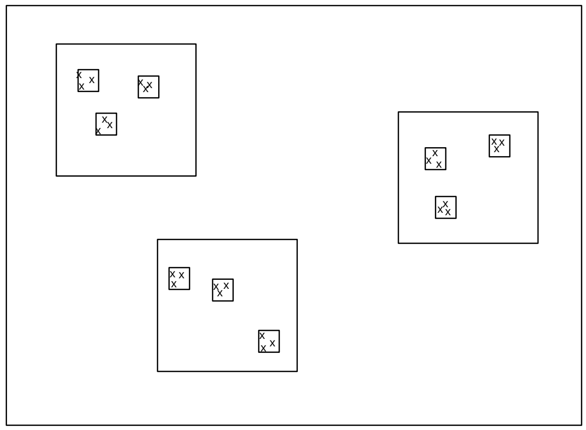

Figure 6 *A nested sampling design with three levels of nesting. The Xs represent permanent stations that would be sampled through time.*

Finally, if habitats are well defined (e.g. sediment types), a better approach would be to stratify the samples among the different habitat types (figure 7): that is, select stations randomly within each of the habitat zones such that each zone has the same number of stations (or similar densities of stations if they differ markedly in size). This provides better insight into how communities vary with habitat, which will be invaluable for designing impact studies when mining is to begin. It will also permit specific tests of hypotheses about habitat differences in community structure.

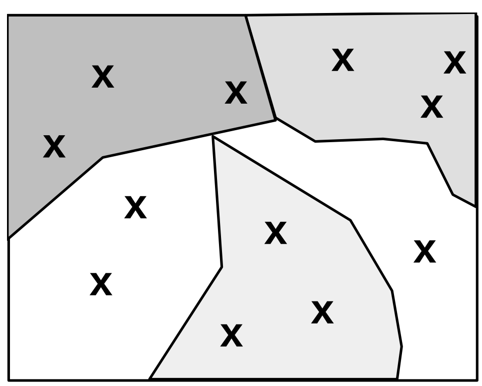

Figure 7 *A stratified sampling design. Each area represented by a different background pattern identifies a different sediment type within a claim area. The Xs represent permanent stations that will be sampled through time. Note that each sediment type has three stations.*

Each of these sampling strategies would provide baseline information on the spatial and temporal variation within polymetallic nodule communities, and allow us to identify environmental correlates of spatial and temporal variation in community structure. However, they would not allow us to test statistically for impacts when mining begins. If these general baseline studies are undertaken, additional sampling programmes will be necessary to test for impacts before mining. The only advantage to these more general sampling programmes is that they may be used to better design a sampling programme to specifically test for an impact. In addition, several other crucial pieces of information would be useful for deciding exactly how to sample abyssal communities to quantify any impact. These were outlined by Smith[12] and include experiments to identify (1) dose responses to sedimentation, (2) chronic disturbance effects, (3) recovery rates from disturbances similar to mining operations, (4) levels of bioturbation and (5) dispersal of a sediment plume from a full-scale mining operation. It might be in the best interest of the International Seabed Authority and the countries that have claim areas to undertake jointly a very detailed study of a mining operation in one area, which could then be used to develop sampling and monitoring strategies in other areas. This could potentially save millions of dollars in unnecessary studies and sampling programmes. In the absence of this information, the only alternatives are outlined above.

PRESENTATION AND SUMMARY ON GENERAL SAMPLING DESIGN FOR BASELINE STUDIES

Dr. Ron Etter began his presentation by stating that, when asked to talk about this topic, he had been under the impression that the purpose was to establish a baseline such that an impact could be identified if it occurred. Through the Workshop's discussions, however, he had come to realise that at least some people believed that the intention was to obtain a better understanding of the benthic communities. Both approaches were valid and he hoped that the sampling design he would propose would accomplish both aims, although the design could be optimised to meet the requirements of each in a better way. He would describe a sampling design that would make it possible to identify an impact of mining. The first step must be to recognise some of the challenges of identifying an impact in the deep sea.

Challenges to sampling studies

If population samples were taken over time – from places *A* and *B* in a mining claim area, for example -- they could be plotted on a graph as two tracks, showing how the population size of some organism varied against time. Since the samples could not be taken instantaneously, they would have to be taken at some point in time. The difference between the two population sizes was their spatial variability. Samples taken later would show that the populations had changed with respect to one another, the differences representing temporal variability. The simultaneous changes in these two factors introduced the idea of spatial-temporal variability, expressed in rank order. In this hypothetical case, population *A* had initially been larger than population *B*, but later *B* had become larger than *A*. The change represented spatial-temporal variability, with the rank orders changing with respect to one another. Nothing was known about how this occurred in the deep sea on any relevant scale. It was not known how the differences between the sites changed as the distances separating them increased – that is, if site *A* were moved progressively further from *B*, how different those populations would become. The relationship could be plotted on a graph as a gentle slope if the spatial change was slow or a steep slope if the change was quick. Moreover, the relationship might be non-linear. These factors were important when trying to determine how to sample the environment.

Another challenge was trying to identify the response variables for ascertaining whether an impact had occurred. There were a variety of these, many of which had already been described in the Workshop and were used by researchers, including density of the organisms, biomass and diversity. Any of these could be divided into different trophic modes, such as feeding styles or functional groups, which characterised the roles of organisms in the environment. Other indicators were species composition and the composition of functional groups. If local extinction was the main concern relating to impact, the study could be confined to those organisms endemic to the area that would be completely wiped out if something happened. In any case, someone had to decide what was meant by impact and what the response variable was for defining it – in other words, what constituted an impact and how the researcher would determine that an impact had happened. As populations could vary quite a bit through time, if a change was measured was it an impact? If it were caused by an anthropogenic effect, it would probably be called an impact. On the other hand, if it were a natural event, it would not be called an impact. The important point of a strategy for sampling the environment was to try to distinguish between natural and anthropogenic events. Of course, that would be a challenge, especially in the deep sea where little was known about spatial-temporal changes in the community.

Sampling strategies for anthropogenic impacts

Early studies of environmental impacts had employed the following strategy: A series of samples were taken from an impacted area, either potentially impacted or known to have been impacted. Then a series of samples were taken from a reference or control area. The controls were represented by box cores taken in particular areas. (While focussing on the macrobenthos, he pointed out that sampling strategies might change in the case of megafauna, meiofauna or some other group of organisms.) The typical approach, using replicate series of samples from an impacted area and a control area, was to contrast the two. If the impacted area differed in terms of whatever response variables were used, the conclusion was that there had been an impact.

However, there were some real problems with that approach. The first problem was that there was only a single impact site. The main problem was that the sites might differ for some reason that had nothing to do with an anthropogenic effect. Much depended on the scale of the differences -- that is, how separate the two samples were. This was not a good test of whether there had been an impact.

Another problem was that spatial variability could bring about differences between the controls and the impacted area. It could change one or the other, or both. Temporal variability could also effect changes, as could interactions between space and time. In any case, this was not a good statistical design. One could not easily detect, with any power, that there had been an impact. One could err either way, finding an impact when there had been none or missing an impact because of the changes in the samples.

The most appropriate course was to have three control areas and three impacted sites, so that samples could be replicated at the correct scale. This would permit a comparison between the controls and the impacted sites, making it possible to say, whenever an impacted site differed from a control site, that the difference had been caused by the anthropogenic effect. However, no one would argue that more nuclear power plants should be built in order to improve tests on the effects of their effluent; nor would anyone call for more sewage outfall to permit better statistical procedures for testing the effects. Similarly, he was not advocating more mining so that tests could be run. On the other hand, if test mining were to occur, it would not be a bad idea to separate it into different areas.

What could be done, in the absence of multiple impacted sites, to address the problem of impact assessment in a rigorous statistical way? In 1979, Roger Green[13] had suggested an approach to an easier and more convincing test for an impact. The basic procedure was now called before-after-control-impact (BACI) studies or analyses. To illustrate this approach, Etter used diversity as the response variable, saying that it did not matter for the sake of determining the sampling protocol whether this was a reasonable choice or not. The populations being studied were varying in both space and time but the investigators did not know this; they could just take samples at some time before and some time after the impact. The data, which could be plotted as dots on a graph, represented not a single sample but the mean of a series of replicate samples in or around each location. Green had argued that the sampling before could be compared to the sampling after for both the control and impact sites to better identify whether there had been an impact. This could be done, he had said, by looking for significant interaction between the localities in time. There would have been no interaction if both locations had responded in the same way to an external influence. On the other hand, a significant interaction would have occurred if the two locations had responded differently. It was expected that the two locations would differ spatially and temporally, but Green's suggestion was that the interaction -- the difference in the change between before and after for the control relative to the impacted -- would indicate whether there had been an impact. The impacted site should show a different kind of response to the anthropogenic influence.

This was one strategy, Etter continued, but it did not solve the problems. It did not account for all of the spatial and temporal variability among these locations. Changes might take place that had nothing to do with the anthropogenic effect, but that fact would go unrecognised because there was no other impacted site with which to compare. Again, one could err either way, finding that there had been an impact when there had not been or that there was no significant difference when in fact there had been one. The conclusion depended on how the control populations and the potentially impacted populations changed with respect to one another over time. There still remained the statistical problem of deciding whether an impact had occurred in a particular place.

In a couple of articles published in the mid 1980s, statisticians had gone a step further in terms of these BACI studies, suggesting that a series of samples be taken before and afterwards. This would provide a better understanding of the temporal variation both before and after. With this improved temporal resolution, if significant interactions were found, the interaction between before and after with respect to the control and impacted areas should again be significant; the differences would not reflect just random noise, which might have been the case if there had been only one data point before and one after. In this case, sustained changes could be recognised but it would still be impossible to attribute them directly to an anthropogenic effect because they might have come about through some other process that had nothing to do with the anthropogenic influences. Moreover, this approach was insensitive to pulse-type events, which were typical of the kind of perturbation expected. A pulse-type event involved a change followed by a slow return to the level of the ambient community. However, this kind of statistical approach would not easily recognise the interaction between before and after. Moreover, even a noise event could influence a finding of significant interaction.

Another approach, proposed by Tony Underwood in a series of papers from 1991 to 1997 and recently summarised in his book on experimental ecology[14], called for using multiple controls to deal with this problem. While the number of impacted sites could not be increased, the number of control sites could be expanded. He suggested setting up an asymmetrical analysis of variance (ANOVA) with a series of control sites instead of just one. Again, a series of samples would be taken before and after, replicated at each station. The idea would be to look for an interaction effect, which would appear as a greater change in impacted sites than the average change in the controls. In statistical terms, an analysis of variance table would show how to identify the impact. The response of the impact locations to the anthropogenic influence would be different from the response of the control sites, in a way that could be separated from the effects of a natural event. The earlier design, with only one sample before and one sample after, was no good because it could not detect whether a spurious event had brought about the differences. Such an event could be spatially located to make it look as if there had been an impact or to remove the effect of an impact. The advantages of the new design were that it had spatial replication, at least among the controls; it had temporal replication with respect to both the controls and the impacted sites, and it allowed the impact to be detected rather unequivocally.

Sampling design for impact assessment

Etter then offered his calculation of how such a sampling strategy could be implemented in a claim area. He recommended that at least two control sites be compared to one impacted site. The impacted site, which might be in the plume, could be a large area with several replicates. If there were three stations in each site, there would be nine stations in all, to be sampled through time. One possibility was to sample four times before mining and four times after. This might be done with varying periodicity -- every year, or at intervals of one, two, four and eight years. Those who did not want to sample for eight years before starting to mine could reduce this to a shorter period or take fewer samples, as he would explain shortly. If the design called for three box-core samplings at each of three stations in three areas, repeated eight times, 216 box cores would be required over the eight-year period. That would be the level of replication in space and time required for an adequate test. Testing at multiple plume sites would increase the amount of replication.

It would be hard to select locations for the control sites. Selection would depend on the scales of the organisms and of the plume. A decision would have to be taken soon after an area was chosen for exploration because the stations would have to be sited before mining began, taking account of the temporal scales required for testing. A power analysis should be done to ensure that an impact could be detected with the minimum amount of replication that he was suggesting. He also suggested that an epibenthic sled sample be taken at each of the stations at least once during the study, to give some idea of how well the communities were being sampled and to provide information on the total community, including things that the box cores might miss. This would also make it possible to do genetic studies if necessary. Epibenthic sleds were important because their large samples, more qualitative than quantitative, were necessary to answer questions about population genetics and gene pools.

His sampling design would end up with 27 box cores replicated through eight years. This would leave the communities well characterised for an abyssal site, better than in many other studies, at all nine stations. Information would be obtained about spatial variation on a variety of scales, because calculations could be made at different scales. Natural temporal variability over a period of up to eight years could also be measured from the samples. An estimate of the recovery rate would be gained from the impacted site, i.e. the temporal series of the recovery rate. Something would be learned about the interaction between space and time, that is, how the samples changed relative to one another over time. Finally, it would be possible to test in a rigorous way whether there had been an impact.

One positive aspect of the course he had outlined was that it supplied basic information about the organisms at the same time that it was testing for an impact. With other strategies, a lot of work would still be needed to quantify what was out in the community but it would not be possible to test for an impact. The simple approach of quantifying might make it easier to identify more efficient sampling strategies for impact assessment but something like the advanced BACI design would still be needed.

Baseline sampling strategies

If the aim was just to figure out what was in the environment in some claim area about which no habitat information was available, a variety of strategies could be used. One would be to randomise sampling in space and time. If a certain amount of money was available to support a certain number of box-core samples, they could just be distributed at random throughout the area of interest, making it possible to quantify the faunal pattern. If the allocation was only in space, temporal patterns could not be identified, but if the box cores were allocated randomly in both space and time, some insight into temporal patterns could be gained. It would be possible to identify environmental correlates that might control the structure of the communities, as well as the kinds of organisms living in different places. This information might be important for understanding what kinds of impact could occur, as well as for targeting sampling to particular types of organisms that would be more sensitive to the sorts of impact likely to occur during mining.

If some habitat information was already available and the aim was to test specific hypotheses, one approach might be stratified random sampling. This called for sampling to be partitioned among various habitat locations – each representing a different sediment type, for example (see figure 7 above). This could be done in different ways: for instance, with the same number of samples in each habitat or with numbers proportional to area. Another approach was nested sampling, which involved taking a basic approach and applying it on different scales: for example, three samples at the smallest scale, three more at a larger scale and so on, up to three at the greatest scale. Doing this ad infinitum meant using a nested ANOVA, by which important questions could be asked about the scale of the processes that structured the communities. Such an analysis was simple once a quantified makeup of the communities was obtained at the different scales. Still another course was some kind of systematic approach in which samples were put down at regular intervals.

In addition to taking samples, some further critical information was required, as spelled out in Craig Smith's paper (chapter 3 above). In any baseline monitoring programme, along with quantitative box core samples taken in a way that allowed the impact to be detected, experiments would still be needed to elucidate data about dose-response, chronic disturbance, time scales of recovery, bioturbation and plume dispersal. Given such information, it would be possible to make predictions about potential impacts and to optimise a sampling design. Such experiments could potentially be done at a single location, and if they were done early, the information they supplied could be used to design new sampling programmes at a variety of locations, assuming that the results could be generalised to larger scales.

SUMMARY OF DISCUSSION

An engineer among the participants observed that the impact zone had two areas of interest – the mining area, where the animals would be destroyed, and the area where the plume settled (provided that the plume area remain unmined, for otherwise it would fall in the first category). Why did the proposed design, by suggesting two control areas to the one impact area, focus more on the controls than on the impact?

Dr. Etter responded that his strategy was not to focus more on the controls than on the impact, but rather to suggest a bare minimum course for detecting the effects. It was known that in the area where the sediment had been torn up there would be a strong impact. If the aim was to know exactly what had happened in the impacted area, more samples should be taken there. However, he did not want to force contractors to take many samples where the results were going to be straightforward. On the other hand, perhaps no one knew exactly what would happen in those areas. Therefore, some balance had to be struck when deciding what information was wanted: whether there had been an impact or how the impact changed from place to place. To design a sampling programme, one had to know specifically what the question was.

Asked how the sampling design took account of the fact that an impact area would have places of heavier and lighter environmental damage, Etter repeated that more sampling would be needed to deal with two different questions: Did the light impact area differ from the controls? Did the heavily impacted area differ from the controls? Another participant said the question re-emphasised the need for dose-response experiments to avoid multiplying studies ad nauseam.

One participant observed that statistical significance was measured by levels of probability, with results falling below the 0.05 level being accepted as significant. The amount of variability between replicates would determine how much replication was needed; employing more replication in time and space, by having more than one control site, would result in a more powerful test. In the end, however, there would still be some degree of uncertainty, even though with more replication the certainty might be 0.01 rather than 0.05. He knew from experience how time-consuming it was to develop a sampling strategy for pelagic work, and he knew that contractors would never accept having that many sites. Were they necessary? On the other hand, did the number depend on the variability between control and impact sites, so that if impacts were strong, then less replication would be needed?

Etter confirmed that that was true. Power analysis made it possible to detect how many samples were needed to detect some level of change. That technique could be used if the level of change was known. Three factors affected a power analysis: sample size, how big a change was to be detected and the level of probability of making an error. He encouraged claimants to perform a power analysis asking whether the proposed replication was sufficient. If the change was big enough, fewer samples would be necessary, but that would not be known until someone did a simulation to test what kinds of impacts to expect.

The same participant also remarked that, while he agreed on the need for a before-after-control-impact approach to determine whether an impact was being detected, researchers were also trying to develop a mechanistic understanding of the functional responses to various types of impacts. In other words, they were not just looking blindly for an impact based on statistics; they also hoped to build a predictive model showing what events would lead to an impact. Such a model could then be tested through BACI analyses.

Etter agreed that having such models would make it possible to take a different approach and to optimise the sampling design so that fewer samples would be needed. That was why he had said that the kinds of experiments proposed by Smith were an important prerequisite to the rest of the work. In presenting general sampling designs for detecting environmental impact, he was not advocating that things had to be done that way; if the other kind of information was available, different approaches could be taken. However, as such information was not yet available, he had suggested a basic sampling strategy.

One participant offered his quick calculation that it would take 21 fast, experienced taxonomists several years, at the rate of one month per core and ten working months a year, to examine the nematodes in 216 core samples –

and he might be underestimating. Another participant mentioned that an evaluation in her laboratory had been under way for at least four years. Etter observed that there would be many fewer species and individuals in the box cores than would be found in places with much higher productivity. In any case, he had suggested a generalised approach that was not well optimised.

A participant said it was important to begin temporal studies before the impact, even if not everything suggested for an ideal situation could be done. Her organisation tried to have replicates in every study, and she had learned from Etter that more than one control area was needed. Perhaps three control stations could be monitored by organising ship time at the international level.

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Chapter 19 Database Requirements

Dr. Michael A. Rex, Professor of Biology, Department of Biology,
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The International Seabed Authority's Workshop to Standardize the Environmental Data and Information Required by the Mining Code and Guidelines for Contractors (25-29 June 2001) discussed the basic framework of a database for exploration, mining and assessment. There was a general consensus that database development and management should include the following features:

- **Basic Station Data**. This would include essential information about sampling sites including the institution, contractor, programme, claim area, vessel, cruise, principal investigator, station number, replicate number, date, longitude, latitude, depth and type of gear deployed.

- **Sampling Circumstances**. It would be very useful in evaluating the quality of data if comments were recorded on weather, sea state, condition of samples, methods of deployment, gear failure and any other relevant circumstances that might bias data.

- **Location of Material**. The destinations (address and contact information) where biological and physical materials are sent and archived should be recorded. For example, benthic organisms should be linked with the name of the natural history museum where they are deposited, and preferably, the museum catalogue number.

- **Variables**. Which variables to include will vary with the subdiscipline. For benthic ecology, variables would include sieve size, species identification, number of individuals per species, depth of sediment in the box-core sample, density, biomass, imagery of the seafloor and megabenthos, etc. For water-column data, variables would include conductivity-temperature-depth (CTD) profiles, light levels, chlorophyll *a* concentration, dissolved oxygen, nutrient levels, salinity, productivity, pelagic community structure, observations of marine mammals, sea turtles and seabirds, etc. Chemical and geological variables would include grain size, distribution of sediments, total organic carbon (TOC), inorganic carbon, mixing depth of sediment, trace metals, pore-water fluids, pH (alkalinity) and so on. (See recommendations of the working groups, chapters 22-24 below.) [This is not an exhaustive list. ISA is encouraged to consult with biological, chemical and physical oceanographers to compile a complete list of useful variables that are realistic for the sampling designs.]

- **Integration**. To understand ecosystem function and impact assessment, it is important to combine information on the biology, chemistry and physics of both the benthic and pelagic environments into a single database.

- **Flexibility**. A relational database is recommended. It is essential to be able to sort the data by taxon, time, location and environmental parameters or any other variable. For example, ecologists should be able to easily extract data on polychaete species and their abundances to calculate species diversity, correlate this with data on particulate organic carbon (POC) flux or sediment grain size, and determine how these relationships vary in space and time.

- **Interface with Analytical Tools**. The database should interface readily with software and hardware for statistical analysis, plotting, mapping and modelling. A good model for applying statistical analyses to databases is Robert K. Colwell's Biota, at the University of Connecticut (http://viceroy.eeb.uconn.edu/biota).

- **Examination of Existing Models**. There are currently several large database management systems for biodiversity and environmental surveys. These include Biocean at l'Institut français de recherche pour l'exploitation de la mer (IFREMER); Linnaeus II at the Expert Center for Taxonomic Identification (ETI), Amsterdam; and the Irish Marine Data Center in Dublin, supported by the European Union's Marine Science and Technology programme (EU MAST). The ENQUAD (Environmental Quality Department) database, using Oracle, that was developed by the Massachusetts Water Resources Authority (www.mwra.com), is extremely well managed, heavily used for both science and policy decisions, and comparable in size and complexity to the database contemplated by ISA. It would be very beneficial for ISA, in creating a database, to explore existing database models and consult with the developers and users of these databases.

- **Professional Development and Management**. Managing large, complex databases has become a highly complex and rapidly evolving specialty. The ISA is encouraged to establish a team of database managers who can interact readily with oceanographers and contractors in the interest of the Authority.

- **Web Site**. The Authority is urged to consider making the database available as part of its Web site. It is realized that contractors have proprietary rights to certain information and that the Authority may regulate the release of information (for example, to establish a lag time until the Authority has published data). In the long term, the interests of business, the scientific community, policy makers and the public will be served by making the database broadly and readily available.

- **Centralization**. The Authority has expressed an interest in managing the database, and has already made progress in this direction. It would be very valuable to include data that are currently available from early baseline studies and exploration by contractors as well as new data anticipated from continued baseline studies, exploration and exploitation.

- **Long-Term Benefits**. It is recognized that the Authority is the international regulatory structure for deep-sea mining and that the purpose of the Workshop was to recommend standards for environmental assessment of commercial exploitation. The assessment studies will also provide vital new information on the earth's largest and least explored environment – the great abyssal plains of the world ocean. The database can make a major contribution not only to planning and regulating future commercial activity but also to our fundamental understanding of global biodiversity and ecosystem function.

PRESENTATION AND DISCUSSION ON DATABASE REQUIREMENTS

Dr. Michael Rex began his presentation by stressing the importance of designing a database. He hoped the Workshop could provide the International Seabed Authority with a framework of what the database might include.

Listing some examples of the possible contents, he began with basic station data such as the programme, cruise number, station number, location depth, kind of gear used and sieve sizes. All of those seemed obvious unless one had actually used some deep-sea electronic databases in which it was difficult to reconstruct what had happened on a cruise.

Also important to include were the sampling circumstances, such as the sea state and the condition of samples. He recalled occasions when researchers, finding a sample that stood out because of its peculiarity, had had to go back to the original logs to find out that there had been something odd about the sample's inclusion.

The location of material, where items had been archived in a museum or other destination, was important for people who wanted to access and work with them. He hoped that, for material properly accessioned into a museum, the catalogue number would be included.

As to the variables to be included, he suggested that the Workshop's working groups make lists of items that should be in the database. Information about biology, chemistry, physics, and benthic and water-column ecology should all be integrated in the same database and not kept in different places. Moreover, the database should be flexible. For example, a natural historian working on benthic ecology should be able to pull out all the polychaetes from the samples, along with their locations and environmental parameters. Benthic ecologists interested in the relationship between species diversity and sediment grain-size diversity should be able to extract data on these and other environmental parameters. In that way, relationships and associations could be established between the ecology and physical parameters.

The database should also interface with analytical tools. Ideally, it should be possible to extract the information, map it and plot it. In the example he had mentioned, the data on polychaetes, sediment grain size and locality might be used to make a contour plot to analyze the relationship between the species diversity of the worms and sediment grain-size diversity in the Clarion-Clipperton Fracture Zone (CCFZ). The database could be used to analyze other kinds of relationships that scientists in different disciplines might think about.

The Authority should be advised to examine existing models rather than try to reinvent the wheel. Myriam Sibuet had talked about the Biocean system for something similar and John Lambshead had mentioned the model used at the British Museum of Natural History. Any number of other good European and American biodiversity databases could be adapted for this purpose, such as those mentioned in his paper. When looking into the kinds of data to be included and the kinds of relationships that people should be able to explore, the Authority should seek advice from consulting companies that had created databases for other organizations.

Database management and development had become a specialized and complex area of programming and software development, Rex continued. Thus, it was important that the Authority have a group of highly trained programmers to develop and manage the database on a continuing basis. Since it would be electronic, its geographical location would make no difference.

He favoured making the database available through a Web site, though he realized that the developers had proprietary rights to the chemistry of the nodules and that the Authority might wish to have rights to all the data, some of which might understandably be held back for a time. Nevertheless, he believed in having a site where the data would be available to the businesses involved because, as time went by and data accumulated, it should be possible to design sampling programmes that were more efficient and less expensive. For the public, the scientific community and policy makers, the Web site could be a useful vehicle for bringing their various interests together.

Concerning the centralization of taxonomic resources, he thought it important to standardize the quality of taxonomy by having individuals who knew groups well do all the taxonomy. This would avoid situations in which, for example, different taxonomists designated the same populations as one species here and three species there. Wherever these taxonomic resources or archives resided, it would be desirable to relate them closely to development of the database. In studies of ecology and taxonomy, for example, it was often necessary to look at a collection to make sure of the species. That became difficult if collections were in different locations.

Speaking of long-term benefits, Rex noted that the Authority's aim was to figure out how deep-sea resources could be mined by interested businesses, how the process could be regulated and how environmental assessment could be done. It was obviously not the responsibility of either businesses or the Authority to develop deep-sea oceanography. However, a database could offer tremendous long-term benefits. It could be a unique source of information on the abyssal environment, representing a huge leap toward understanding global biodiversity and ecosystem function. Thus, the database would be a vehicle in which the benefits of this enterprise could be widely shared through time by businesses, the public and the scientific community.

SUMMARY OF DISCUSSION

Database development and contents

A participant expressed the view that Dr. Rex had submitted a wonderful shopping list, based on the idea that there was no need to shoot low at the start. However, he suggested that the proposal for an "interface with analytical tools" be replaced by "flexible query and download capabilities", because the Authority should not have to develop analytical tools in a variety of disciplines. Users had to be able to query, select and retrieve the data in a form they could use.

Rex responded that the analytical tools he had in mind were statistical tools. Big software packages such as geographic information systems (GIS) enabled users to plot data as well as to explore databases, as long as one could connect to the database easily.

Another participant said that the developers of the Biocean database at IFREMER had gradually come to see which parameters had to be included. In addition, over the last ten years they had thought about new aspects to be introduced and how the parameters should be linked. She agreed that, to supplement the database, it was important to have statistical, mapping and other tools that would help in sorting the parameters that users wanted to combine. This was the aim of Biocean, which contained 30 years of deep-sea cruise results. Its computer design, based on Oracle software, was closest to the model that Rex had described.

She added that a database could not be useful unless the data were entered in exactly the way scientists wished. Having a computer specialist was not enough. Biocean had not worked while it was in the computer division at IFREMER but it was working now because it was in a scientific department. As the data from each scientist were entered, the name of the scientist was included, making it possible to get back to the responsible person. A tool for scientists was not the same as a database that no scientists looked at.

Agreeing, Rex said the management of such a database was a complicated task requiring a constant rapport between computer people and those who could regularly assess the quality and consistency of the data.

A participant suggested that a catalogue of the database be made available. He added that the difficult process of extracting information would be aided by some indication of where, when and by whom the data had been introduced.

Asked whose database it would be and whether it was meant for the individual operators, Rex said that, without suggesting who should own it or where it should be located, he presumed that the data would be contributed by and broadly available to all those involved. The questioner said he supposed that every contractor or operator would have a database, so that it would be more logical to develop cataloguing and metadata standards enabling them to talk to each other. Rex observed that an operator would be crazy not to keep its own database.

Maintenance needs

A speaker remarked that, if a database that could be queried were to be placed on the World Wide Web, a metadata file would be needed to set up searches. Such a tricky and expensive feature would require constant maintenance by a staff. Rex agreed, but added that maintaining a small professional staff, as long as the data were contributed, would provide a huge benefit for a relatively small investment.

A questioner wanted to know whether the Authority would have to add staff for the database and, if so, how much that might cost. Rex responded that he guessed two or three programmers would be needed, along with hardware and software. He knew nothing about the finances or whether money would be available.

In this connection, a speaker mentioned that the Biocean database had been developed over 10 years with much help from specialized firms, at a cost of 200,000 French francs a year (roughly 30,000 United States dollars) or a total to date of more than ?1 million for contractual services, not including the cost of the IFREMER staff.

An ISA official noted that the Authority had recently begun work on establishing a central data repository on manganese nodules, sulfide deposits and crusts. The aim was to put it on the Authority's Web site and make it available to everybody – business, public, the scientific community and policy makers – just as Rex had suggested for the proposed environmental database.

Within house, he added, the Authority had resources for specialists, such as a marine biologist on staff, as well as information technology people including programmers. One of its primary interests was to be able to utilize the data and information already gathered, and make it available to the public. Data submitted by contractors that met the requirements identified by the Workshop would be rather useless sitting in files. If additional specialists were needed to assist in developing the database, the Finance Committee would be approached about the requirements.

Specimen collections

A participant urged the Workshop to recommend that, when voucher collections were transferred to a museum, the museum should archive them as voucher collections. Otherwise, if the museum received no instructions, it would break the collection up taxonomically, because museums were taxonomic institutions. This was not a terrible problem, because a properly run museum, given the right code, should be able to lay its hands on any specimen in ten minutes. However, complications would arise if a researcher was looking for 50 species. The Natural History Museum, London, had developed a special archive system for commercial voucher collections, so that, for example, someone wanting to look at the polychaete collection could get a box archived as the CCFZ polychaetes.

Commenting on the importance of this approach to users of museums, Rex said that, with a catalogued collection built up over centuries and accessible from the catalogue or by computer, a user would have to be familiar with large parts of the collection in order to know what to look for and how to look for it. This was particularly true for deep-sea materials because biodiversity would be documented not by publishing the classification of every group that came in but, initially at least, by having competent people sort specimens into species, tabulate the number of individuals and ensure that they were properly archived in the museum. Obviously, researchers would not want to wait for the complete taxonomy to be done on all those groups before analyzing them.

Asked about the possibility of linking the computerized database to physical objects such as manganese nodules or nematodes, Rex reiterated the importance of including information in the database about where specimens were archived. Much current scientific work involved synthesizing old information and revisiting old material, because it could be measured in different ways. One of the huge sources of frustration in deep-sea taxonomy and ecology was the fact that people responsible for material had no idea several years later where it was located. Paying careful attention to such a simple thing could solve many problems.

Sources of data

Rex suggested that, with a modest investment, specimens already collected by contractors might be sorted by species, thereby hugely increasing the database and helping in the construction of sampling designs.

A questioner wondered how much existing data might be placed into the database. Would it include material dating back 10 or 20 years and information from non-contractors? Rex replied that as much as possible should be included, including material from such preliminary investigations as DOMES (Deep Ocean Mining Environmental Study). Once the database existed, those who possessed data would judge what they could relinquish and share, and what they thought would be useful to include. One source might be groups sponsored by governments to do impact assessment studies, where the results were public.

A participant cautioned that, even when the results were public, access to the raw data would probably be difficult. Moreover, he questioned the value of information from DOMES, for example, asking whether it was comparable to other data. It could be dangerous if somebody were to produce a meaningless synthesis of all the data on mineral resources or other things in the sea.

Rex agreed but still thought that such information should be made available as broadly as possible. Public advocacy on environmental issues had become extraordinarily sophisticated and the proponents could often afford attorneys who were dangerous as well. Given the need for public accountability, the best course in the long term would be to put all of the data out from the beginning.

The Secretary-General said that, in addition to information that contractors were obliged to give under the mining code, the Authority had had good responses from a number of non-contractors, from North America in particular and recently from France, who had provided general data and information about activities in the seabed. The Authority was trying to enter into dialogue with other institutions to see what could be made available. Of course, it had to be selective in view of its limited capacity.

Rex observed that good rapport was needed between scientists and policy makers to exercise judgement in distinguishing between the useful and the junk.

A participant suggested that non-contractors could benefit from contributing data if the Authority allowed them to publish comparisons based on the database.

Access to data

A participant cited the *Brent Spar* case of 1995, in which the Shell oil company had been prevented from carrying out its plan to dispose of a petroleum platform in United Kingdom waters in the Atlantic Ocean. As he described it, the company had had permission from the British Government but had lost a public relations battle with Greenpeace, after which it had been forced to tow the platform from the dump site and eventually break it up on land, at a cost of millions or billions in lost sales, bad publicity and defensive corporate advertising. Shell had lost the case not because it was doing anything wicked or evil – it had worked entirely within the framework of the law -- but because it had been outclassed by Greenpeace and public relations. By treating its science as confidential, Shell had allowed Greenpeace to hire British, French and German scientists and to use their data, against the policy of the British Government. The company had lost the public relations battle in part because of its failure to release or use data properly.

Professor Craig R. Smith said he assumed that, in accordance with the standard approach, new information would not be released for two or three years while the scientists who had collected it got a first shot at interpreting it and writing papers. He cited an archive at the Woods Hole Oceanographic Institution in Massachusetts containing photographs taken from the deep submergence vehicle *Alvin* during scientific research. All those photographs that might have a scientific use, along with much other data collected by *Alvin*, were opened to the public after two years. The contractors would have to consider how much time should elapse between data collection and publication. Obviously, a 20-year delay would not serve the open scientific function but it had to be a reasonable amount of time.

Environmental concerns

The Secretary-General, commenting on the Authority's concern about environmental matters, recalled that its main objective was to administer deep-seabed resources and allow them to be developed for the benefit of mankind as a whole. Within that aim, it had to take into account the current concern for the environment. Thus, it had introduced environmental aspects into the mining code and elsewhere, reasoning that it would be better for the Authority to do so on its own terms than to have standards imposed on it from outside. The environmental norms governing the seabed were probably more extensive than those followed by any other organization or activity. Norms had been established ranging from baseline studies to impact studies. It was good public relations to preempt outside attempts to establish norms by setting standards inside. When the Secretariat insisted on environmental studies and norms, it was not in order to punish, penalize or burden the contractors, but because there was a need to do so as a responsible actor in the oceans. The Authority did not want others to say that it was ignoring the environment and that its standards were so tame that they lacked real value. This was important because the viability of the Authority and of activities by contractors depended on public opinion and people's concerns about the environment aspect.

The contractors might misunderstand and think the Authority was trying to impose unnecessary duties and obligations on them, he continued. However, he recalled studies cited at the Authority's 2000 workshop on mining technology indicating that, in the early stages of exploration, the equipment used had taken no account of environmental concerns. Developers had since realized that they had to redesign everything to take those concerns into account. He reiterated the importance of having the Authority set its own standards so that outside people would not impose standards through publicity or adverse comments.

Rex said that, in suggesting public access to the database on a Web site, he did not imply that the public should use it to suggest standards. Rather, the aim was simply to make information ultimately available to the public.

Chapter 20 Open Discussion on Standardization Strategies

Dr. Craig R. Smith, Professor, Department of Oceanography, University of Hawaii, Honolulu, United States of America

SUMMARY OF DISCUSSION

Dr. Smith moderated an open discussion aimed at identifying aspects of data collection and management that could be profitably centralized, and models or general approaches that might facilitate standardization in particular areas. He began by defining "profitable" centralization as the kind that would minimize or reduce the cost and effort invested by seabed contractors and others, while enabling them to arrive more efficiently at scientific and monitoring conclusions.

Taxonomy

Smith said the need for taxonomic centralization and for some kind of centralization of collections was clear, at least to the biological advisers at the Workshop. Giving an example of why he felt the need for a uniform taxonomy to guide the contractors' programmes was obvious, he cited the case of one of his post-doctoral students, Adrian Glover, who had been investigating the polychaete collection from the EqPac (equatorial Pacific Ocean) studies. Working with Gordon Paterson at The Natural History Museum, London, the student had identified or differentiated all the polychaetes from the equatorial Pacific collection, and wanted to compare them with those collected by Echo-1, an earlier environmental study, which had been classified by another taxonomist, Kristian Fauchald at the Smithsonian Institution. Fauchald and Paterson were excellent taxonomists but because they had not worked together it was not known whether the species from the equatorial Pacific were the same as those found in the Echo-1 study. Thus, nothing could be said about species ranges. At some point, Glover might have to go to the Smithsonian and spend months going through Fauchald's collection to see whether his species A, for example, corresponded to one of the species there. Clearly, this was a problem for the contractors as well, for if they wanted to understand the potential for extinction in a mining area, they would have do a diversity comparison by looking at the distribution of particular species.

Asking participants for their views on whether and how the centralization of taxonomic identification and collections might be realized, he recalled the suggestion in his background paper (chapter 3, section 3.2) that one museum with broad taxonomic expertise be identified for this purpose. Then, if contractors wanted to generate diversity information or a species list, they would send their collection to that museum. One possible choice was The Natural History Museum, London, which had done much work in the Pacific including the nodule-mining area.

Voicing the view of one contractor, a participant said there was an obvious need to standardize information, but how to do this would vary for different taxonomic groups, depending on how easy it was to classify by genus and species. With mollusks, for example, when material was sent to Guy Boucher at the National Museum of Natural History in Paris, most of the species were identified without a problem. Nematodes, with so many species that would never be described, required a different approach. Moreover, for a large group like the polychaetes, Gordon Paterson cold not possibly identify them all by genus and species.

As to the suggestion for designating a single museum to receive collections, she said that when she collected samples in the Pacific or Atlantic she sent them to Boucher, who put them in the museum in France. It would not be easy to ask a specialist to send a polychaete holotype to the Smithsonian or some other natural history museum, although how to handle a general collection of unidentified species was a different question.

A scientist working at a museum expressed the view that the management of taxonomy should be done in one place, by one individual or a small team that would know where the collections were going. It did not matter whether the polychaete collection was in Paris or Washington or London, because museums made collections available in any case. What was important was that all the contractors from different countries have a telephone number or electronic mail address where they could learn the location. Someone had to manage this – perhaps coordinate might be a better word – and he suggested that it be done in a museum, because that was what museums did.

He also spoke of the need for taxonomic quality control. The Natural History Museum, London, with 80 million specimens, was not looking for new collections, given the expense of incorporating and curating them forever in such a way that any specimen could be retrieved within ten minutes. For taxonomic standardization, it did not matter who identified species so long as everybody used the same criteria. The London museum addressed this issue for meiofaunal groups by holding workshops and appointing specialists from around the world for every group. For example, London might do nematodes while the Paris museum dealt with copepods and polychaetes were handled by Fauchald at the Smithsonian. The specialist who coordinated the polychaete criteria would not tell people what to do; rather, he/she would operate through workshops at some convenient location where several experts could assemble and take responsibility. In addition, experts collaborated with each other by calibrating different collections to be sure they used the same species criteria. If a contractor ran into a problem, it could have an E-mail address for the coordinator, who would pass the matter on to the appropriate party. The contractor might also send a representative to the specialized workshops, where the experts could give advice and build a relationship. This was not complicated; the London museum did it all the time at nematode workshops, where it trained people from all over the world at low cost.

Expressing interest in this approach, a contractor said his group had problems with taxonomy and would like to see work done on that issue. First, however, he wondered whether contractors should have responsibility regarding the taxonomy or genetics of all the benthic and plankton species. Second, as the transfer of knowledge was easy in the modern world, and as people could readily be sent somewhere for training, such activity did not have to be concentrated at one place or time. For many years there had been calls for international cooperation on the environmental aspects of deep-sea mining. Such cooperation could take the form of international programmes in designated areas, including those assigned to pioneer investors, and also having the Authority organize an international environmental research team to do the work that the Authority was asking the contractors to do. Every contractor could contribute to such a team.

Smith responded that contractors should clearly not be expected to identify all groups from picoplankton to megabenthos. Certain key groups likely to be impacted were important for evaluating impacts. The Workshop should identify what faunal groups and what part of the environment should be a focus of environmental studies. The biggest impacts were expected to be on the seafloor, where polychaetes were the largest component of the macrofauna. They constituted a diverse group for which species-level data were needed. Nematodes seemed to be another likely group.

A participant suggested that echinoderms should also be identified by a group of people working together, in light of studies showing the dominance of those animals, and especially the holothurians, among the epibenthic fauna.

A contractor said it was not clear whether the idea was to collect all the samples at one place for identification or whether a reference center or museum should be identified which someone could consult when a problem arose. It would be proper for each contractor to develop its own expertise instead of centralizing the expertise in one place. At the same time, a number of reference centres might be selected for different animal groups, which could be contacted as required.

Smith responded that it would be neither desirable nor even practical to ask Gordon Paterson, for example, to identify all the polychaetes collected by a research programme. What might be practical and beneficial for both parties was for somebody like Paterson to be a contact and organizer. When the Indian collection, for instance, was at the point of species differentiation, a scientist from India might work with Paterson for several months, preparing and learning the fauna so that the same kinds of judgements were made on species-level differentiation. Alternatively, a workshop could be convened to do the same thing. The problem with having a workshop take care of all the training or learning, however, was that the programmes were at different stages of data collection and sample identification, so an Indian, a Chinese or a Russian scientist would probably benefit at different times from interaction with the central taxonomist. In any event, it was important to have one taxonomist for each group act as an overseer or a clearinghouse, which taxonomists would like to do because it allowed them to understand biogeographic patterns.

The contractor who had raised this point thought Smith's first suggestion could work by improving specialization all over the world instead of centralizing it.

Another participant suggested that, with the aid of a quality-control taxonomist, many voucher collections could be produced. For example, someone working on polychaetes in the Clarion-Clipperton Fracture Zone (CCFZ) could assemble voucher collections of the main species for all the contractors. Three or four such collections could be loaned to contractors, who could use them until they had created their own voucher collection. When they were satisfied that they knew what species A looked like, they would have their own animals labeled species A. The coordinator – "central management" sounded authoritarian – would have the job of overseeing this work, to ensure that the contractors did not end up with different voucher collections.

One speaker, concerned about the declining numbers of taxonomists, said the new programmes being envisaged pointed to the need to train young scientists. A coordinating group could help with this problem. As another participant put it, the new assessment tasks generated by seabed activities could accelerate the desperation of taxonomists. A third speaker observed that this was the responsibility of the scientific community in all countries and not of the Authority.

Smith agreed that having a coordinating taxonomist would facilitate the training of scientists in other countries. It would also benefit environmental studies on mining impacts, deep-sea biology in general and the scientific culture in the contractors' countries.

Molecular biology

Asking about the new technique of DNA analysis, a participant wondered whether traditional taxonomists would disappear once easier and accurate methods came into play. Smith replied that, for a group like the polychaetes, it was important to use both approaches. A huge knowledge base rested on traditional taxonomy. Since what scientists thought they knew about evolution was based on the traditional methods, that whole approach could not just be thrown out. The molecular approaches and classical, morphologically based taxonomy had to be combined.

Another participant remarked that John Lambshead, in his presentation (chapter 16 above), had talked about molecular methods in relation to the meiofauna. For the hundred or so macrofaunal individuals that came out of an abyssal box core, it would be more efficient to sort them to species without applying molecular methods. Lambshead, confirming that he had referred specifically to nematodes in this connection, said it was the task of museums, as part of their scientific obligations, to calibrate the old taxonomy with the new, a problem about which the contractors need not be concerned.

Another speaker observed that molecular biology was the only way to understand the diversity of bacteria, the primary consumers of the detritus in the oceans. Smith agreed that bacteria were essential to the knowledge of ecosystem function, but their role in understanding mining impact was another issue. With a view to keeping the scale of investigation at a reasonable level, the contractors could not be asked to do too much. There was a limit to what was reasonable, and it was clearly a tighter limit than what scientists would like to have done.

Chemical analysis and sample processing

Smith said that in certain places, in France at one time and still in some parts of the United States, sorting centers were maintained to standardize and streamline the processing of material such as macrofaunal samples. A group of people with the appropriate equipment and expertise would efficiently sort samples and return them to the laboratory that had collected them. Either the government supported the center financially or, in the United States, the collector paid the company that did the sorting. He saw this as one possible way of streamlining or increasing the efficiency of sample processing and also of promoting standardization. If one laboratory was responsible for doing a certain difficult chemical analysis, for example a trace-metal analysis, or one laboratory or location was responsible for sorting macrofaunal samples, the process could be standardized. One way this approach might work in the seabed context would be for each contractor to contribute money to maintain a sorting centre that would process their samples, whether this involved macrofaunal sorting or chemical analyses. One of the downsides was that it would take some of the scientific work out of contractors' hands and put it elsewhere, possibly in another country, so that contractors would lose some of the opportunity for training and supporting their own scientists.

One contractor expressed the view that such an approach was unnecessary. Since everyone used the same equipment, standards and methods for chemical analysis, there was no need for a central chemical laboratory. On the other hand, it might be needed if the Authority were to set up an international research team and its own centre.

Another contractor also disagreed with such an approach, saying that people in his group were working not just for the contract but also as scientists. The Korea Ocean Research and Development Institute (KORDI) was trying to become like the Woods Hole Oceanographic Institution in Massachusetts and was investing in chemical analysis, which would help in building its own capacity.

In the same vein, a third contractor, seconded by a fourth, felt that too much centralization would delay things, especially when sending samples from the sea. With a mining site 2000 kilometres offshore, bringing samples back to his country and then transporting them to some central location would be difficult. Each country should develop its own capabilities, with assistance from outside experts.

One participant said that Germany had the same experience as the United States with new commercial sorting centres that were working well, using handicapped people as employees and receiving additional support from the state. Universities did not have the capacity to do this because they were also conducting scientific research. The situation might be different in other countries, however, so that it should be left to the contractors to decide.

Another speaker thought that each country, if it was able, should undertake the sorting because it would provide the initial knowledge of deep-sea biology. The role of a sorting centre was not just to split up different groups; it also had to work closely with scientists, a task that could not be done at a distance. Some of the data from her organization had been the result of a good sorting centre that had provided evidence of general trends in deep-sea biology. Such a centre, far from being insignificant, was a distinct asset in helping to understand the ecosystem.

Smith agreed, adding that he did not send his samples to sorting centres but still sorted many of them himself because he learned a lot from looking at the animals. Environmental consulting firms in the United States were not interested in training or being scientists; their concern was to do things as efficiently as possible. From a scientific perspective, the ability of environmental programmes to provide resources for training scientists deserved to be encouraged. He concluded that centralized sorting centres were a bad idea in the seabed context.

Field sampling

Observing that he had spent a lot of time on ships collecting box cores, Smith said the different rates at which box corers were lowered to the seabed adversely affected the quality and even the comparability of their samples. To a large degree, however, deep-sea biologists politely ignored this problem. One possible way of trying to standardize deployment techniques and the quality of samples might be to have a seagoing advisory team, perhaps consisting of a biologist, a chemist and a physical oceanographer, go to sea with the various programmes and interact with them about deployment techniques. By dealing with such matters as how to put the box core onto the bottom and what it should look like, they could provide training for new technology. Though he did not know where the funding would come from, this would be one way to get people working with a similar approach. One approach was not necessarily better than another, but when people used different ones they might end up with data that differed not because the environment was different but because the data were collected in different ways.

One participant felt that inviting people to cruises organized by different countries would be better than a workshop or an advisory team, because a lot was learned by going on a two- or three-week cruise. For example, the people from the sorting centre she had mentioned belonged to her group's team; they went out to sea and, if they saw that a box core was not good enough, the sample was rejected. The other people on board learned a great deal as a result.

Another participant commented that any contractor who wanted to do an environmental survey would have a group of scientists who had been working in oceanography for 10-20 years. Therefore, while he thought workshops, training and the exchange of scientists were good ideas, he was not sure about advisory teams. It could be left to individual groups or contractors to have an advisory team if they felt the need. What was required was a clear protocol, possibly drawn up by the Workshop, which had to be followed. Once such a protocol existed, people experienced enough to go to sea could do whatever was required to achieve data comparability

Another contractor also saw a problem with this idea. On his group's cruises foreign scientists were always asked to participate, and foreign scientific bodies were also requested to let some of his group's scientists take part in their fieldwork. Such methods functioned well, enabling people to learn from each other. However, his group's cruises generally had a full complement that included a physical oceanographer, a biologist, a chemist, a geologist and a sedimentologist. As it would be difficult to cut somebody out, he did not see how there would be room for a seagoing advisory team with experts in the same fields. However, if the Authority were to set up an international research team or cooperative programme, the capacity problem might be resolved.

Explaining one of the ideas behind his suggestion, Smith mentioned the work of the Hawaii Ocean Time-series (HOT) programme, funded by the National Science Foundation in the United States. The data it was collecting were being made available to the international oceanographic community. An advisory team of scientists visited every year to look at what had been collected and how it had been collected. The team offered advice on whether things were being done in an optimal or desirable way from the broad community perspective. This programme was run by Dr. Dave Karl, an internationally well-regarded scientist, who saw it as a valuable exercise.

Smith thought that the exchange of seagoing scientists was an excellent idea which the Authority might facilitate by helping scientists from one contractor go to sea with another one, or aiding an outside group of scientists to participate. It could do this through an exchange programme under which a contractor might seek advice on some issue, for example by asking the Authority for help in securing the onboard services of a scientist experienced with a new analytical technique that the contractor was learning. It might even provide travel funds.

A contractor commented that his group knew best what skills it lacked and it knew whom to contact. He did not think the Authority would know what was needed or that its recommendation would be better.

Another suggestion was to set up a protocol "cookbook" laying down detailed methods, or at least minimum requirements, that every contractor could decide to follow if it felt it had the knowledge and expertise and that it did not need any help. Alternatively, the contractor could obtain whatever outside expertise it needed.

Smith agreed that the Workshop might recommend acceptance of published international standards for analytical techniques such as the chemical analyses outlined in the protocols of the Joint Global Ocean Flux Study (JGOFS). However, certain procedures could not be put into a cookbook. To understand response to sedimentation, for example, it would not be productive to tell everybody to monitor their experiments at intervals of six months and one, two and four years; while that might be good the first time, someone might learn more from a modified experiment by changing the monitoring intervals. Given the need for scientific flexibility, the Workshop should be careful not to be too constraining in what it recommended.

A participant observed that, by the time mining began, the industrial organizations involved might not have the knowledge developed by the present contractors. He suggested, therefore, that the Authority keep lists of specialists and methodologies that would give future contractors the chance to make adjustments, get help with monitoring, recruit advisory teams and so on.

A contractor suggested that, before trying to standardize, the various methods used by each country should be compared, along with their benefits and disadvantages. Account had to be taken of differences in such factors as ship sizes, survey lengths and sample collection methods. However, another participant disagreed, saying that such an approach would make it impossible to compare results, even within a single area such as the CCFZ.

A member of the Legal and Technical Commission (LTC) pointed out that the purpose of the Commission's recommendations was to specify a certain course that contractors should take. A contractor who wanted to do something else would have to explain afterwards why another methodology had been chosen and would assume the burden if inter-comparison problems arose.

Another participant said that, as part of an international programme, the Workshop must think about the benefits of international cooperation and help to acquire better data, using the same protocol when possible in order to allow comparisons. However, giving advice would often be preferable to standardization. Moreover, sampling strategy was a matter for individual scientists; it could not be standardized because the choice of strategies depended on the question being addressed.

One speaker, referring to the time that would elapse before mining took place, warned against specifying something that might eventually become a barrier. Protocols could be selected if there was assurance that they would not change in the 10-15 years before mining. However, the objective was not to standardize but rather to acquire enough knowledge to determine whether activities were harming the environment.

Another participant cautioned that changes in methodology would probably make any comparison through time impossible. The question was not whether a technology was obsolete; rather, once a methodology was adopted it had to be retained, because if it was changed the data would not be comparable and therefore might as well not exist. He cited as an example, a massive plankton recording system that had been running in the United Kingdom for a hundred years.

Smith interjected that there were different reasons for changing a protocol. One might be the discovery of a method that narrowed the error bar, giving a better-defined answer with a gain in statistical power but without necessarily forfeiting comparability. On the other hand, if a method was found to be introducing a bias toward one side of the population mean, which often happened, it might not be advisable to adopt in mid-stream another method biased toward the other side that would make the dataset lose its comparability. Whatever recommendations were made, enough flexibility was needed to leave room for future improvements in technology, without losing sight of the long-term nature of a dataset.

A participant observed that, unlike the usual situation with individual scientific investigators, seabed exploration involved about eight groups working in the same area with the common goal of trying to assess the environmental impact of a proposed activity. Therefore, a degree of comparability was needed so that the work done by one contractor could be added to the work of others. For example, if someone was measuring primary productivity or studying the abundance of a species, the numbers should be comparable to similar research by others. However, if people were using different sieve sizes, the numbers would not be comparable. Thus, there was a responsibility to maintain comparability. The Authority had an important role in this area, which it could fulfill not necessarily through a group of overseers but rather by establishing workshops where results could be discussed and assessed jointly. Otherwise, it was easy for research groups to become isolated, with one group adopting one technique and another group following a different one. A degree of exchange was needed, so that if a group was going to take box cores, for example, and had a question about how to employ this technique, it could send its scientists to work with another group that had been doing such work. While the contractors wanted to avoid over-regulation, they should recognize their responsibility and the Authority should act as a facilitator through means such as workshops.

Summing up some conclusions that had emerged from the discussion, Smith said that the Workshop should start by identifying the key parameters that were important to measure and then list those for which there were currently accepted standards and protocols. An easy way to do this might be to identify protocol manuals or key scientific papers whose methods were useful as a standard. These would include relatively noncontroversial items such as macrofaunal sampling, for which a sieve size of 250 microns seemed acceptable. Although the Workshop should not be too constraining and should avoid forcing people to do things that might become obsolete in a few years, it was important to identify common ground by recommending the use of particular protocols. He saw this as a communications function more than an enforcement function.

Single monitoring firm

Smith asked for comments on the idea – which he characterized as extreme – of identifying a single firm to conduct monitoring. He noted that the United States Government often employed a single firm to perform a huge environmental study because it knew the data would be comparable. However, this seemed to be an inappropriate model in an international setting.

A participant said this was not only inappropriate but also contrary to the free market and the legislation of the European Community.

Cooperative activities

Smith suggested that the Workshop identify community-wide issues that would benefit from a common approach. One example was the coordination of taxonomy, on which he thought a consensus had been reached. Another was identifying the key questions that needed to be addressed in understanding impacts, and in this regard he believed that a series of dose-response experiments might be a useful subject for a common approach. Another example might be interannual variability, perhaps focussing on one site in the CCFZ to study longer-term processes and get a sense of the temporal variability of environmental conditions, with the expectation that the results could be generalized to some degree to the whole area.

He also hoped to see a brief outline of a cooperative programme that might address some of the community-wide issues, with proposals for answering key questions surrounding environmental response and mining impact. He saw a dilution of effort over time, during which the Benthic Impact Experiment (BIE) had been frequently repeated and had generated much knowledge. However, more could be learned by combining efforts and getting enough samples and expertise focused on particular questions so as to make important strides forward.

Finally, he said the Secretary-General had asked for an indication of how ISA could facilitate cooperative work and the maintenance of high data quality and standards. Among the suggestions discussed were workshops on data comparability for baseline studies, the design and contents of a database, and help in organizing oceanographic cruises.

On the latter point, a participant said she would like to see exchanges of personnel between research cruises. France had three remotely operated vehicles that could obtain useful environmental data and knowledge about physical oceanography near the bottom, resuspension and flux of particles and turbidity, and eventually conduct a colonization experiment. This research could not be planned, however, without discussions about sharing ship time.

Chapter 21 Standardization Strategies

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1. Summary

Environmental data collection is gaining momentum as a prerequisite for commercial mining of marine mineral resources. Various research groups are attempting to assess and predict the impact on the marine environment from small-scale disturbance experiments, as well as modelling studies. However, due to differences in scale of operation and design of future mining systems, it is necessary to adopt standard procedures and protocols to enable intercomparison of data and to formulate guidelines for conducting impact-assessment studies as well as monitoring the marine environment.

The procedures include those for sample collection, preservation, preparation and analysis. This involves data from navigation systems, evaluation of topography and seabed features, analyses for chemical, grain-size, stratigraphic and geotechnical properties of sediment, studies of benthic fauna (mega-, macro-, meio- and micro-), suspended particles from sediment plume, as well as physical and chemical characteristics of the entire water column.

Besides the standardization of procedures, there is a requirement to identify indicator parameters and to set up acceptable limits of environmental impacts, which will act as guidelines for a potential contractor to design and operate a mining system in future.

2. Introduction

Assessment of environmental impact resulting from any commercial venture has become a prerequisite for successful implementation of a project, due to an increasing concern for conservation of the environment. It is essential not only to be able to predict the potential impact on the environment but also to provide measures to restrict and counter that impact. Thus, it is becoming mandatory for a contractor to ensure the safety of the environment before launching any new venture. Similar concern for conservation of the marine environment has led to concerted efforts at evaluating the potential effects and developing means to control the impacts of deep-sea mining during the exploitation of seabed minerals.

The initial studies on impact assessment were done during the testing of certain mining systems in the Pacific Ocean in the late 1970s. These were followed up by simulated small-scale experiments conducted in restricted areas by research groups from Germany, the United States, Japan, the Interoceanmetal Joint Organization (IOM) and India[1].

The results of the environmental impact studies carried out so far have brought out the effects of small-scale disturbances on the geological, biological, chemical and physical conditions, and have highlighted the need for monitoring the effects of large-scale operations. Although some of the results can be applied to test mining or commercial mining, detailed investigations are required to establish the impacts and monitor the effects, due to differences in the scale of operations and design of the mining equipment as compared to small-scale disturbances.

Hence, it is imperative that baseline data are collected in the entire area of the potential mine sites, to take into consideration the variations in environmental characteristics between different locations and monitor the effects of pilot-mining tests, in order to predict the impact of large-scale mining.

The development and state of the art of the technology for mining of deep-sea minerals have been evaluated by experts[2] for the mining of 3 million tons of nodules per year. Detailed results from the impact experiments have shown that the resuspension of sediment and ploughing of the seafloor does affect the geological, biological and physico-chemical conditions close to the seafloor[3].

As all the studies are conducted by independent groups, using various techniques for assessment of impacts, intercomparison of results may not always be possible. It is essential to formulate a set of guidelines and standard procedures for the collection of environmental data.

Most countries have laid down guidelines for the assessment of environmental impacts accruing from various industrial and social activities in coastal areas. These include specific methods and limits for environmental impact assessment, which vary according to the standards set by the controlling authority in the region. As environmental impact assessment for deep-sea mining is a newly developing field, some authors have described methods for the study of marine benthos[4], potential effects of deep-ocean mining, sediment dispersion and other impacts of ocean mining, estimation of discharge characteristics of commercial nodule mining[5], and problem areas and regulation of deep-sea mining. Other authors have given a checklist of contents for an environmental statement from a potential contractor for waste treatment and disposal[6] as well as a detailed account of different stages of environmental impact assessment from planning to preparation of a report[7].

This paper attempts to evaluate some of the data-collection protocols followed during various experiments and their results, and to suggest the need and approach for the standardization of environmental data and information.

3. Collection of environmental data

Consequent to the demarcation of potential polymetallic nodule sites in the deep oceans around the world, these deposits are being looked upon as alternate resources for strategic metals such as Cu, Ni, Co, Zn, Pb and Cd in addition to Mn and Fe. Many countries and consortia have surveyed and identified areas for future mining, an activity that is expected to gain momentum in the present century.

The focus is now on collecting environment-related data for the purpose of:

1. Understanding the environment,
2. Predicting the impact of ocean mining,
3. Designing a suitable mining system and
4. Preparing a plan to offset the environmental impacts to the extent possible.

Deep-seabed mining, as an activity of the future, gains an advantage from the time available for collecting adequate information in advance, and experimenting with various methods and components for mining the deposits. With this in view, results from pre-pilot-mining tests by various consortia (in 1978-79), as well as simulated environmental impact experiments by various groups (1989 onwards), form an important database for designing large-scale mining equipment and predicting environmental impacts in the potential mining areas.

3.1. Selection of impact and preservation zones

For experimental purpose, small impact and preservation zones should be selected. An impact can be simulated using suitable devices, and monitored over a period, for environmental impact assessment. These studies would help in predicting the impacts of large-scale pilot-mining tests in future. However, detailed baseline environmental data need to be collected in the experimental area as well as in potential mining areas (outside the experimental sites) in order to ascertain the impacts due to local and regional variations in environmental conditions in the area.

Out of the large areas surveyed, the potential contractors would identify areas that are more profitable for mining; these would be the impact reference zones. The preservation zones would be areas outside the impact zones where no mining activity would take place and would serve as reference zones for natural (undisturbed) conditions, in order to assess the environmental impact of mining in impact zones.

However, certain criteria must be followed for selection of these zones:

a. They must have broadly similar environmental settings, to facilitate comparison of pre- and post-mining conditions.

b. They must be close enough for easy access from one to the other, but far enough to avoid any contamination from the impact zone to the preserved zone.

3.2. Reasons to collect environmental data

A summary of the probable impacts on the seafloor and at various levels in the water column is given in the following subsections[8]:

3.2.1. Potential impacts on the seafloor and benthos

It is anticipated that the primary benthic impacts caused by mining will be:

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; and

c. Clogging of suspension feeders' and dilution of deposit feeders' food resources.

3.2.2. Potential water-column impacts

Discharge of tailings and effluent below the oxygen-minimum zone may cause some environmental harm to the pelagic fauna, such as:

a. Mortality of zooplankton species resident at mid-water depths or that migrate to these depths on a 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 effects on abundance of their prey;

d. Impacts on bacterioplankton through the addition of fine sediment in meso- and bathypelagic zones;

e. Depletion of oxygen by bacterial growth on suspended particles;

f. Effects on fish behaviour and mortality caused by the sediments or trace metals;

g. Mortality of zooplankton and changes in their 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; and

i. Possible clogging of zooplankton by filtering particles in the plume.

3.2.3. Potential upper-water-column impacts

If tailings consisting of sediments (including clay) and effluent are discharged in near-surface waters, there are impacts additional to those listed in subsection 3.2.2 above, such as:

a. The potential for trace-metal bioaccumulation in surface waters due to discharges from the test-mining ship;

b. Reduction in primary productivity due to shading of phytoplankton by the surface discharges;

c. Effects on phytoplankton from trace metals in the surface discharge;

d. Effects on behaviour of marine mammals caused by the mining operation; and

e. Persistence of tailing suspension, especially with at-sea processing.

3.3. Levels for collection of environmental data

A contractor who wishes to mine the deposits will be required to have a complete database of environment-related information not only for monitoring the impact but also for the operation of the mining system, at the following levels:

3.3.1. Surface and atmosphere

The behaviour of the mining platform will depend upon the meteorological and sea-surface conditions, such as wind speed and direction, pressure, temperature, rainfall, storms, cyclones, wave height, current speed and direction, and various other parameters. The operational capability of such a platform must be designed to optimize the output/performance of the subsurface mining activity. Surface conditions will also determine the number of working days per year, from season to season and in different months. This will also affect ore transfer to the shore.

3.3.2. Water column

As the operation of any equipment would involve traversing the entire water column, physico-chemical conditions such as currents, temperature, salinity, oxygen and chemical composition of the water at various depths, and their seasonal variation, would be important considerations in the design of subsurface components.

3.3.3. Near-bottom waters

Most of the activities, such as the operation of the nodule collector, filtering of sediments, separation of nodules, storage and pumping from the buffer, and release of suspended matter would be concentrated in waters close to the bottom (about 100 to 200 metres above the seafloor). Therefore, the baseline conditions of this area must be known in order to assess the impact of mining activity.

3.3.4. Seafloor

As the nodules lie loose on the seafloor, partially buried under the sediment, seafloor characteristics such as topography, sediment type, thickness, grain size, chemical composition and engineering characteristics will influence the performance of the nodule collector. In addition, the redistribution of sediment over the area would change the bio- and geochemical conditions that sustain the megabenthos, macrobenthos, meiobenthos and microbes, which form essential components of the environment that will be disturbed by nodule mining.

3.4. Parameters for environmental data collection

Baseline studies are essential for environmental impact assessment, as they provide:

i. Reference information for comparison with post-perturbation data, and

ii. Inputs for planning, design and execution of mining operations.

These studies should therefore be conducted at all sites, both experimental sites for simulation of impact as well as potential mining sites, in order to determine the existing environmental conditions in the area.

The following parameters should be studied:

i) *Topography and seafloor features*: Topographic undulations, gradients/slopes, microtopography, sediment thickness and relief would determine the operating path of the bottom-crawling mechanism and help identify locations for sampling in the area.

ii) *Sediment characteristics*: Composition, structure, size variation, water content and engineering properties would determine the resuspension and resedimentation process of the plume which will be created by the separation of the nodules and the operation of the collector device.

iii) *Water-mass characteristics*: Circulation patterns from surface to bottom will determine the stability of various components of the mining system, from surface platform to subsurface lifting pipes and the dispersion of the plume to adjacent areas. Salinity, temperature, light transmission and chemical parameters would provide additional information about the structure of water masses at various levels.

iv) *Biomass*: Distribution, species diversity and population density of mega-, macro-, meio- and microorganisms throughout the water column, especially in the benthic areas, would form important baseline data for evaluating and predicting environmental impact.

3.5. Requirements of observations

i) Repeated observations must be made in order to evaluate seasonal variations of physical, chemical and biological characteristics.

ii) Observational methods must be internationally standardized for intercalibration of data.

iii) Locations of observations must represent various environmental settings.

3.6. Applications of environmental parameters

Different parameters would have different applications, as shown in table 1 of the annex.

4. Impact Assessment Studies

4.1. Requirements

4.1.1. Observations

The nature and intensity of impact would depend on whether it is a result of an experimental simulation, a pilot-mining test or commercial mining. Accordingly, observations should cover both pre- and post-impact phases. However, consistency in the methods used for data acquisition in baseline, pre- and post- impact studies is necessary to facilitate a proper assessment of the environmental impact.

4.1.2. Site selection

The sites chosen for the impact and its assessment would depend on the scale of impact. The location, shape, orientation and dimensions of the site would depend on the capability of the impacting device.

4.1.3. Method of impact

The extent of impact would vary depending on the impacting device, and the observations should be planned accordingly.

4.1.4. Indicator parameters

To assess the environmental impact, indicator parameters should be given adequate emphasis during the studies.

4.1.5. Monitoring of impact

Time-series observations of various parameters would facilitate the monitoring of impact. The results of monitoring would help in predicting the effects of large-scale mining in other areas, provided baseline data are available from the other areas.

4.2. Extrapolation of impact experiments to large-scale mining

A comparative study of the impact experiments conducted by different groups in the Pacific and Indian oceans has shown the following.

1. The mechanism for disturbing the seabed differed between the DISCOL (Disturbance and Recolonization) and other benthic impact experiments (BIEs). In DISCOL, the emphasis was on ploughing the seabed, while the other BIE projects concentrated on sediment resuspension. Both operations are based on tow-type instruments and are complimentary to each other in their actual mining scenario. Combining these approaches could afford a more realistic means of studying the potential effects on the seafloor.

2. The duration of these experiments, two weeks (DISCOL) or several tens of hours (18-88 hours for the BIEs), is much smaller than any kind of large-scale mining operation, which is expected to last for about 300 days per year[9]. The distances covered during these experiments (33-141 kilometres) are also quite small. Similarly, the volume of sediment recovered during different experiments, calculated as 0.77 m^3/minute (NOAA-BIE), 1.17 m^3/min (JET), 1.4 m^3/min (IOM-BIE) and 1.35 m^3/min (INDEX), ranges between 2 and 3.7 percent[10] of the estimated volume of sediment (54,000 m^3/day, i.e. 37.5 m^3/min) to be recovered during a commercial mining operation. Hence, all these experiments can be considered as microscale experiments in terms of sediment resuspension. In future, it may be advisable to conduct a relatively larger-scale experiment to study the impacts of such a disturbance on the benthic ecosystem.

None of the results from impact studies can be applied to predict the effects of large-scale mining for the following reasons:

a. The size of the site selected for impact assessment for a pilot-mining test will be a few orders smaller than that of commercial mining.

b. The volume of resuspended sediment and the depth at which it will be released may not be the same as in large-scale mining.

c. The capability of the nodule collector to penetrate into the seafloor and discharge the slurry into the water column will not be the same.

d. The duration of the operations will be different. Whereas pilot mining will be a short-term process, commercial mining will be a continuous process.

4.3. Recommendations for future benthic disturbance experiments

To assess the environmental impact of nodule mining, it is necessary to increase the scale of the disturbance, so that it resembles the commercial mining operation to some extent in terms of sediment resuspension, altitude of discharge and areal coverage. Some suggestions for this are given below.

4.3.1. Greater sediment discharge

Commercial mining is expected to remove 3 million t of nodules over about 300 days per year, which is about 10,000 t per day. Since the nodules are associated with sediment in the ratio of 1:5, about 50,000 t of sediment is expected to be disturbed every day. In view of this large volume of sediment, the capacity of the pumps as well as the discharge from the disturber must be substantially enhanced to increase the volume of sediment resuspension in the water column in order to assess the effects of such a large- scale disturbance.

4.3.2. Altitude of sediment discharge

Since the sediment and debris may be discharged at a buffer expected to be a few hundred metres above the bottom, sediment discharge in the future experiments should be at a higher altitude to assess the effects of dispersion of the plume.

4.3.3. Towing pattern

As observed during INDEX, the actual duration of disturbance is only 24% of the total time of each operation, which is highly time-consuming and less productive. It would be advisable to devise different towing patterns that would occupy more space and time on the seabed, resulting in more area coverage and a greater volume of disturbance. A few examples follow.

a. *Linear two-directional* - The linear pattern could be followed in two directions along the disturbance site to avoid loss in transit time.

b. *Linear two-directional on two parallel tracks*: In order to account for turning space for the vessel, two parallel strips can be disturbed, leaving an undisturbed strip in the centre for resedimentation and monitoring.

c. *Doughnut pattern*: A circular area with an undisturbed zone in the centre may be most economical in time and highly productive, as it requires no time for hauling up the disturber or for turning the vessel.

d. *Cartwheel pattern*: All tracks passing through a centre point would give rise to a highly disturbed central zone and gradually less-disturbed zones toward the periphery. This pattern may be used for assessment of relatively less-disturbed areas with respect to highly disturbed areas, similar to those of large-scale mining operations.

4.3.4. Autonomous disturber

Unlike the present passive disturber, a disturber of the ROV (remotely operated vehicle) type, with thrusters and rotors attached to an umbilical cable from the depressor, would cover a larger area in much smaller time, making the operation economical and productive.

4.3.5. Real-time assessment of impact

In addition to sediment traps and sediment sampling after the disturbance, observation of the plume with a rosette sampler, transmissometer and television camera from another vessel following the disturbing vessel would give a much better assessment of the immediate effects of sediment resuspension in the water column and on the seafloor.

5. Preparation for Deep Seabed Mining

5.1. Environmental considerations

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

?? Minimizing sediment penetration of the collector and mining vehicle,

?? Avoiding the disturbance of the more consolidated suboxic sediment layer,

?? Reducing the mass of sediment swirled up into the near-bottom water layer,

?? Inducing a high rate of resedimentation from the plume behind the miner,

?? Minimizing the transport of sediment and abraded nodule fines to the ocean surface,

?? Reducing the discharge of tailings into bathyal or abyssal depths, and

?? Reducing the drift of tailings by increasing their sedimentation rate.

5.2. Some unanswered questions

1. What type of mining system or systems likely to be developed over the next 20 years can be a basis for environmental tests?

2. How do we categorize and identify pollutant or effluent discharges from the ship, buffer and miner/collector resulting from land processing and at-sea processing?

3. Given answers to questions 1 and 2, how do we develop an approach to disturbance-flow simulation models or component-disturbance tests above the seafloor, and verify the simulation models?

4. How do we generalize the test parameters from the tow-sled collector and miner/collector vehicle?

5. How much room do we leave in environmental test planning for unidentified deep-sea questions?

6. How do we integrate the test data on bottom disturbance and other effects into ecologically safe (environment-friendly) mining-system design and operations?

5.3. Requirements of an environmental impact assessment statement

A contractor should be required to furnish a statement containing the details of:

a. Baseline data on various environmental parameters collected at the experimental site as well as in the proposed mining area;

b. Results of a simulated impact experiment and details of methods and equipment used for assessment of impact;

c. Expected environmental impact due to mining activity;

d. Criteria for the selection of experimental, test and commercial mining sites;

e. Measures undertaken to minimize the effects of mining on the environment; and

f. Parameters for monitoring the effects of any potential environmental impact due to mining.

5.4. Tasks of the Authority

The International Seabed Authority will need to do the following in anticipation of seabed mining:

a. Lay down guidelines for the environmental impact assessment of nodule mining;

b. Prescribe standard methods for assessment of impact so as to allow intercomparison between mining sites and operations;

c. Specify acceptable limits for environmental impact on various parameters;

d. Regulate monitoring of impacts from commercial mining operations.

To meet these objectives, it is necessary to form working groups to develop detailed protocols for each parameter. Each of these working groups will collect inputs from others working in the field and compile the information for consideration and acceptance by the Authority, after a follow-up meeting to finalize these protocols.

The key tasks to be addressed are:

1. To categorize parameters into critical, important and regular;

2. To identify indicator parameters for impact assessment and monitoring;

3. To define protocols for sampling, subsampling, storage and analyses;

4. To define the acceptable limits of impact for each parameter;

5. To decide the contents of environmental statements required from each contractor; and

6. To specify the format for data archival.

ANNEX: PROTOCOLS FOR DATA COLLECTION

The guidelines for the assessment of the environmental impacts from the exploration for polymetallic nodules in the Area, recommended by the 1998 ISA Workshop held in Sanya, China, state the following with respect to data collection and analysis[11]:

> "... Collection and analytical techniques must follow best practices such as those developed by the Intergovernmental Oceanographic Commission (IOC) of the United Nations Educational, Scientific and Cultural Organization (UNESCO) and available at World Data Centres and Responsible National Oceanographic Data Centres, or those established or recommended by the Authority..."

Selected IOC manuals and guides are listed in appendix A to the Sanya Workshop's report.

IOC manuals and guides for suggested protocols, as well as those adopted or recommended by scientists working on environmental impact assessment of deep-sea mining at the National Institute of Oceanography (NIO), Goa, India, are listed below.

1. IOC manuals and guides

Methods and protocols for data collection on various oceanographic parameters for environmental impact assessment have been published in the following manuals and guides by IOC:

1. *Guide to Oceanographic and Marine Meteorological Instruments and Observing Practices*[12], which covers:

?? Requirements and standardization of instruments
?? Sea-surface temperature
?? Salinity
?? Temperature versus depth
?? Wind, waves and swell
?? Current
?? Wind speed and direction
?? Atmospheric pressure
?? Air temperature and humidity
?? Precipitation and visibility
?? Water transparency and colour

2. *Chemical Methods for Use in Marine Environmental Monitoring*[13], which covers:

Determination of pH, oxygen, hydrogen sulfide, inorganic phosphate, total phosphorus, silicate, ammonia, nitrate, nitrite etc.

3. *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements*[14], which covers:

?? Shipboard sampling procedures
?? Conductivity-temperature-depth (CTD) and related measurements
?? Quality evaluation and intercalibration
?? Salinity determination
?? Dissolved oxygen by Winkler procedure

- ?? Total inorganic carbon by coulometric procedure
- ?? Determination of nitrite, nitrite+nitrate, orthophosphate and reactive silicate
- ?? Nitrate, nitrite, phosphorus and reactive silicate in seawater
- ?? Algal chlorophylls and carotenoids by high-performance liquid chromatography (HPLC)
- ?? Chlorophyll *a* by fluorometry
- ?? Particulate organic carbon and nitrogen
- ?? Dissolved organic carbon
- ?? Bacterioplankton, bacterial production
- ?? Microzooplankton biomass
- ?? Sediment-trap methods

4. *Oceanographic Survey Techniques and Living Resources Assessment Methods*[15], which covers:

- ?? Navigational systems
- ?? Marine processes
- ?? Oceanographic techniques
- ?? Ecological survey
- ?? Monitoring
- ?? Information management

Although these protocols may be slightly different from those required for deep-sea mining, they could be modified for environmental impact assessment studies for deep-sea mining. However, none of them includes a protocol for environmental parameters in the benthic environment, which is expected to be affected the most in case of deep seabed mining, as the minerals occur on the surface of the seafloor.

2. Procedures suggested by NIO (India)

Outlines of procedures adopted or recommended by scientists working on environmental impact assessment of deep-sea mining at NIO are given in the three following tables in this chapter and in appendix B at the end of this volume.

Table 1 Applications of environmental parameters.

Subject	Parameters	Application
Geology		
Evaluation of seafloor features	Bathymetry, morphometry, sediment thickness, type of substrate	Selection of test and reference areas, demarcation of test site, evaluation of seabed characteristics
Geochemical analysis of pore waters and sediments	pH, Eh, alkalinity, phosphate, nitrate, nitrite, silica, organic carbon	Geochemical status and effects of disturbance on their stability
Sediment-size analysis and clay mineralogy	Sand, silt, clay fractions, mineral assemblages	Size variation during suspension and resedimentation
Geotechnical analysis	Water content, shear strength, wet density, specific gravity, porosity, plasticity index	Bearing strength and loading capacity on seafloor for design of mining system
Biostratigraphic analysis	Radiolarian zonation, bioturbation	Intactness and depth of mixing of sediment
Analysis of particle fluxes	Total flux, major and minor elements, biogenic silica	Distribution and concentration of suspended matter
Biology		
Biological productivity in surface waters	Phytoplankton, zooplankton, primary productivity, chlorophyll *a*, optical properties	Effects of effluent discharge
Mega-, macro- and meiobenthos and their diversity	Abundance, distribution and species variation	Impact on benthic communities
Microbes and their biochemical environment	Colony-forming units of bacteria and fungi, total count of bacteria, adenosine triphosphate (ATP), labile organic matter, total organic carbon	Microbial and biochemical changes in sediments
Physics		
Meteorological data	Net radiation, sunshine, wind speed and direction, relative humidity	Conditions for installation of platform
Hydrographic data	Potential temperature, salinity, density, vertical stability, light transmission	Effects on physical characteristics and design of mining system
Water mass circulation	Current speed, direction, total kinetic energy, spectral analysis	Modelling of plume movement
Chemistry		
Chemical characteristics of seawater	Dissolved oxygen, pH, alkalinity, nutrients, trace metals	Effects on chemical characteristics due to effluent discharge

Table 2 Core sections analyzed for various parameters.

Core depth (cm)	Sediment chemistry	Sediment size	Clay mineralogy	Pore-water chemistry	Meiobenthos	Microbes and biochemistry	Geotechnical properties	Shear strength	Macrobenthos	Biostratigraphy
0-2	?	?	?	?	?	?	?		?	?
2-4	?	?	?	?	?	?	?		?	X
4-6	?	?	?	?	?	?	?	?		?
6-8	?	?	?	?	?	?	?		?	X
8-10	?	?	?	?	?	?	?			
10-12	?	?	?	?	?	?	?			?
12-14	?								?	X
14-16	?	?	?	?	?	?	?	?		?
16-18	?									X
18-20	?									
20-22	?	?	?	?	?	?	?			?
22-24	?									X
24-26	?	?	?	?	?	?	?	?		?
26-28	?									X
28-30	?									
30-32	?	?	?	?	?	?	?		X	?
32-34	?									X
34-36	?	?	?	?	?	?	?	?		?
36-38	?									X
38-40	?									

? **=** section analyzed **, X** = section not analyzed.

Table 3 Parameters analyzed at specified depths in the water column.

Water depth (m)	Temperature	Salinity	Currents	Meteorology	Dissolved oxygen	pH	Alkalinity	Nutrients	Trace metals	Phytoplankton	Zooplankton	Primary production	Chlorophyll *a*	Optical property	Sediment flux
0-200	▲	▲		?	???	???	???	???	???	?	▲	?	?		
200-400	¦	¦			???	???	???	???	???		¦				
400-600	¦	¦	?		???	???	???	???	???		¦				?
600-800	¦	¦			??	??	??	??	??		▼				
800-1000	¦	¦			??	??	??	??	??						
1000-1200	¦	¦			?	?	?	?	?						
1200-1400	¦	¦	?												
1400-1600	¦	¦			?	?	?	?	?						
1600-1800	¦	¦													
1800-2000	¦	¦			?	?	?	?	?						
2000-2200	¦	¦													
2200-2400	¦	¦													
2400-2600	¦	¦			?	?	?	?	?						
2600-2800	¦	¦													
2800-3000	¦	¦			?	?	?	?	?						
3000-3200	¦	¦													
3200-3400	¦	¦													
3400-3600	▼	▼	?		?	?	?	?	?						
3600-3800															
3800-4000					?	?	?	?	?						
4000-4200															

4200-4400			?												
4400-4600					?	?	?	?	?						
4600-4800															
4800-5000			??		?	?	?	?	?						
5000-5200			??		???	???	???	???	???						???

+ = single observation, ++/ +++ = multiple observations, ✍✍ = continuous observations.

PRESENTATION AND DISCUSSION ON STANDARDIZATION STRATEGIES

Dr. Rahul Sharma addressed the Workshop on the need to standardize environmental data and the approach that might be taken to achieve this. Although the talk so far had concentrated on baseline conditions and impact assessment, he said, environmental data had many more applications, including modelling and prediction, design of mining systems, mining plans and environmental conservation. Thus, when collecting environmental data, the other applications should also be borne in mind, as mining engineers or modellers could not be expected to go back to the sea after 10 or 15 years to get the kinds of data they required.

Although most Workshop participants were biologists, it had to be realized that impact assessment was not merely biological impact assessment. There were many parameters, such as the meteorological parameters of temperature, pressure, wind, sunshine and rain, which would interest mining engineers when they wanted to deploy a mining system. A disturbance on the surface, or in the water column, the near-bottom waters or the sediment, would affect photosynthesis, increase turbidity and change productivity levels in the surface waters. Disturbing the physico-chemical characteristics of the water column would ultimately have an impact on the biological forms. The benthos would be affected because of changes in pore-water conditions, nutrient levels, bioturbation and sediment characteristics – all factors that supported benthic life either in the near-bottom waters or in the sediment itself. Therefore, many more parameters should be taken into consideration beyond those already discussed.

The test and reference sites would be small dots, or probably single lines, just a few square kilometres or a few tens of square kilometres in area, in contrast to the scale of the mine site, which would cover a few hundred or a few thousand square kilometres. Thus, environmental data were needed not only from the test and reference sites, which some had already investigated and others would study in the future. The lateral extensions of the mine site also had to be studied, because the environment throughout the mining area would not be the same as it was at the test and reference sites. Enough baseline data would have to be collected throughout the entire mine site, which meant that two lists of parameters were needed -- one with baseline data needed for many applications and a separate list for impact assessment.

Reviewing the environmental and mining applications for the various parameters, Dr. Sharma observed that much of the data collected at the surface, including productivity, would be of interest for environmental assessment, but a lot of it would be useful to the mining engineers and modellers. They would be interested in methods of controlling discharge to diminish its impact and conserve the surface waters. Temperature profiles, oxygen levels and other data would be useful for deciding the point of discharge. Geological data would be useful for the engineers concerned with mining-vessel design, the stability of the vessel and its operation. Water-chemistry data would help in predicting the corrosion levels of underwater systems. The number of operating days, transfer of ore at the surface and other matters also required environmental input.

In the water column, studies were already underway on currents, the oxygen-minimum zone, temperature profiles, water chemistry and particle fluxes, all useful for impact assessment. These would also be helpful for the mining engineers as they thought about the behaviour of their pipes under water, leakages, corrosion and the migration of sediment at the point of discharge.

At the seafloor, environmental assessors were concerned about the sediment plume, resedimentation, geological and biochemical changes in seafloor features, and the effect on biomass. Some of these, relating to seafloor features and others, were of interest in mine-site selection, coping with obstructions on the seafloor during the operation of a mining system, the benthic transport of sediment and nodules, and the design of other mining-system components.

Besides their utility for impact assessment and for mining planners and engineers, environmental data were needed for the selection of impact reference zones (IRZs) and preservation reference zones (PRZs). As envisaged by the Legal and Technical Commission (LTC) of the International Seabed Authority,[16] the IRZ and PRZ would have to have similar environmental settings. Therefore, the various parameters would have to be examined, including current patterns, sediment fluxes and other physical, chemical, biological and geological factors. The zones would have to be close enough for easy access from one area to the other but far enough apart to avoid contamination. The IRZ would be within the mining area, whereas the PRZ would be outside the mining area so that it would remain intact and not be affected at any time during mining.

Sharma went on to give examples demonstrating the need for standardization -- without, he said, intending to criticize the five benthic impact experiments (BIEs) done so far, all of which had their limitations. He cited some of their observations on meiofauna:

?? The Disturbance-Recolonization (DISCOL) experiment -- meiofauna composition was not the same even after seven years.

?? The United States National Oceanic and Atmospheric Administration (NOAA) – the meiofauna had decreased after nine months; no later information had been given.

?? The Japan Deep-Sea Impact Experiment (JET) – the meiofauna had returned to their original condition after two years.

?? The Interoceanmetal Joint Organization (IOM) – the meiofauna was more affected in the disturbed zone.

?? The Indian Deep-sea Environment Experiment (INDEX) – effects differed within and outside the disturbance track; the Indian group was going to monitor this area for only three years.

These results clearly suggested different time scales of observation and thus created a problem when trying to compare them, he said. If the Authority wanted to set rules, guidelines and methods of monitoring what each experiment or mining operation was doing, it had to specify observation times and monitoring intervals and periods so that the data would be intercomparable.

Regarding the sampling protocols utilized for meiofauna, he said DISCOL had sampled at 1 centimetre intervals up to 6 cm; NOAA at 0.5 cm intervals up to 3 cm; JET at 0.25 cm intervals up to 1 cm, then 0.5 cm intervals up to 3 cm and 1 cm intervals up to 5 cm; IOM at 0.5 cm up to 3 cm and 1 cm intervals up to 6 cm, and INDEX at 2 cm intervals up to 10 cm. The Indian group had chosen broad intervals because it did not have access to a multicorer. Once again, there was non-uniformity in the sampling protocols for meiofauna. Yet, the meiofauna was a good indicator of impact from mining for nodules. Many biologists said that the top 2 cm would be critical, as the largest numbers of meiofauna in the sediment column were located there and mining would disturb the top 5 to 10 cm.

He next cited an example of the measurement of water content from three samples taken at the same location but using two different coring devices. The data from a box core, even taking the averages at three different levels in the sediment core, indicated that the water-content levels were extremely heterogeneous, with no particular profile or trend. The multicorer, however, showed a clear downward trend in water content. Thus, different samplers gave different patterns of data for samples collected at the same location.

In another comparison, he cited sediment-density estimates from Indian and Japanese sites using four different methods involving the removal or non-removal of air from the sediment: (1) measurement without creating a vacuum in the sediment, where the sample was dried but exposed for some time; (2) similar measurement where the sample was dried but not exposed; (3) measurement by creating a vacuum and exposing the sample for some time, and (4) similar measurement but without exposing the sample. Again, different values had been obtained for sediment density. Probably the ideal method would have been to use a vacuum device, dry the sediment, not expose it to the atmosphere, remove all moisture, remove all air and then measure the density of the sediment.

He then compared the scales of the BIEs. Their duration had been between 18 and 88 hours, whereas the expected duration of mining was 300 days/yr. The experiments covered areas of 33-141 km^2, whereas the expected area of mining was about 300-600 km^2/yr. The recovery rate in the experiments had been 0.77-1.4 m^3/minute, while the expected rate during mining was about 37.5 m^3/min. Thus, the experiments were orders of magnitude smaller than mining, so that extrapolation of data was a question mark.

Turning to the requirements for future impact experiments, Sharma said he was broaching this topic because the requirements needed to be set now. He listed the following: greater discharge of sediment; variable altitudes of discharge in the water column; assessment of impact at all levels in the water column, since mining would impact levels other than the benthic area; a pattern of disturbance more closely resembling what a nodule collector would cause, to be defined after talking with engineers; real-time impact assessment; regular monitoring, and preferably use of a pilot-mining system. Investigators should avoid repeating the mistake of generating a disturbance without knowing whether it conformed to the design of a mining system and thus whether the resulting data would be applicable.

He offered some suggestions that environmental scientists might give to mining-system developers and mining engineers: minimize sediment penetration, restrict sediment dispersal to the seafloor so that it would not spread, minimize nodule and sediment transport to the surface, discharge tailings below the oxygen-minimum zone and treat the tailings before discharge. Environmental scientists had a responsibility to sit with the mining engineers to discuss such matters.

He identified several unanswered questions: What kind of mining system was likely for the future? What were the likely impacts of this system? How would pollutants from the collector or ship be identified? How should test data be integrated with the mining-system design and operations?

The Authority should expect statements from each contractor giving detailed baseline data, criteria for the selection of test and reference sites, the results of any simulated impact experiment, the expected environmental impact due to mining, parameters for monitoring of impact and proposed measures to minimize the effects. He raised these points because the contractors would need to know in advance what was expected from them.

He then gave an example from the Indian site, stating that India was in the process of relinquishing the extra area of its original claim, leaving it with 75,000 km^2. The area covered by test and reference sites so far was about 700 km^2, meaning that less than 1 percent of the claim had been studied from an environmental point of view. That was not enough because, over the area of 75,000 km^2 where a mine site could somewhere be located, there was a variation in sediment types and hence in physico-chemical conditions and biological species, and probably also in biomass, diversity and other factors. Thus, India and all other contractors would need detailed baseline data on the entire area they had claimed; environmental information from the test and reference sites alone were not enough to represent the entire mining area.

In mining an average of 10 kilograms of nodules per square metre, an area of about 300 km^2/yr would be disturbed. Such an area was not large compared to the rest of the ocean, amounting to 0.4% of the 75,000-km^2 claim area. Even if the affected area were ten times larger, it would still be much smaller than the entire ocean area. Rather than devising a complete list of environmental data to be collected, the Authority should select critical parameters that had to be monitored, given the small size of the mining areas and zones of influence.

He then listed what the Authority was expected to do: develop guidelines, which it had already been doing; prescribe standard protocols, which it was in the process of doing; eventually specify acceptable limits for impact on various parameters, which the contractors would like to know before or while developing their mining systems; and regulate the monitoring of impacts.

The parameters should be placed into different categories such as critical, important or routine (less important). It should be made clear which parameters were most crucial for baseline data and for impact assessment. In addition, at some time in the future indicator parameters had to be identified, to serve as a good reference of what the impact would do and what should be looked at. Protocols should be defined for data collection, sampling, subsampling, analysis and storage. Acceptable limits of impact should be defined if possible, and the contents of environmental statements and the format for data archival should be specified. Protocols had already been suggested for such topics as the study of marine benthos, effects of deep-ocean mining, sediment dispersion and other impacts. Manuals and guides prepared by the Intergovernmental Oceanographic Commission (IOC) could also form the basis for preparing protocols.

Finally, if the Workshop could not complete this massive job, he extended an offer to host a further meeting at NIO in Goa the following year to discuss and recommend standard protocols for environmental data and information.

SUMMARY OF DISCUSSION

Size of environmental assessment area

A contractor wondered whether it would have to conduct a vast environmental study on its entire claim area when it was likely to mine only about 10,000-20,000 km^2 over the next 25 years. As the economical viability was unknown, the likely scenario would be to start small, see how things went and, if they did not go well, close down.

Dr. Sharma replied that, if a contractor had not yet identified its mine sites, it could collect baseline data for the entire claim area, but if it knew its sites and thought they would be enough, there would be no need to gather baseline data all over the area.

Scale of impact

Participants, referring to Sharma's figure of 300 km^2/yr as the size of the area to be mined by a single contractor, discussed how the size of the impact area should be extrapolated from BIEs to actual mining, and how large the impact area would be relative to the area mined.

Dr. Craig Smith recalled that the JET experiment had made 26 tows with a disturber that had resuspended sediment from a track 1 m wide. Thus, by analogy, a swath of sediment 26 m wide had been mined. Resedimentation effects had been detectable up to 200 m on either side, so that the mined area could be multiplied by a factor of 20. Actual mining would cover a swath 1-10 km wide, extending for 15-20 km, and the plume would cover an area several times larger.

However, a participant observed that, as the tracks were parallel, the 200-m impact area in the experiment was smaller than Smith had calculated, running only from the border of the overall mined area. A miner would want to clear the entire area, which might be in the range of 1-3 km wide by 10 km long. The likely extent of the plume was unknown, given the fact that contractor might be able to limit it in a way that reduced the width of the disturbed area. Moreover, the miner would run back and forth over the area disturbed during a previous pass, until at the end the disturbed area would be confined to the margin of the mined area. Thus, the disturbed area would amount to much less than each track multiplied by 400 m.

Smith objected that that calculation was optimistic, partly because a finer plume, dispersed well beyond 200 m, had not been detected. If a miner continually produced a more diffuse plume, much larger than in the experiment and dispersing farther, an effect would be visible. Moreover, the sampling intensity of all the BIEs was so small that a huge effect would have been needed to see an impact. As a biologist, he was convinced that effects would be seen over a much larger range – 2 km or more -- from the edge of the mined area than had been reported from the edge of the BIE track. Thus, every square kilometre of mined area would produce a disturbed area 2 km on each side, a factor of 4 or 5. The 300-km² mined area should be multiplied by 5, times 20 years.

A participant pointed out that the shape of the mined area would be directed more or less by the topography. In the French area of the North Pacific Ocean, for instance, the area that could be mined using the proposed technology was about 2-3 km wide and 10-20 km long, bordered by hillsides and cliffs up to 300 m high. The collector would mine the area by going along one track, returning on the next track as close as possible in order not to miss any nodules, and continuing back and forth to the end. During the first pass the impact area would be, say, on the left side and at the final pass it would be mainly on the right side, with other impact areas at the far ends. Thus, the 2-km impact area on each side would be double the area of the 2-km-wide mined swath.

Smith responded that no deep-sea biologist alive believed that the impact of mining would be limited to 300 km². That figure would have to be multiplied by 20 yrs and then by a minimum of 3 times – he thought 10 times was more realistic – to account for the scale of resedimentation relative to the scale of mining. A participant noted that this would amount to about 30,000-50,000 km².

Another participant stated that the impact would not occur on both sides because currents would cause the plume to drift in one direction. Smith disagreed, saying that the predominant component of the current in most of the potential mining areas was tidal, so the current would be going around. Sharma concurred, saying that in the Indian area the direction changed every month.

Smith added that the scale of dispersal of the plume was a big unknown. He did not believe that enough was known from the BIEs to make any estimate of the scale of plume impact.

Asked whether he thought the results from the different BIEs were comparable, Sharma said they were generally comparable because the method of disturbance had been the same. However, the degree of disturbance was not the same because the amount of disturbed sediment ranged from 1500-6000 m^3. Nor was the background environment the same. The impacts were comparable, however.

A participant observed that, from an engineering point of view, the collector should be designed to minimize the formation of a plume because it was to the miner's advantage not to resediment material to the area that would be mined along the next leg. Furthermore, it was imperative to consider the currents so that the next leg would not go through the resedimented area. Thus, he did not agree that a huge area would be affected.

Responding, Smith questioned the idea that the sediment could be made to drop back into the track just mined to avoid covering the adjacent nodules. The behaviour of deep-sea sediments, the constraints of mining and the unknown benthic response to resedimentation effects made it difficult to speculate on the scale of the impacts. Even without assuming the worst case, the precautionary principle dictated the need to consider what could happen by conducting controlled studies. BIE-type experiments were not sufficiently controlled to provide the necessary answers.

Costs and consequences

A participant said he had been surprised to hear during the course of the Workshop how many parameters should be measured, a number that would probably rise even higher over time. Such activity had consequences in terms of cost, time and personnel, for instance requiring taxonomists to devote years of work, to the exclusion of anything else. Even then, there would not be a complete picture of the extent of possible damage to the local environment. However, one day the time would come to decide whether to authorize or forbid a contractor to mine an area with whatever means were proposed, taking into consideration all recommendations issued to reduce the impact. He was afraid that, at that point, the Authority would have to accept some awful effects on the marine environment, the extent of which would not be completely understood. However, it was already accepted that the damage would affect only a small portion of the marine environment and would not produce any catastrophic effects as perceived by the average person. Nevertheless, if the costs of environmental studies were too high compared to what was viewed as a reasonable preliminary investment before a decision to mine, investors would turn to a less costly long-term operation where they would be authorized to cut a whole forest without having to make such complicated preliminary studies. He endorsed Sharma's recommendation to focus on significant parameters in order to avoid measuring too much.

Characterizing this as a relevant observation, Smith said that a balance had to be struck between what people would like to know and what they needed to know about the ocean and the impacts.

Another participant recalled the calculation he had made earlier, during the discussion on a design strategy for baseline studies (chapter 18 above), that one experiment would require several years of work by 21 taxonomists using conventional morphology. With molecular technology, however, it would take 21 months to do the same project using one DGGE machine, or a year using two machines, at a cost of 5,000 pounds sterling for each and without need for specialized taxonomic knowledge. With the right technology, the job could be done.

As a final suggestion, Sharma urged each working group to pick up any existing protocol – for water-column observations or sediment parameters, for example – and start working on it rather than beginning from scratch, detailing the parameters that needed study and possible methods of observation

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PART V

Conclusions and Recommendations of the Workshop and its Working Groups

The results of the Workshop are set out in four parts: a report containing its recommendations on general topics relating to its mandate, and the recommendations of its three working groups on the measurement of key environmental parameters.

The Workshop devoted much of its time to technical matters that must be resolved to ensure that contractors with the International Seabed Authority will know what data and information they are expected to submit on environmental conditions in the areas allocated to them for polymetallic nodule exploration. During the discussion, however, several broad issues were raised that go beyond the specifics of standardising data gathering and measurement. The main report contains recommendations on the following:

?? *Cooperative biological research* into five specific questions centring on how deep-sea animal communities are likely to respond to seabed mining. The ISA is urged to facilitate such research and to identify sources of support.

?? The creation of *databases* that will enable contractors to keep up to date on the environmental information collected by other contractors, including a central database managed by ISA in which all such information is assembled in one place for easy retrieval. Detailed requirements for an ISA database have been prepared by one of the Workshop participants, Dr. Ron Etter (chapter 19 above).

?? *Taxonomic coordination* utilizing recognised experts to assist in the correct identification of animal fauna living on the deep seabed. This is needed so that contractors will know whether species they find in one exploration area are the same as those found by others elsewhere. Such information is necessary to establish the geographical ranges of species and thus the likelihood of their extinction by a mining operation.

?? The *exchange of seagoing scientists* to help contractors benefit from each other's expertise in data collection, and *cooperative cruises* in which a research vessel covers areas allocated to several contractors.

?? *Workshops* to be organized by the Authority that will enable scientists and technicians from different countries involved with environmental monitoring to share, compare and standardise procedures.

?? *Other standardisation* activity, including the development of environmental measurement standards where they do not yet exist.

Each of the working groups sets out recommendations for identifying and measuring key parameters (variables) about which data will be needed to assess environmental conditions and effects in exploration areas.

In a series of tables, the *Chemical/Geological Working Group* lists parameters and proposed methodologies for measuring them, covering sediment properties, sediment pore waters, the water column and trace metals in organisms.

The *Benthic Biological/Environmental Working Group* suggests procedures for sampling key biological parameters (megafauna, macrofauna, meiofauna, microbial biomass, nodule fauna and demersal scavengers) and environmental parameters (habitat quality, sedimentation and bioturbation).

The *Water-Column Working Group*, concerned with oceanographic sampling, splits its recommendations into two categories: key variables that should be routinely measured by all contractors and optional variables from which further useful information can be obtained.

The working groups did not attempt to outline systematic procedures for collecting and analysing data. Instead, they cited protocols that other international organizations have developed for this purpose.

Chapter 22 Report of the Workshop

The Workshop to Standardize the Environmental Data and Information Required by the Mining Code and Guidelines for Contractors, convened by the International Seabed Authority, met at the Headquarters of the Authority in Kingston, Jamaica, from 25 to 29 June 2001.

The Workshop was convened to provide expert guidance that would assist contractors and the Authority in their task of assessing and monitoring the marine environment in the international seabed Area. The Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area[1], approved by the Authority on 13 July 2000 and informally known as the Mining Code, provide that every contract for exploration for polymetallic nodules shall require the Contractor, in cooperation with the Authority and the sponsoring State or States, to establish environmental baselines against which to assess the likely effects of its programme of activities on the marine environment and a programme to monitor and report such effects (regulation 31.4).

The Legal and Technical Commission has drawn up a set of recommendations, formerly called guidelines, for the guidance of contractors in assessing possible environmental impacts arising from exploration for polymetallic nodules in the Area[2]. The recommendations are accompanied by an explanatory commentary detailing some of the data and information required during the two phases of exploration: environmental baseline studies, and monitoring during and after tests of collecting systems and equipment.

The Workshop is the fourth in a series convened annually by the Authority as a means of consulting the international community of engineers and scientists, including contractors, on technical matters involved in the performance of its tasks. An earlier Workshop, held in Sanya, China, in 1998[3], prepared an initial set of guidelines for the assessment of environmental impacts, which assisted the LTC in the preparation of its recommendations.

Thirty-nine engineers, scientists and other experts from 17 countries and the United Nations took part in the proceedings, including nationals from six of the seven registered pioneer investors and four members of the LTC. They heard and discussed 21 presentations on various topics, most of them accompanied by papers. These presentations, by academic and government experts, reviewed work already carried out in the international seabed Area to assess environmental conditions, with details on the parameters measured and the methods used. Several of the papers suggested standards that contractors might adopt to improve the comparability of data.

The leader of the Working Group was Professor Craig R. Smith, Professor in the Department of Oceanography at the University of Hawaii, Honolulu, United States.

Following three days of discussions, the participants broke into three working groups to formulate recommendations concerning baseline and impact environmental studies. These working groups were:

- ?? Chemical/Geological Working Group
- ?? Benthic Biological/Environmental Working Group
- ?? Water-Column Working Group

The charge to each working group was to complete the following tasks:

1) Identify key parameters to be measured and to be listed in an ISA database;

2) Identify currently accepted standards and protocols for measuring these key parameters;

3) Identify key community-wide issues that would benefit from a common approach;

4) Outline a cooperative research programme or programmes to address the key community-wide issues;

5) Indicate ways in which the ISA can facilitate cooperative work, maintenance of high data standards and responses to major environmental questions.

The recommendations of the working groups on the sectoral issues in points 1 and 2 are appended to this report (chapters 23-25 below). Their recommendations on the broader points 3-5 are consolidated in the remaining part of this report. The group that made each recommendation is identified in square brackets [BB = Benthic/Biological, CG = Chemical/Geological, WC = Water Column].

1. Cooperative Biological Research

It is very important to address a number of biological questions in order to improve the ability to predict the environmental impacts of manganese nodule mining. Such questions are listed below, in approximate order of priority.

a. What are the typical latitudinal and longitudinal ranges of benthic species, and what are the rates and spatial scales of gene flow?

b. What is the dose-response function for the benthic community, given a single deposition event?

c. How frequently must modest deposition events (less than 1 millimetre) occur for their effects to become chronic (i.e., non-independent)?

d. What are the time scales of community recovery following various intensities of disturbance (e.g., removal of the top 2 centimetres of sediment, heavy burial, light burial) and how do these recovery times vary with the spatial scale of disturbance?

e. What are the natural patterns and scales of benthic community variability in space and time?

We recommend that the Authority facilitate additional research programmes, using new resources, to address these questions. Facilitation may take the form of bringing scientists and funding-agency representatives together for discussions, providing support for the writing of proposals, and convening a workshop to formulate coordinated scientific research plans. Facilitation of these research activities and identification of new resources should be given high priority. [BB]

2. Databases

In accepting the data provided by contractors, the Authority should facilitate the integration and distribution of this information through database development. It should give guidance to the contractors on the maintenance of databases, including data standards, standard data formats, accessibility and lifetime. [CG/WC]

It would be very beneficial to set up a common environmental database as outlined by Dr. Michael Rex in his paper for the Workshop (chapter 19 above). We recommend that ISA hire consultants to set up and manage this database as outlined. [BB]

As part of this effort, ISA should facilitate the compilation of a metadatabase linking the various Contractor and non-contractor databases and its publication on the World Wide Web (WWW). [CG]

3. Taxonomic Coordination

The taxonomy of microzooplankton, deep-water zooplankton and small phytoplankton in the exploration areas is problematic. We recommend that contractors collaborate with each other and with other scientists to coordinate taxonomic descriptions. [WC]

The issue is to ensure that species are being identified similarly (and accurately) during taxonomic analysis of samples that may have been taken by different contractors, in different locations and at different times. A common (and accurate) taxonomy among field programmes is essential to determine species ranges, and to evaluate the potential for extinctions, within the nodule-mining areas. Producing accurate taxonomy is particularly problematic in the deep sea because many abundant taxa (e.g., polychaetes and nematodes) contain a large proportion of undescribed species; consequently, useful taxonomic keys are virtually nonexistent. It is recognized that taxonomic research is largely carried out in museums, so that such organizations are likely to be particularly, but not exclusively, useful for taxonomic coordination.

We recommend the following:

a. Taxonomic standardisation of species identification in samples collected during the environmental monitoring of mineral exploration and exploitation areas should be coordinated through a single location so that contractors have a central facility, and a reference taxonomist, to assist them in finding the taxonomic advice and expertise that they might require. The central coordinator will compile a taxonomic database for the taxon in question and make available such information as (1) key taxonomists working on the group and (2) the location of voucher collections.

b. A recognized taxonomic expert should be appointed as reference taxonomist for each taxonomic group to facilitate taxonomic standardization within that group. This expert will be responsible for taxonomic quality control within the taxon. This will involve such actions as offering advice, checking identifications, preparing and controlling voucher collections for quality, and contributing to the training of taxonomists from the contracting countries. Coordinators for different taxa will probably be located in various institutions.

c. Voucher collections will be especially important in taxa having many unknown species. Supplying contractors with such collections will be an important contribution toward ensuring taxonomic standardization.

d. The coordinating taxonomists will need to be provided with some financial resources to conduct this task. The ISA should assist in selecting coordinating taxonomists and identifying the required resources. [BB]

4. Exchange of Seagoing Scientists and Cooperative Cruises

Because it is vital for scientists from different countries to use similar techniques and protocols for collecting data, periodic exchanges of scientists from different countries should take place onboard cruises to sample exploration areas. This would enable scientists to compare and standardise exactly how particular procedures are conducted in the field (e.g. lowering box cores). If possible, the ISA should support/facilitate such efforts. [BB]

In addition, the Authority should facilitate the organization of cooperative cruises in order to allow for the exchange of samples, technologies and protocols, and for sampling in areas allocated to different contractors and over longer periods. [CG]

5. Workshops

Workshops should be held periodically for scientists and technicians from different countries who are involved with environmental monitoring of exploration and mining operations, enabling them to share, compare and standardise procedures. Among the topics for such workshops are methods for sampling, storage, preservation and curation, and other analytical methods related to oceanography and the marine environment. Such workshops will be essential to ensure that the data collected from different programmes are comparable. [BB/CG]

Assessment of spatial and temporal variability in the exploration areas is a key issue that will be facilitated by coordination of cruises and collaborative interpretation of the data among contractors. It is recommended that ISA sponsor workshops to this end. [WC]

6. Other Standardisation

?? Quality assurance and quality control (QA/QC) procedures should be followed. Contractors should ensure the use of standards approved by the International Organization for Standardization (ISO) and should document all methods and procedures. [CG]

?? Reference standards should be established, such as a deep-sea sediment standard. [CG]

?? A methodology should be developed and/or current methodologies should be assessed for the measurement of parameters such as grain size, bulk density and similar properties difficult to quantify. [CG]

Notes and References

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2. International Seabed Authority, Legal and Technical Commission, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area (ISBA/7/LTC/1), 10 April 2001, with annex I, Explanatory commentary; further revised and approved

by the Commission as ISBA/7/LTC/1/Rev.1 of 10 July 2001. On 12 July 2001, the ISA Council deferred consideration of the recommendations until its eighth session (August 2002).

3. *Deep-Seabed Polymetallic Nodule Exploration: Development of Environmental Guidelines* (1999), Proceedings of the International Seabed Authority's Workshop held in Sanya, Hainan Island, People's Republic of China (1-5 June 1998), ISA (Kingston, Jamaica), 289 pp. The recommended guidelines are in chapter 9, pp. 219-239.

Chapter 23 Recommendations of the Chemical/Geological Working Group on Key Environmental Parameters

Leader Gerald Matisoff

Participants Baidy Diene, Sang-Mook Lee, Jean-Pierre Lenoble, Bhaskar Rao, Rahul Sharma, Michael Wiedicke-Hombach, Boris Winterhalter, Huaiyang Zhou

The Chemical/Geological Working Group based its deliberations on the recommendations and commentary which the Legal and Technical Commission (LTC) of the International Seabed Authority had prepared to guide deep-seabed contractors when they assess the environmental impacts arising from exploration for polymetallic nodules in the Area beyond national jurisdiction[1]. Key parameters and methodologies for three environments (sediment properties, sediment pore water and water-column chemistry) are identified below.

Parameters recommended for measurement were identified based on their importance for one or more of three criteria: *geotechnical*, *habitat* and *impact assessment*. *Geotechnical* criteria are those that are important for predicting the nature of the sediment plume and for assessing the physical nature of the seabed. In addition, some geotechnical criteria are important for understanding the benthic habitat. *Habitat* criteria are those that are directly related to the benthic habitat, such as sediment grain size, as well as those that indirectly affect the life support of the organisms, such as nutrients. *Impact assessment* is used for those criteria that present a toxicological concern, either to the organisms themselves, or to human health by bioaccumulation up the food chain. Heavy metals are examples of this category.

For a baseline study, the number of samples to be collected should be dependent on the size of the area and the local variability of the sediment and topographic characteristics. This number should provide a representative data set for the mining area.

1. Sediment Properties

Sediment properties are important for understanding sediment resuspension and transport of the plume as well as providing supporting information for benthic and chemical studies. The Working Group agreed with the LTC commentary on the key parameters to be investigated: specific gravity, bulk density, water content (porosity), shear strength, grain size and distribution, depth of the redox boundary, organic and inorganic carbon content, chemical composition and bioturbation depth (table 1). For several of these parameters no one standard method of analysis exists, nor could the Working Group agree on a preferred method. It is recommended that any one of several common, state-of-the-art methods be used. In addition, these methodological gaps are identified as potential community-wide issues (see the Workshop report in chapter 22 above, section 6).

It is recommended that, in wet sieving for grain-size analysis, seawater should be used and no chemical detergents should be added. This will result in larger grain sizes, but should more closely approximate the nature of the suspended sediment plume.

As sedimentation rates in claim areas are generally considered very low, they were determined not to be an important parameter and they have therefore been excluded from the list of key parameters.

It is recommended that the parameters cited in table 1 be measured at the following core-depth intervals: 0-1, 1-3, 3-5, 5-8, 8-12 and 12-20 centimetres.

Parameter	Primary purposes	Methodologies	Recommendations
Specific gravity	Geotechnical properties	Wet weight and volume	No common standard; use best available method
Bulk density	Geotechnical properties	Gamma-ray attenuation; volume and dry weight	No common standard; use best available method
Water content	Geotechnical properties	Wet weight; dry weight	Dry at 105 degrees Celsius for 24 hours
Porosity	Geotechnical properties, environmental risk	Calculated from other measured parameters	Calculated from other measured parameters
Shear strength	Geotechnical properties – variation with depth	Vane shear; best available method	Best available method may be in situ
Grain size	Geotechnical and habitat properties (benthic communities)	Sediment balance; sedigraph; wet sieving; pipette analysis	No common standard; use best available method. Use seawater
Oxidation-reduction potential (ORP)	Impact assessment	Eh/ORP electrode	Eh/ORP electrode
Organic carbon	Habitat	CHN analyzer	CHN analyzer
Inorganic carbon	Impact assessment	CHN analyzer; acid dissolution-CO_2	Best available method
Chemical composition	Impact assessment	X-ray fluorescence (XRF), atomic absorption spectroscopy (AAS), inductively coupled plasma (ICP) spectroscopy	Best available method
Bioturbation depth	Benthic mixing depth	Pb-210	Pb-210

Table 1 Key parameters for physical properties of sediment.

2. Sediment pore waters

The LTC commentary is vague in its identification of the "geochemistry of the pore water". Moreover, it does not define how the pore waters are to be obtained.

The Working Group noted that there are two commonly used methods to obtain pore water: squeezing and centrifugation. Although squeezing appears to produce more pore water than centrifugation, it was determined that the quality of the data would be equally comparable as long as the extraction of the pore water and the analysis of its redox-sensitive species were done in an inert atmosphere.

Because of the need for high vertical resolution and the limited pore-water volume obtained at depth, the following depth intervals are recommended: 0-1, 1-3, 3-5, 5-8, 8-12 and 12-20 cm.

Table 2 lists the chemical parameters recommended for analysis provided sufficient pore-water volume is obtained: nutrients, oxidation/reduction measures, metals, and redox-sensitive species important in bacterial metabolism.

Parameter	Purposes	Methodologies	Recommendations
Phosphate	Habitat	Spectrophotometric; ion-exchange chromatography (IEC), flow injection analysis (FIA)	Best possible method
Nitrate	Habitat	Spectrographic; IEC, FIA	Best possible method
Silicate	Habitat	Spectrophotometric; IEC, FIA	Best possible method
Nitrite	Habitat	Spectrophotometric; IEC, FIA	Best possible method
Carbonate alkalinity	Habitat and impact assessment	Titration; spectrophotometric	Titration; spectrophotometric
Eh	Impact assessment	Electrode	Electrode
PH	Impact assessment	Electrode	Electrode
Fe	Impact assessment	AAS; ICP-MS (mass spectrometry); spectrophotometric	AAS; ICP-MS; spectrophotometric
Mn	Impact assessment	AAS; ICP-MS; spectrophotometric	AAS; ICP-MS; spectrophotometric
Zn	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Cd	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Pb	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Cu	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Hg	Impact assessment	AAS; ICP-MS	AAS; ICP-MS

Table 2 Chemical parameters in sediment pore waters.

Fluxes across the sediment/water interface can be approximated from Fickian diffusion calculations using concentrations from the bottom water and the 0-1 cm interval.

3. Water Column

The purpose of water-column chemical analysis is to monitor for oxygen content and metal bioaccumulation as a consequence of the release of sediment and pore waters both to the bottom water and, via discharge, to the water column. Therefore, chemical parameters in the water column should preferably be measured at the following levels above the sediment bottom: 10, 20, 50 and 200 metres, and 1.2-2 times the elevation of the highest topographic feature in the area; and also in the oxygen-minimum zone, at about the depth of the forecasted discharge, and at the measurement depths recommended by the Water-Column Working Group (surface, base of the mixed layer and within the subsurface chlorophyll maximum).

The chemical parameters to be measured are given in table 3. In addition, these parameters should be measured at the same depths as physical parameters (temperature, salinity, turbidity). Recommended analytical methods are the standard, accepted methods, such as those utilised in the programmes of the Joint Global Ocean Flux Study (JGOFS) and the Geochemical Ocean Sections Study (GEOSECS). Sample collection for the trace metals will require ultraclean techniques.

Parameter	Primary purposes	Methodologies	Recommendations
Phosphate	Habitat	Spectrophotometric; FIA, IEC	Best available method
Nitrate	Habitat	Spectrophotometric; FIA, IEC	Best available method
Nitrite	Habitat	Spectrophotometric; FIA, IEC	Best available method
Silicate	Habitat	Spectrophotometric; FIA, IEC	Best available method
Carbonate alkalinity	Impact assessment	Titration; spectrophotometric	Titration; spectrophotometric
O_2	Impact assessment	Winkler titration	Winkler titration
Zn	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Cd	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Pb	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Cu	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
Hg	Impact assessment	AAS; ICP-MS	AAS; ICP-MS
TOC	Habitat and impact assessment	CHN analyzer	CHN analyzer

Table 3 Chemical parameters in the water column.

4. Trace metals in benthic and epi-, meso- and bathypelagic organisms

It is recommended that trace metal concentrations be measured in dominant benthic and epi-, meso- and bathypelagic species. Analysis of the Zn, Cd, Pb, Cu and Hg concentrations should be performed for at least five individuals from each of the three most dominant species collected as zooplankton and micronekton among the pelagic communities, as well as benthic macroinvertebrates and bottom fish. Metal-clean sampling techniques are recommended.

Note and Reference

1. International Seabed Authority, Legal and Technical Commission, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area (ISBA/7/LTC/1), 10 April 2001; further revised and approved by the Commission as ISBA/7/LTC/1/Rev.1 of 10 July 2001; includes annex I, Explanatory commentary. On 12 July 2001, the ISA Council deferred consideration of the recommendations until its eighth session (August 2002).

Chapter 24 Recommendations of the BENTHIC Biological / Environmental Working Group on Key Environmental Parameters

Co-Leaders: Michael Rex, Craig Smith

Participants: Ron Etter (Rapporteur), John Lambshead (Rapporteur), Tomohiko Fukushima, Viatcheslav Melnik, Mati Pal, Giovanni Rosa, Gerd Schriever, Myriam Sibuet

The Benthic Biological / Environmental Working Group identified key parameters to be measured and their accepted protocols, as set out below. It also made recommendations on community-wide issues, common approaches and actions to be taken by the International Seabed Authority; these are incorporated into the report of the Workshop (chapter 22 above).

The Working Group concluded that experimental designs and sampling programmes, for both baseline studies and the detection of impacts from mining, should be statistically rigorous and their ability to detect impacts statistically defensible. Levels of replication should be determined from a power analysis based on the expected levels of and variation in response variables due to mining, and the acceptable levels of type I and type II errors. Examples of standard experimental designs to detect environmental impacts, especially when only one impact site exists, are provided by Underwood[1].

To facilitate coordination on taxonomy and understanding of species distribution and rates of gene flow, it is vital to collect biological samples, suitable for DNA sequence analyses, of a broad range of benthic species. We strongly recommend that duplicate benthic biological samples of all types be preserved in DNA-grade ethanol for DNA analyses, in parallel with the fixation of samples in formaldehyde for morphological studies. Such samples should be fixed and preserved in DNA-grade alcohol (at least 95 per cent non-denatured ethanol by volume). The DNA samples must never be fixed or preserved in formalin or industrial grade alcohol. Special procedures during processing of samples before fixation may also be required (e.g., working in a cold room) to avoid degradation of DNA before fixation in ethanol. The Working Group's recommendations on taxonomic coordination are presented in the report of the Workshop (chapter 22 above, section 3).

The following key parameters should be measured, and the appropriate raw data (e.g., number of the individual from a particular species in a particular sample) should be provided for entry into the ISA database.

1. Key Biological Parameters

1.1. Megafauna

Data on megafaunal abundance, biomass, species diversity, number of individuals per species and spatial distributions are to be obtained from photographic surveys in such a way that organisms larger than 2 centimetres in smallest dimension can be readily identified. Suggested techniques to be used include quantitative photographic transects, using methods such as those discussed. Each photo should cover an area at least 2 metres wide, within which the megafauna should be quantifiable. Sampling stations for photo transects should be defined taking into account the various features of the bottom, such as topography, variability of sediment characteristics, and abundance and type of nodule. Megafauna should be collected, for example by epibenthic sled, trawl, baited traps and/or submersible, to identify species, for molecular phylogenetic analyses and for voucher specimens. It would be desirable to develop sled or trawl technology to collect epibenthic megafauna without nodules (which grind up specimens).

1.2. Macrofauna

Data on macrofaunal abundance, biomass, species diversity, number of individuals per species, sediment depth distribution (sample to 10-cm depth with some vertical sectioning) and spatial distribution should be obtained from 0.25-m^2 box cores. Lowering the box corers to the seabed should follow the protocols of Schriever and Borowski or Hessler and Jumars [2]. Samples should be gently sieved through nested 300- and 250-micron sieves.

1.3. Meiofauna

Data on meiofauna (32-250 µm), covering abundance, biomass, species structure and depth distribution (suggested depths: 0-0.5, 0.5-1.0, 1-2 and 2-3 cm), as well as spatial distributions, should be collected from multiple (or mega-) corer tubes. The number of core samples from separate multiple corers should be determined by a statistical power analysis of preliminary (or earlier) samples. Meiofauna should be processed on nested sieves of 63, 45 and 32-µm mesh sizes. The focus will be on the most abundant identifiable taxa, which are the Nematoda and Harpacticoidea.

1.4. Microbial biomass

Microbial biomass should be determined using adeosine triphosphate (ATP) or other standard assay for 0-1 cm intervals of cores. One tube per station of a multiple corer-sampling pattern could be devoted for this purpose. Suggested intervals for sampling are 0-0.5, 0.5-1.0, 1-2, 2-3, 3-4 and 4-5 cm. [Paragraph taken from explanatory commentary by the Legal and Technical Commission of ISA[3].]

1.5. Nodule fauna

Abundance and species structure of the fauna attached to or otherwise associated with nodules should be determined from selected nodules taken from the top of the box cores. Techniques should follow Thiel *et al*.[4].

1.6. Demersal scavengers

Both baited camera studies and baited traps should be used to characterize the demersal scavenger community.

2. Key Environmental Parameters

2.1. Habitat quality

A time-lapse camera should be installed at the study area for at least one year to examine the physical dynamics of surface sediment, and to document the activity level of surface megafauna and the frequency of resuspension events.

2.2. Sedimentation

One set of sediment traps should be deployed on each of two moorings for at least 12 months. One trap on each mooring should be at a depth of about 2000 m to characterize mid-water particle flux, and one trap on each mooring should be ~500 m above the seafloor (and outside of the benthic boundary layer) to evaluate deep particle flux. A current meter should also be deployed at the approximate level of each trap to evaluate the current regime at trap level. Traps should sample sequentially at no longer than one-month intervals. Traps may be deployed on the general current meter moorings. Variables measured on sediment trap samples should include the fluxes of total mass, particulate organic carbon, calcium carbonate, biogenic silica and excess Pb-210. Published protocols of the Joint Global Ocean Flux Study (JGOFS) should be used for these analyses[5].

2.3. Bioturbation

Bioturbation rates and depths should be evaluated using excess Pb-210 profiles from multiple cores. Five replicate profiles per station are recommended, each from separate, randomly located, multiple core lowering. Excess Pb-210 activity should be evaluated at $\geq$ 5 levels per core (suggested depths 0-0.5, 0.5-1.0, 1.0-1.5, 1.5-2.5 and 2.5-5 cm), and mixing intensities evaluated from standard advection-diffusion models.

Notes and References

1. A.J. Underwood (1997), *Experiments in Ecology: Their Logical Design and Interpretation Using Analysis of Variance* (Cambridge University Press, England), 528 pp.

2. R.R. Hessler and P.A. Jumars (1974), Abyssal community analysis from replicate box cores in the central North Pacific, *Deep-Sea Research* 21:185-209.

3. International Seabed Authority, Legal and Technical Commission, Recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules in the Area (ISBA/7/LTC/1, 10 April 2001), annex I, Explanatory commentary, par. 8; further revised and approved by the Commission as ISBA/7/LTC/1/Rev.1 of 10 July 2001, from which the cited paragraph was dropped. On 12 July 2001, the ISA Council deferred consideration of the recommendations until its eighth session (August 2002).

4. H. Thiel et al. (1993), Manganese nodule crevice fauna, *Deep-Sea Research* 40(2): 419-423.

5. A. Knap et al. (eds.) (1996), *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements* (JGOFS report 19), vi+170 pp. (reprint of *IOC Manuals and Guides* 29 [United Nations Educational, Scientific and Cultural Organization, 1994]).

Chapter 25 Recommendations of the Water-Column Working Group on Key Environmental Parameters

Leader: Anthony Koslow
Participants: Hasjim Djalal, Woong-Seo Kim, Takaaki Matsui, Charles Morgan

The Water-Column Working Group was assigned the following tasks:

?? To identify a set of basic oceanographic variables, fundamental to the assessment of environmental impacts, that would be routinely measured by all contractors working in the exploration area and archived in the database of the International Seabed Authority. These variables would be measurable without requiring significant amounts of ship time when stations are occupied.

?? To identify a second set of variables which, while useful to assess the environmental impact of deep-seabed mining on the water column, require greater commitments of time and effort than the basic set. Their measurement would be left to the discretion of the contractors.

?? To identify currently accepted protocols for the measurement of these variables, so that data collected by the various contractors would be comparable.

?? To identify community-wide issues that would benefit from a collaborative approach and to recommend programmes to address these issues. (The Group's recommendations on this topic have been consolidated in the report of the Workshop, chapter 22 above.)

1. Key routine oceanographic sampling

The Working Group identified the following basic oceanographic variables that should be routinely measured by all contractors:

a. Meteorological variables: sea state, wind speed and direction, cloud cover

b. Conductivity-temperature-depth (CTD) profiles in the top 1000 metres: conductivity and salinity, temperature, water depth, light level, chlorophyll *a*, dissolved oxygen

c. Water samples to calibrate the CTD and to determine nutrient levels to be taken at the surface, within the mixed layer, at the base of the mixed layer, and within the subsurface chlorophyll-maximum and oxygen-minimum zones

d. Routine measurements from water samples:

    i. Nutrients (silicate, nitrate, phosphate)
    ii. Dissolved oxygen
    iii. Chlorophyll
    iv. Salinity

e. An oblique tow for zooplankton from the sea surface to 200 m depth with a 200-micron mesh net. Use of a standard (60-centimetre-diameter mouth opening) bongo net with flow meter is recommended. Displacement volume will be measured at a minimum.

CTD and water-sample analysis will follow the protocols of the Joint Global Ocean Flux Study (JGOFS)[1]. Zooplankton sampling will follow the protocols of the *Zooplankton Methodology Manual* of the International Council for the Exploration of the Sea[2].

2. Optional oceanographic sampling

Further useful information can be obtained from:

1. Epifluorescence-microscope counts of bacterial cell abundance and biomass, and of phytoplankton to assess species composition

2. Inverted-microscope counts of settled microzooplankton samples

3. Analysis of particulate organic carbon (POC) and nitrogen (PON) from water samples

4. Carbon-14 primary productivity measurements from the surface water and chlorophyll maximum

5. Tritiated methyl thymidine measurement of bacterial productivity

6. Estimation of microzooplankton grazing rates

7. Analysis of zooplankton tows to genus or species level

8. Micronekton tows from the surface to 200 m, 200 to 1000 m and 2000 m to near-bottom, using an opening/closing net with flow meter

9. Observations of marine mammals, sea turtles and sea birds while underway between stations within the exploration area, based on standardised bridge watches following protocols of the International Whaling Commission (IWC)[3]

10. Collection of deep zooplankton from near the seafloor to about 2000 m with an opening/closing net

11. Measurement of currents in the upper waters with an acoustic Doppler current profiler (ADCP).

Analyses of water chemistry, bacteria and phytoplankton will follow the JGOFS protocols[4]. Zooplankton sampling will follow the protocols of the ICES *Zooplankton Methodology Manual*[5]. The International Young Gadoid Pelagic Trawl (IYGPT) in combination with the Pearcy opening/closing net[6] is recommended for depth-stratified micronekton sampling.

Notes and References

1. A. Knap et al. (eds.) (1996), *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements* (JGOFS report 19), vi+170 pp. (reprint of *IOC Manuals and Guides* 29 [United Nations Educational, Scientific and Cultural Organization, 1994]) (available as a pdf file from the JGOFS Web site, ads.smr.uib.no/jgofs/jgofs.htm).

2. R.P. Harris et al. (eds.) (2000), *ICES Zooplankton Methodology Manual* (International Council for the Exploration of the Sea, Working Group on Zooplankton Ecology, Academic Press, San Diego, California), 684 pp.

3. A.R. Hiby and P.S. Hammond (1989), Survey techniques for estimating abundance of cetaceans, in G.P. Donovan (ed.), *The comprehensive assessment of whale stocks: The early years* (Special issue 11, International Whaling Commission, Cambridge, England) 47-80.

4. A. Knap et al. (eds.) (1996), *Protocols for the Joint Global Ocean Flux Study (JGOFS) Core Measurements* (JGOFS report 19), vi+170 pp. (reprint of *IOC Manuals and Guides* 29 [UNESCO, 1994]).

5. R.P. Harris et al. (eds.) (2000), *ICES Zooplankton Methodology Manual* (International Council for the Exploration of the Sea, Working Group on Zooplankton Ecology, Academic Press, San Diego, California), 684 pp.

6. W.G. Pearcy (1980), A large opening-closing midwater trawl for sampling oceanic nekton, and comparison of catches with an Isaacs-Kidd midwater trawl, *Fishery Bulletin* 78: 529-534.

APPENDIX A

Abbreviations and Acronyms

AAA/AAS atomic absorption analysis / atomic absorption spectroscopy
AABW Antarctic Bottom Water
ADCP acoustic Doppler current profile/profiler
AFERNOD Association française pour l'exploration et la recherche des nodules (French Association for Exploration and Research of Nodules)
AMS accelerator mass spectrometry
ANOVA analysis of variance (statistics)
APDC ammonium pyrrolidine dithio-carbamate
ATESEPP Auswirkungen technischer Eingriffe in das Ökosystem der Tiefsee im Süd-Ost-Pazifik vor Peru (Impacts of potential technical interventions on the deep-sea ecosystem in the Southeast Pacific) (German programme)
ATP adenosine triphosphate
BACI Before-After-Control-Impact (sampling)
BGR Bundesanstalt für Geowissenschaften und Rohstoffe (German Federal Institute for Geological Sciences and Raw Materials)
BIE benthic impact experiment
BIONESS Biological Net and Environmental Sampling System
CCD Calcite (or Carbonate) Compensation Depth
CCFZ Clarion-Clipperton Fracture Zone (Central Pacific Ocean)
CEC Control Equipment Corporation
CFU colony-forming unit (microbiology)
CHN carbon, hydrogen and nitrogen
COMRA China Ocean Mineral Resources Research and Development Association
CPG cable-photo grab (sampler) (KODOS)
CSIRO Commonwealth Scientific and Industrial Research Organization
CTD conductivity-temperature-depth (measurement)
DAPI 4,6-diamidino-2-phenylindole dihydrochloride (fluorochrome stain)
DDT dichloro-diphenyl-trichloroethane
DGGE denaturing gradient gel electrophoresis

DGPS	differential global positioning system
DEA `	DISCOL Experimental Area
DISCOL	Disturbance and Recolonization (German project in Pacific Ocean)
DNA	deoxyribonucleic acid
DO	dissolved oxygen
DOD	Department of Ocean Development (India)
DOMES	Deep Ocean Mining Environmental Study (United States)
DORD	Deep Ocean Resources Development Co., Ltd. (Japan)
DSC	digital still camera
DSSR	Deep-Sea Sediment Resuspension System
EIA	environmental impact assessment
EISET	Environmental Impact Studies and Equipment Tests (COMRA project)
ENQUAD	Environmental Quality Department (Massachusetts, United States)
EqPac	Equatorial Pacific (Ocean)
ES	effect size (statistics)
ETI	Expert Center for Taxonomic Identification (Netherlands)
EU	European Union
FBOS	Freefall Benthos Observation System (DISCOL)
FDC	Finder-installed Deep-Sea Camera (JET)
FFG	free-fall grab (sampler)
FIA	flow injection analysis
FITC	fluorescein isothiocyanate (fluorochrome stain)
GEOSECS	Geochemical Ocean Sections Study
GF/F	glass-fibre filter
GIS	geographic information system(s)
GPS	Global Positioning System
HEBBLE	High Energy Benthic Boundary Layer Experiment (North Atlantic Ocean)
HOT	Hawaii Ocean Time-series
HPLC	high-performance liquid chromatography
ICAP	inductively coupled argon plasma
ICES	International Council for the Exploration of the Sea
ICP-AES	inductively coupled plasma - atomic emission spectrometer/spectrometry
ICP-MS	inductively coupled plasma - mass spectrometer/spectrometry
IEC	ion-exchange chromatography
IFREMER	Institut français de recherche pour l'exploitation de la mer (French Research Institute for Exploitation of the Sea)

INDEX	Indian Deep-sea Environment Experiment
IOC	Intergovernmental Oceanographic Commission (UNESCO)
IOM	Interoceanmetal Joint Organization
IOS	Institute of Oceanographic Sciences (United Kingdom)
IRZ	impact reference zone
ISA	International Seabed Authority
ISO	International Organization for Standardization
ITCZ	Intertropical Convergence Zone (Pacific Ocean)
IWC	International Whaling Commission
IYGPT	International Young Gadoid Pelagic Trawl
JET	Japan Deep-Sea Impact Experiment (CCFZ)
JGOFS	Joint Global Ocean Flux Study (IOC)
KODOS	Korea Deep Ocean Study (Republic of Korea)
KORDI	Korea Ocean Research and Development Institute (Republic of Korea)
LOM	labile organic matter
LTC	Legal and Technical Commission (ISA)
MAP	Madeira Abyssal Plain (North Atlantic Ocean)
	Module Autonome Pluridisciplinaire (IFREMER device)
MAST	Marine Science and Technology (EU programme)
MCA	4-methylcoumarinyl-7-amide
MIBK	methyl isobutyl ketone
MMAJ	Metal Mining Agency of Japan
MMS	Minerals Management Service (United States)
MOCNESS	Multiple Opening and Closing Net and Environmental Sensing System
M-OTU	molecular operational taxonomic unit
MUF	methylumbelliferone
NaVaBa	Natural Variability of Baseline (COMRA project)
NERC	Natural Environment Research Council (United Kingdom)
NIO	National Institute of Oceanography (India)
NOAA	National Oceanic and Atmospheric Administration (United States)
OFOS	Ocean Floor Observation System (DISCOL)
OMA	Ocean Mining Associates (consortium)
OMI	Ocean Management Inc. (consortium)
ORP	oxidation-reduction potential
ORV	Oceanographic Research Vessel
PAP	Porcupine Abyssal Plain (North Atlantic Ocean)
PC	polycarbonate
PCB	polychlorinated biphenyl

PEIS	programmatic environmental impact statement (United States)
P-I	photosynthesis/irradiance (curve)
POC	particulate organic carbon
PON	particulate organic nitrogen
PRZ	preservation reference zone
QA/QC	quality assurance / quality control
RCM	recording current meter
RDBMS	relational database management system
REE	rare earth element(s)
REP	Russian Experimental Polygon (CCFZ)
RNA	ribonucleic acid
ROVNav	remotely operated vehicle – navigation
RV	Research Vessel
SBE	Sea-Bird Electronics, Inc.
SeaWIFS	Sea-viewing Wide Field-of-view Sensor (United States)
SEG	Society of Exploration Geophysicists
SOPAC	South Pacific Applied Geoscience Commission
SPM	suspended particulate matter
TCA	trichloroacetic acid
tif	Tag Image File (format)
TN	total nitrogen (measurement)
TNHM	The Natural History Museum (London)
TOC	total organic carbon (measurement)
UNESCO	United Nations Educational, Scientific and Cultural Organization
USNEL	United States Naval Electronic Laboratory
UTM	Universal Transverse Mercator
WOCE	World Ocean Circulation Experiment (IOC)
WWW	World Wide Web
XBT	expendable bathythermograph
XCTD	expendable CTD (data/probe)
XRD/XRF	X-ray diffraction / X-ray fluorescence

APPENDIX B

Inputs for the Standardization of Physical Oceanography and Marine Microbiology

Contribution from scientists at the National Institute of Oceanography
Dona Paula, Goa, India

1. Methods and equipment for assessing environmental parameters for deep-seabed mining

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Discipline	**Category**	**Parameter**	**Methods/Equipment**
Geology			
Seafloor features	Bathymetry	Seafloor depth	Narrow beam echosounding (about 12 kilohertz) Multibeam bathymetry
		Sediment character	Sub-bottom profiler (3.5-5 kHz) Deep-towed sonar surveys (~5 kHz) – penetration to few hundreds of metres
		Seafloor photography	Sampler-mounted cameras Cameras attached to moored devices
		Bottom sediment	Deep-towed systems Box corer Multiple corer
Sediment studies	Mineralogy	Textural analysis	Wet sieving followed by pipette analysis[1]
		Clay mineralogy	Semi quantitative analysis of major clay mineral assemblages by X-ray diffraction analysis using Ni-filtered CuK? radiation operated at 22 milliamperes and 40 kilovolts[2]

Discipline	Category	Parameter	Methods/Equipment
Sediment studies (cont.)	Geotechnical analysis	Water content	Weight-loss method – drying samples for 24 hours at 105 degrees Celsius
		Shear strength	Shear-strength apparatus
		Wet bulk density	Measuring weight and volume of sediment
		Specific gravity	Gravity bottles
		Porosity	Using standard formula
	Geochemistry	Major and trace elements Organic carbon	Sample digestion and analysis using atomic-absorption spectroscopy (AAS) or inductively-coupled plasma spectroscopy by atomic emission or mass spectroscopy (ICP-AES / ICP-MS) CHN analyzer / wet oxidation method
	Pore-water chemistry	Nitrite	Autoanalyzer
		Silica	Autoanalyzer / Spectrophotometric determination
		Organic carbon	CHN analyzer / wet oxidation method
	Stratigraphic analysis	Radiolarian abundance	Wet sieving followed by quantification and identification
	Particle fluxes	Quantification	Time series sediment-trap samples wet-sieved to separate finer from coarser particles and vacuum-filtered onto preweighed polycarbonate membrane filters, dried at 60° C and weighed
		Major component analysis	$CaCO_3$ weight-loss method or Ca extraction and determination by ICP-AES analysis Biogenic opaline silica – 2-mole sodium carbonate extraction followed by spectrophotometric determination. Organic matter – CHN analysis Lithogenic matter – Al determination by ICP-AES analysis
		Suspended solids	Known volume of water samples filtered through preweighed nucleopore filters and dried at 60° C, allowed to cool and reweighed

Discipline	Category	Parameter	Methods/Equipment
Biology			
	Water column	Phytoplankton	Water samples collected in euphotic and below-euphotic zones (to 150 m), preserved in plastic bottles using formalin and Lygol's iodine solution, and concentrated for quantification and identification
		Zooplankton	Water samples collected using plankton net to 1000 m water depth, preserved with concentrated formalin for taxonomic identification on shore
		Primary productivity	C-14 measurement
		Chlorophyll *a*	Fluorometric measurement
		Light penetration	Depth of euphotic zone measured with Secchi disk Profiling ultraviolet radiometer used to study special nature of light in euphotic zone
	Benthos	Mega-, macro-, meio- and microfauna	Samples fixed with formalin and dyed with rose Bengal; after 24 hrs, wet-sieved through larger-than-1-millimetre, 300- and 45-micron sieves to measure abundance and identify mega-, macro-, meio- and microfaunal components
		Microbial analysis	Total bacterial counts – samples fixed with formalin, sonicated, filtered, stained and mounted on glass slides; slides observed under epifluorescence microscope for identification and total counts Colony-forming units (CFUs) – selective isolation of groups of microorganisms carried out using Zobell Marine Agar, Malt Extract and Kusters' medium; after 7-10 days, number of CFUs counted from plates

Discipline	Category	Parameter	Methods/Equipment
Biology (cont.)	Benthos (cont.)	Biochemical analysis	Total biomass (adenosine triphosphate [ATP]) – measuring luminescence by luminometer Protein, lipid, carbohydrate (CHO) estimated using spectrophotometric techniques
Physics			
Air	Meteorological observation	Air pressure, temperature, relative humidity, wind speed, sunshine and duration, and net radiation	Automatic weather station containing sensors
Water column	Hydrographic data	Temperature and salinity	Data on temperature and salinity obtained through hydrocasts, conductivity-temperature-depth (CTD) measurement, expendable bathythermographs (XBTs) and expendable CTD probes (XCTDs)
		Benthic currents	Self-recording current meters moored to obtain and record vector-averaged speed and direction of currents, temperature, conductivity and pressure
		Light transmission	Transmissometer attached to mooring systems
Chemistry			
Water column	Seawater chemistry	Dissolved oxygen	Winkler's titration method
		Eh	Analyzed by digital pH/millivolt meter with platinum electrode
		ph	Multiwavelength spectrophotometry using cresol red
		Alkalinity	Multiwavelength spectrophotometry using bromocresol green
		Nutrients (nitrate, nitrite, silicate)	Autoanalyzer
		Dissolved trace metals	APDC-MIBK extraction followed by instrumental analysis (graphite-furnace atomic absorption spectroscopy [AAS])

Discipline	Category	Parameter	Methods/Equipment
		Suspended solids	Known volume of water samples filtered through preweighed nucleopore filters and dried at 60° C, allowed to cool and reweighed

2. Inputs for standardization of protocols for environmental studies of deep-seabed mining

2.1. Physical oceanographic parameters

By V. Ramesh Babu, V.S.N. Murty, A. Suryanarayana, of the National, Institute of Oceanography, India

Area	Parameters	Instruments	Levels of observation
Meteorology	Sunshine Wind speed Wind direction Air temperature Atmospheric pressure Atmospheric humidity	Automatic weather station	10 m above sea surface
Surface wave field	Wave height and period Sea state	Ship-borne wave recorder Visual	Surface
Ocean current field	Speed and direction	Recording current meters (RCMs)	Recommended recording levels (one meter in each subsurface layer): Surface Mixed layer Upper thermocline Lower thermocline Intermediate depth (~1000 m) Lower depth (~3000 m) Abyssal depth (4500-5000 m) Close to bottom
Hydrography	Temperature, salinity and water sampling	Hydrocast (water sampling bottles)	Discrete or standard depths (5, 10, 20, 30, 50, 75, 100, 150, 200, 300, 500, 600, 800, 1000, 1200, 1500, 2000, 2500, 3000, 3500, 4000, 4500 and 5000 m, and near bottom)

Area	Parameters	Instruments	Levels of observation
	Temperature, salinity and light transmission profiles and water sampling	CTD meter fitted with light transmissometer and altimeter	Entire water column close to bottom; water sampling at above depths

2.2. Microbiological and biochemical analyses

By P.A. Loka Bharathi, Shanta Nair, Chandralata Raghukumar, C. Mohandass, NIO

	Parameter	Variables	Methodology for analyses
1	Sample collection	Sampler Core length Sections	Multiple corer, box corer 30 centimetres 0-2, 2-4, 4-6, 6-8, 8-10, 10-15, 15-20, 20-25, 25-30 cm Samples directly extruded into sterile plastic bags for microbiological and biochemical analyses
2a	Microbiology	Direct bacterial counts	Bacteria enumerated following Hobbie et al.[3]: aliquot of sediment sample diluted and fixed with filter-sterilized buffered formalin to give final concentration of 2 percent; fixed sample ultrasonicated at 20 hertz for 30 seconds, filtered through 0.22-? black nuclepore filter and stained with 0.01% acridine orange for 3 minutes. Bacterial cells counted using epifluorescence microscopy; average of 200 cells/sample counted, with counts expressed as numbers/gram dry weight. Sediment dried at 60? C for 24 hours.
2b		Plate counts of CFUs	Bacteria: ¼-strength Zobell Marine Agar Fungi: 1/5-strength Malt Extract Agar fortified with streptomycin and penicillin to prevent bacterial growth Incubating temperature: 5-10? C for 10-12 days Serially diluted sample used as inoculum; numbers expressed as CFU/g dry wt^{-1}

	Parameter	Variables	Methodology for analyses
2c		Total microbial biomass	*Method*: Measured in terms of ATP according to Parsons et al.[4] using ATP standard. *Extraction*: ~2 spatulas of wet sediment (=0.5-1.0 g dry wt) boiled for 3-5' in 3 millilitres of boiling Tris buffer (pH 7.7-7.8 with 20% HCl); extract transferred into clean dry glass vial; contents cooled to room temperature and centrifuged; supernatant stored at –20?C pending further analyses. *Assay*: Enzyme mixture prepared by adding 5 ml of Tris buffer to vial of ~50 milligrams of lyophilized firefly-lantern extracts (Sigma); vial allowed to stand at room temperature 2-3 hours; 0.2 ml of enzyme preparation pipetted into glass vial, then placed into sample holder with 0.2 ml of sample; integration-time readings taken after 30 seconds using luminometer. Light emitted proportional to amount of ATP present, calculated against standard curve; ATP converted to biomass carbon using conversion factor of 250[5].
3	Biochemistry	Labile organic matter (LOM)	Carbohydrates, proteins and lipids
3a			*Sample preparation:* Air-dried sediments homogenized using mortar and pestle and analyzed for protein, carbohydrates and total lipids. *Carbohydrates*: Method: Estimated using phenol sulphuric acid method with glucose as standard[6]. Extraction: Sediment extracted in 5% trichloroacetic acid (TCA) by heating 3 hours in water bath at 80-90?C; slurry centrifuged and aliquot of clear supernatant used for estimation. *Protein*: Method: Estimated following method of Lowry et al.[7], using bovine serum albumin as standard. Extraction: Extracted by digesting 0.1 g of sediment with 1 Normal NaOH in water bath at 100?C for 5'; slurry centrifuged and aliquot of clear supernatant used for estimation. *Lipids:* Method: Estimated using acid dichromate oxidation with stearic acid as standard. Extraction: Pretreatment of samples by solvent extraction (chloroform : methanol : water = 5:10:4).

	Parameter	Variables	Methodology for analyses
	Biochemistry (cont.)	Sediment enzymes	Phosphatase, lipase, protease and glucosidase
3b			*Sample preparation*: Sediment from each subsection of core air-dried, homogenized with mortar and pestle, and stored at 5?C pending analyses. *Method*: Enzyme activity measured using substrate analogues linked to fluorochrome methylumbelliferone (MUF)[8] with sodium salt of MUF as standard; fluorescence intensity measured and activity expressed as enzyme units (U) per g^{-1} of sediment per h^{-1}, where U = millimoles of MUF released. *Assay*: Sediment slurry from each section diluted with sterilized artificial seawater, homogenized and incubated in centrifuge at 1 atmosphere in dark at room temperature (28±2?C); reaction started by adding different concentration of substrate (micromoles) in duplicate (each section's concentration of substrate varies); after incubation for 1 hr, tubes centrifuged at 12,000 revolutions/minute at 4?C for 2' and relative fluorescence measured.
			Phosphatase activity[9]**:** Substrate: 4-MUF-phosphate Standard: sodium salt of MUF Fluorescence: excitation 365 nanometres, emission 455 nm
			Lipase activity: Substrate: MUF butyrate Standard: sodium salt of MUF Fluorescence: excitation 365 nm, emission 455 nm
			Protease activity: Substrate: leu-MCA (L-leucine-4-methylcoumarinyl-7-amide) Standard: 7-amino-4-methylcoumarine Fluorescence: excitation 380 nm, emission 440 nm
			Glucosidase activity: Substrate: MUF-?-d-glucosidase Standard: Sodium salt of MUF Fluorescence: excitation 365 nm, emission 455 nm

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