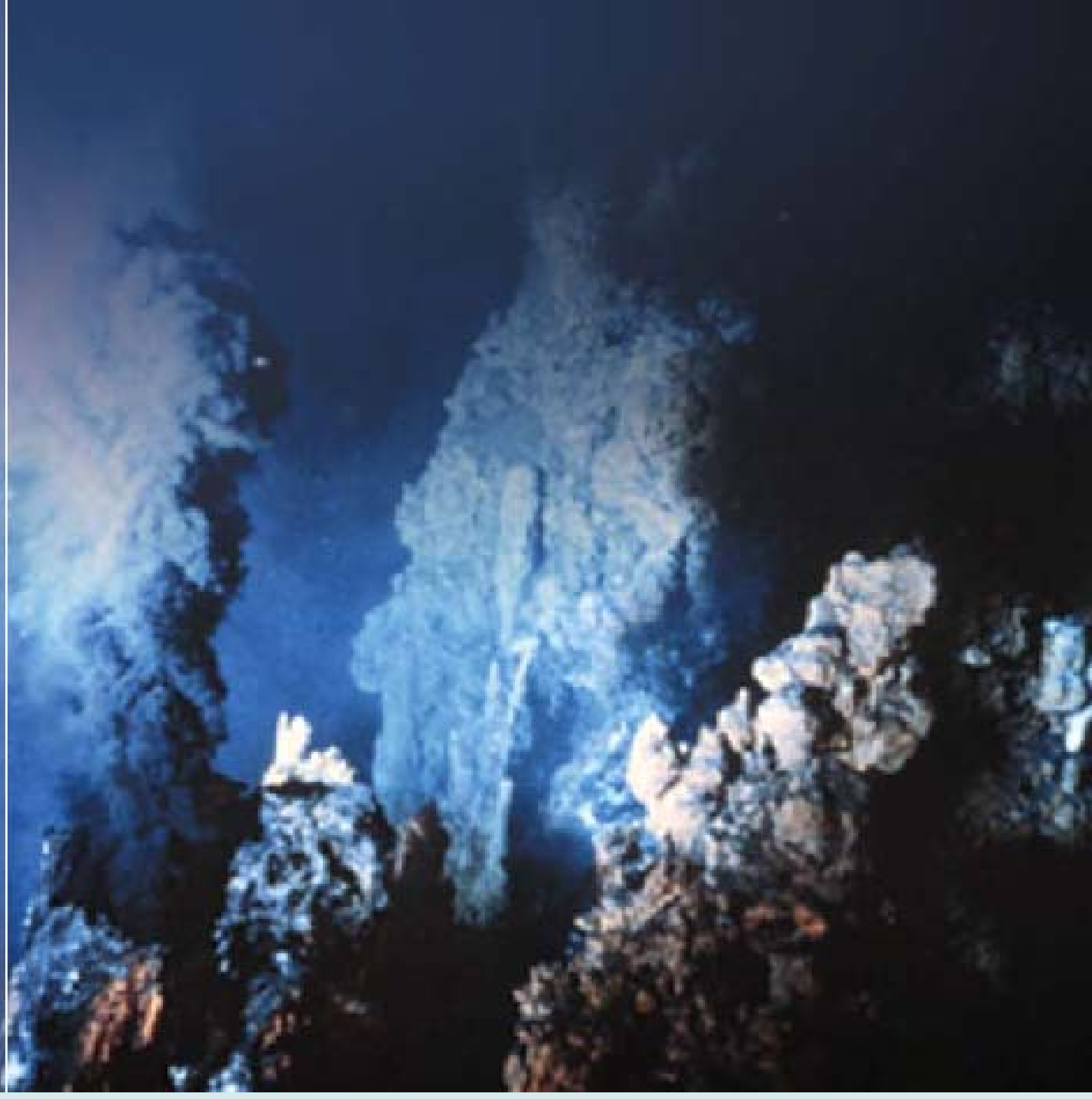
POLYMETALLIC SULPHIDES AND COBALT-RICH FERROMANGANESE CRUSTS DEPOSITS:

ESTABLISHMENT OF ENVIRONMENTAL BASELINES AND AN ASSOCIATED MONITORING PROGRAMME DURING EXPLORATION



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International Seabed Authority
14-20 Port Royal Street, Kingston, Jamaica WI
Tel: (876) 922-9105, Fax: (876) 922-0195

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FOREWORD

Satya N. Nandan, Secretary-General, International Seabed Authority

Colleagues and friends,

I welcome you to the seventh in the series of workshops convened by the Authority. For those of you who have not been here before, we hope that this is the first visit of many, and for those of you who have attended previous workshops, welcome back.

The Authority's workshops are essential to its work, as they provide the necessary background information on the subject matter under consideration. They are also useful for participating scientists, as they provide them with a forum for the exchange of information and ideas. As you are aware, the title of this workshop is "Polymetallic Sulphides and Cobalt Crusts: Their Environment and Considerations for the Establishment of Environmental Baselines Associated with Monitoring Programmes for Exploration".

The purpose of this meeting is to provide a list of suggestions to the Legal and Technical Commission which can be of use when the Commission is preparing environmental guidelines for contractors for prospecting and exploration for polymetallic sulphides and cobalt-rich crusts. Such guidelines were provided by the Legal and Technical Commission in the case of polymetallic nodules and we had a similar workshop preceding the adoption of those guidelines by the Commission. As you know, the Authority is the organization through which States Parties to the United Nations Convention on the Law of the Sea, in accordance with its Part XI and the Implementing Agreement, organize and control activities on the seabed and ocean floor, and subsoil thereof beyond the limits of national jurisdiction, which is defined in the Convention as the "Area".

The Authority's responsibility is to organize and control activities in the Area, particularly, with a view to administering the resources of the Area. During its initial phase, the focus of the work of the Authority was on the completion of regulations for prospecting and exploration for polymetallic nodules. We are now beginning to focus on regulations for prospecting and exploration for polymetallic sulphides and cobalt-rich crusts.

In June 2000, a workshop was convened to examine what mineral resources other than polymetallic nodules existed in the Area. The workshop provided information on the occurrence, technical parameters, economic interest in and potential reserves contained in mineral resources other than polymetallic nodules, and it identified existing institutional factors that have contributed to the discovery of such resources and the continuing research on them. The information provided will assist in drafting rules, regulations and procedures for prospecting and exploration of deep-sea polymetallic sulphides and cobalt-rich crusts.

While emphasis was placed on these two types of minerals, the workshop also reviewed activities relating to undersea hydrates, oil and gas, marine phosphorites and basic deposits of precious minerals, such as diamond. The proceedings of the workshop have been published in hard-copy format and can also be obtained online. The publication is available from the Authority's Library.

Since the workshop in 2000, and until recently, the Legal and Technical Commission of the Authority had been preparing a set of draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts. These were presented to the Council of the Authority at the tenth session in 2004. The Council will further examine the draft regulations at the eleventh and twelfth sessions, in 2005 and 2006.

According to article 145 of the United Nations Convention on the Law of the Sea, the Authority has a responsibility to ensure effective protection for the marine environment from harmful effects that may arise from activities in the Area. In order to address this, the Legal and Technical Commission included a number of detailed provisions within the draft regulations submitted for the consideration of the Council. They are designed to monitor the impact on the environment which occur from prospecting and exploration activities and require the establishment of environmental baselines against which future activities would be monitored.

In order to address the matters referred to in the regulations the objectives of this workshop are:

1. To understand the potential impact the mining of these resources will have on the environment;
2. To determine what is required for baseline studies;
3. To ascertain what, if any, current or past research programmes are relevant;
4. To design a monitoring programme for exploration and mining;
5. To determine any potential collaboration to reduce costs for contractors;
6. To propose guidelines for the consideration of the Legal and Technical Commission on the establishment of environmental baselines and for ongoing environmental monitoring.

I hope you will be able to address all or most of these issues by the end of this week.

I want to thank you once again for participating in this workshop. I thank you for the readiness with which you have all agreed to make presentations and to contribute to the proceedings. I hope that you will have a productive exchange over the next few days.

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PARTICIPANTS LISTING

Dr. Frida Armas-Pfirter, Legal and Technical Commission, Austria 2373, Buenos Aires, 1425, Argentina. Email: fza@mrecic.gov.ar

Professor Aike Beckmann, Division of Geophysics, University of Helsinki, P.O. Box 64, 00014 Helsinki, Finland. Email: aike.beckmann@helsinki.fi

Mr. Mayumy A. Cabrera-Ramírez, Facultad de Ingeniería, UNAM, Prol San Borja #156, Col Independencia, C.P. 03630, Mexico. Email: mayari77@yahoo.com.mx

Dr. Lúcia de Siqueira Campos, Departamento de Zoologia – Instituto de Biología, Universidade Federal do Rio de Janeiro Av. Pau Brasil, 211 - Prédio do CCS - Bloco "A", Cid. Universitária, Ilha do Fundão, Rio de Janeiro-RJ, CEP 21941-590, Brazil. Email: campos-lucia@biologia.ufrj.br

Dr. Malcolm Clark, Principal Scientist, Deepwater Fisheries, National Institute of Water & Atmospheric Research, Private Bag 14-901, Wellington, New Zealand. Email: m.clark@niwa.co.nz

Professor Colin Devey, Chair of InterRidge, "Dynamics of the Ocean Floor", Leibniz-Institut für Meereswissenschaften, IFM-GEOMAR, Gebäude Ostufer Wischhofstr. 1-3, D-24148 Kiel, Germany. Email: cdevey@ifm-geomar.de

Ms. Shannon Dionne, International Affairs Specialist, National Oceanic & Atmospheric Administration, 14th & Constitution Avenue, NW, Room 6228, Washington, DC, 20005, United States of America. Email: shannon.dionne@noaa.gov

Mr. Nguyen Dac Dong, Official Staff, Ministry of Natural Resources and Environment, 83 Nguyen chi Thant, Hanoi, Viet Nam

Ms. Samantha Eaton, Legal Officer, Ministry of Foreign Affairs and Foreign Trade, 21 Dominica Drive, Kingston 5, Jamaica. Email: legalmfaja@cwjamaica.com

Professor Anton Eisenhauer, Professor of Marine Environmental Geology, IFM-GEOMAR, Wischhofstr 1-3, 24148 Kiel, Germany. Email: aeisenhauer@geomar.de

Professor Elva Escobar-Briones, Professor and Head, Biological Oceanography, Biodiversity, Deep-Sea, Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnología, A.P. 70-305 Ciudad Universitaria, 04510 Mexico City, Mexico.
Email: escobri@mar.icmyl.unam.mx

Mr. Craig Foreman, Geologist, Economic Minerals Unit, Mines and Geology Division, Ministry of Land and Environment, Hope Gardens, Kingston 6, Jamaica.
Email: commissioner@minesandgeologydivision.gov.jm

Ambassaador Kent Francis-James, Embassy of Colombia, 53 Knutsford Boulevard, 4th Floor, Victoria Mutual Building, Kingston 5, Jamaica. Email: emcoljam@cwjamaica.com

Dr. Tomohiko Fukushima, Researcher, Ship and Ocean Foundation, Kaiyo Senpaku Building, 1-15-16 Toranomon, Minato-ku, Tokyo, Japan 105-000. Email: t-fukushima@sof.or.jp

Mr. Luíz Gamboa, Senior Geologist, PETROBRAS, Av. Chile 65/1301, Rio de Janeiro RJ – 20 031-912, Brazil. Email: gamboa@petrobras.com.br

Ms. Valentina Germani, Law of the Sea Ocean Affairs Officer, Division for Ocean Affairs and the Law of the Sea, United Nations, 2 United Nations Plaza, Room DC 2-412, New York, N.Y. 10017, United States of America. Email: germani@un.org

Professor Peter Herzig, Director, IFM-GEOMAR, Wischhofstr 1-3, D-24148 Kiel, Germany.
Email: pherzig@ifm-geomar.de

Mr. Albert J. Hoffmann, Chairman of the Legal and Technical Commission and Chief Director, Legal Affairs, Department of Foreign Affairs, Room 141, Hatfield Court, Private Bag X152, Pretoria, 0001, South Africa. Email: nicreat@telkomsa.net

Dr. Baban Ingole, Scientist, Biological Division, National Institute of Oceanography, Dona Paula, Goa-403004, India. Email: baban@darya.nio.org

Mr. Jincai Jin, Deputy Representative to the International Seabed Authority, Embassy of the Republic of China, Seaview Avenue, Kingston 10, Jamaica. Email: jin@comra.org

Mr. Jung-Keuk Kang, Principal Research Scientist, Korea Ocean Research and Development Institute, Ansan, P.O. Box 29, Kyungkido 425-600, Republic Of Korea. Email: jkkang@kordi.re.kr

Dr. Woong-Seo Kim, Principal Research Scientist, Deep-Sea Resources Research Center, Korea Ocean Research and Development Institute, Ansan, P.O. Box 29, Seoul 425-600, Republic Of Korea. Email: wskim@kordi.re.kr

Dr. Julian Anthony Koslow, Senior Principal Research Scientist, CSIRO Marine Research, Private Bag 5, Wembley, Western Australia 6913, Australia. Email: tony.koslow@csiro.au

Mr. Bin Mao, Secretary-General, COMRA, 1 Fuxingmenwai Avenue, Beijing 100860, People's Republic of China. Email: mao@comra.org

Dr. José Hipolito Monteiro, INETI – Marine Geology Department, Apartado 7586, 2721-866 Amadora, Portugal. Email: hipolito.monteiro@ineti.pt

Mr. Jorge Alfonso Morales, Minister Counsellor, Embassy of Colombia, 53 Knutsford Boulevard, Victoria Mutual Building, 4th Floor, Kingston 5, Jamaica. Email: jamcol@cwjamaica.com

Professor Jorge Nieto-Obregón, Facultad de Ingeniería, Universidad Nacional Autónoma de México, Div. Ing. Ciencias de la Tierra, Ciudad Universitaria, D. Coyoacán, 04510, Mexico City, Mexico. Email: nieto@servidor.unam.mx

Mr. José Luis Briceño Oviedo, Consul, Embassy of Chile, 17 Kingsway, 2FW, Embassy Apartments, Kingston, Jamaica

Dr. Lindsay Parson, Project Leader – Law of the Sea, Southampton Oceanography Centre, European Way, Southampton, United Kingdom. Email: L. Parson@soc.soton.ac.uk

Dr. Francisco Querol-Suñe, Technical Adviser to the Under-Secretary, Coordinación General de Minería – Secretaría de Economía, Puente de Tecamachalco #6, Col Lomas de Tecamachalco, Naucalpán, EDO de México, Mexico. Email: fquerol@economia.gob.mx

Professor Peter A. Rona, Institute of Marine and Coastal Sciences, Rutgers University, 71 Dudley Road, New Brunswick, New Jersey 08901-8521, United States of America. Email: rona@imcs.rutgers.edu

Mr. Carlos Valero Sandoval, Second Secretary, Embassy of Colombia, 53 Knutsford Boulevard, Kingston 5, Jamaica. Email: consuljam@cwjamaica.com

Professor Steven Scott, Professor and Department Chair, Department of Geology, University of Toronto, Toronto, Ontario, Canada M5S 3B1. Email: scottsd@geology.utoronto.ca

Dr. Rahul Sharma, Scientist, National Institute of Oceanography, Dona Paula, Goa 403004, India. Email: rsharma@darya.nio.org

Mr. Vu Truong Son, Vice Director, Marine Geology Union, Ministry of Natural Resources and Environment, 125 Trung Kinh, Hanoi, Viet Nam. Email: vtson-mgu@yahoo.com

Mr. Calvin Sidona Thompson, Manager, Topographic and Hydrographic Surveys, National Land Agency, Survey and Mapping Division, 23½ Charles Street, Kingston, Jamaica

Dr. Andreas Thurnherr, Doherty Associate Research Scientist, Columbia University, LDEO, Oceanography, Palisades, New York 10964, United States of America.
Email: ant@ldeo.columbia.edu

Professor Cindy-Lee Van Dover, Biology Department, College of William & Mary, Millington Hall, Landrum Drive, Williamsburg, Virginia 23185, United States of America.
Email: clvand@wm.edu

Dr. Michael Wiedicke-Hombach, Marine Geologist, Federal Institute for Geosciences and Natural Resources, Stilleweg 2, D-30655, Hannover, Germany. Email: michael.wiedicke@bgr.de

Professor Huaiyang Zhou, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Wushan, 510640 Guangzhou, People's Republic of China. Email: zhouhy@gig.ac.cn

SECRETARIAT OF THE INTERNATIONAL SEABED AUTHORITY

Mr. Satya N. Nandan, Secretary-General
Mr. Nii Allotey Odunton, Deputy to the Secretary-General
Mr. Adam Cook, Scientific Affairs Officer
Ms. Anna Elaise, Web/Publications Officer
Ms. Margaret Holmes, Administrative Assistant
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EXECUTIVE SUMMARY

At the tenth session of the International Seabed Authority, held in May 2004, the Legal and Technical commission presented "Draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area" to the Council for its consideration at the eleventh session.[1] The document comprised 43 regulations and 4 annexes. Annex 1 was entitled "Notification of intention to engage in prospecting," annex II was on "Application for approval of a plan of work for exploration to obtain a contract," annex III was entitled "Contract for exploration," and annex IV contained standard clauses for exploration contracts. Of the 43 regulations, 9 concerned the protection and preservation of the marine environment from activities in the Area. These were: regulation 5 in part II (Prospecting), regulations 20 and 22 in part III (Applications for approval of plans of work for exploration in the form of contracts), regulations 33, 34, 35, 36 and 38 in part V (Protection and preservation of the marine environment), and regulation 41 in part VI (Confidentiality). Of these, regulation 33 (Protection and preservation of the marine environment), regulation 34 (Environmental baselines and monitoring) and regulation 41 (Recommendations for the guidance of contractors) were most pertinent to the objectives of the workshop discussed in this publication.

Article 165, paragraph 2 (e) of the Convention requires the Commission to make recommendations to the Council on the protection of the marine environment, taking into account the views of recognized experts in this field. This workshop, the seventh convened by the Authority, entitled "Polymetallic sulphides and cobalt-rich ferromanganese crusts: Their environments and considerations for the establishment of environmental baselines and an associated monitoring programme for exploration" was convened to address that requirement.

Although the workshop was scheduled to be held from 6 to 10 September 2004, it ended on 9 September, owing to threats posed by hurricane Ivan. The workshop was attended by 40 participants from 18 countries, 16 of whom made presentations. One of the invitees to the workshop, Mr. David Heydon, Chief Executive Officer of Nautilus Minerals Limited, a company that had been active in the development of polymetallic sulphides in the territorial waters of Papua New Guinea, was unable to attend. However, Mr. Heydon sent two presentations to help in the discussions on impact and technology for polymetallic sulphides development. These were entitled "Exploration for and pre-feasibility of mining seafloor polymetallic sulphides – a commercial study" and "Mining on land vs. the seafloor - a case study."

The objectives of the workshop were:

1. To increase understanding of the potential impact of exploring for and mining these resources;

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[1] ISBA/10/C/WP.1

2. To determine what was required for baseline studies;

3. To ascertain the relevance of current or past research programmes;

4. To design a monitoring programme to be carried out during exploration for, and mining of these resources;

5. To determine any potential collaborations in applicable research in order to reduce costs for potential contractors, and

6. To propose guidelines to be submitted to the Legal and Technical Commission to facilitate its work in establishing environmental baselines at potential sulphides and cobalt-rich crusts mines, and for subsequent environmental monitoring.

One of the working groups (chaired by Dr. Andreas Thurnherr) considered chemical and physical baseline requirements at deposits of both resources; the second (chaired by Professor Cindy-Lee Van Dover) considered the biological baseline requirements at polymetallic sulphides deposits; and the final group (chaired by Dr. Anthony Koslow) considered the biological baseline requirements at cobalt-rich ferromanganese crusts deposits. The schedule was such that the working groups were to discuss their recommendations at the workshop, but the impending hurricane made this impossible.

On the first day of the workshop, following welcoming remarks by the Secretary-General, participants saw a movie entitled *"Volcanoes of the Deep Sea"* by Professor Peter Rona of the Institute of Marine and Coastal Sciences of Rutgers University that illustrated the environment of deposition of polymetallic sulphides deposits. After that, the Chairman of the Legal and Technical Commission, Mr. Albert Hoffman, made a presentation on the environmental provisions contained in the draft regulations. Subsequently, two presentations that highlighted the technologies that might be involved when commercial activities (exploration and mining) occurred at polymetallic sulphides and cobalt-rich ferromanganese crusts deposits were made by Professor Steven Scott of the University of Toronto and Dr Rahul Sharma of the Indian National Institute of Oceanography. These presentations were essential to ensure that all participants understood the impact of the potential technologies for exploration and mining on the physical, chemical and biological components of the in situ environments that characterize these resources.

In his presentation utilizing an IMAX film entitled *"Volcanoes of the Deep Sea"*, Professor Peter Rona informed workshop participants that the movie clearly illuminated, for the first time, the environmental setting for deep-sea polymetallic sulphides deposits and their associated ecosystems. He also informed participants that the Executive Producer had been James Cameron, the Producer of the blockbuster film, "Titanic", and that Stephen Lowe, the award-winning IMAX Director, had directed the film. Subsequently, Professor Rona highlighted some points from the film that he thought were relevant to the workshop

Professor Rona said that, in the film, it was possible to see a sealing of a lava flow, with the flow destroying the vent ecosystem, which was composed primarily of giant tubeworms and other fauna. He stated that one of the important questions was how long it would take to re-establish the community following lava flows and how often the lava flows occurred. With regard to lava flows, Professor Rona noted that eruptions on fast-spreading ridges in the Pacific were quite frequent, and that they could occur on a timescale of up to tens of years. He suggested that some people might use the re-establishment of communities as evidence that it was possible to disregard the effects of destroying the ecosystem by marine mining because the system was resilient and biodiversity would recolonize the area. However, Professor Rona stated that this was not true, because when lava flow destroys an ecosystem, all the seeds of rejuvenation (the heat and organisms) are still present. He emphasized that this situation differed from destroying a system by tearing the bottom out with mining equipment.

Professor Rona concluded his presentation by pointing out that, if scientists learnt how to explore for larger deposits, they would probably find ancient deposits on the seabed away from the ecosystems found at active ridge crests. He noted that current knowledge indicates the discovery of many more deposits in the future. Considering this, he suggested that the environmental guidelines should remain flexible to incorporate research emanating from such discoveries.

Mr. Hoffman, the Chairman of the Legal and Technical Commission of the Authority made a presentation on "The Authority's draft Regulations for prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area". He observed that his task was to present the draft Regulations emphasizing those provisions of the draft regulations relating to the protection and preservation of the marine environment, including the data and information requirements that were relevant to the objectives of the workshop.

Mr. Hoffman said that, at the tenth session of the International Seabed Authority held in 2004, the Legal and Technical Commission completed new draft Regulations for Prospecting and Exploration for Polymetallic Sulphides and Cobalt-rich Ferromanganese Crusts in the international seabed area ("the Area"). The Legal and Technical Commission submitted the draft Regulations to the Council at that session. Mr. Hoffman said that the Council decided to continue examination of the draft Regulations at the eleventh session in 2005, to allow Council members time to study the document and consult with their respective Governments. He said that the draft Regulations were the product of more than two years of deliberations within the Legal and Technical Commission. He noted that these new regulations followed on the earlier elaboration of Regulations for Prospecting and Exploration for Polymetallic Nodules in the Area by the Legal and Technical Commission. He informed participants that the Assembly eventually adopted those regulations, in July of 2000. With regard to these new regulations, Mr Hoffman said that the Legal and Technical Commission had completed its deliberations on them on the general understanding that, as far as practicable, the new regulations should follow the framework of the regulations for polymetallic nodules. More importantly, he said that the Commission agreed that the regulations should be in conformity with the provisions of the Convention and the Agreement related to part XI.

Nevertheless, according to Mr. Hoffman, significant adjustments had to be made, in order to reflect not only the differences in the nature and distribution of nodule deposits from those of crusts and sulphides deposits, but also the fact that each of the latter deposits differed from the other. He also noted that different political and economic considerations applied.

Mr. Hoffman observed that the most significant differences in the new regime related to the definition of blocks, the sizes of areas for exploration, and subsequent relinquishment. He also proposed that, because of the different distribution of these resources on the seafloor, in addition to the site banking system, the contractor could elect to participate in an equity interest, joint venture, or production-sharing arrangement with the Authority. Based on these discussions, Mr Hoffman said that the Legal and Technical Commission felt that despite differences in geometry and dimensions of the two types of deposits, the size of the exploration areas made available to contractors would be the same for both types of deposits.

Most of Mr. Hoffman's presentation was dedicated to outlining the various sections of the draft regulations, with particular reference to those which were relevant to the environment, and hence, the workshop. Mr. Hoffman felt that it was noteworthy that, of the 43 regulations, nine concerned the protection and preservation of the marine environment from activities in the Area.

In his presentation on "Proposed exploration and mining technologies for sulphides", Professor Steven Scott, Professor and Chairman of the Department of Geology of the University of Toronto in Canada noted that, while the technology required for exploration for hydrothermal deposits was non-intrusive, evaluating these deposits for the mineral resources and mineral reserves that they contained would be a challenging process. In this regard, he said that evaluating sulphides deposits required a carefully arrayed series of samples obtained by drilling holes into the deposits. He said that even though the exploitation of sulphides resources in the Area remained unproven, two companies (Nautilus Minerals and Neptune Resources) had begun to explore for sulphides reserves in the territorial waters and exclusive economic zones (EEZs) of Papua New Guinea and New Zealand. He stated that set-up costs for a marine mineral operation are higher than for a land-based operation. He suggested, however, that operational costs may be lower and that, although the technology for mining polymetallic sulphides was not currently available, it was expected that the methods used would be adaptations of those already used for offshore diamond mining and those proposed for polymetallic nodule mining. He informed participants that it is not cost-effective to mine the deposits by extracting the metals from hydrothermal fluids (active vents). He noted that it is better to let nature accumulate the minerals from the fluids and recover the minerals from the deposits formed from the fluids.

Professor Scott reminded the participants that even geologists used the term "ore" loosely. Professor Scott defined "ore" as naturally occurring material from which one or more metals of economic value could be extracted at a reasonable profit. Professor Scott said that while it was possible to have something that looked like a rich deposit, when all of the costs associated with its recovery were considered (exploration, mining, enironmental protection, processing, shipping, sales and dividends for investors), the material may not be profitable enough to make its recovery viable. Therefore, it was questionable whether some of the known deposits were indeed ores.

According to Professor Scott, the advantages of ocean mining include movable mining platforms, lower shipping costs and less pollution when compared with land-based mining. Professor Scott noted that the biggest problems created for the environment by land-based mining were acid drainage (rainfall on iron sulphides makes sulphuric acid) and the fact that the product of mining was not aesthetically pleasing. He pointed out that none of these problems would occur from ocean mining. He did note, however, that there were other problems, as ocean mining would degrade the seabed. In this regard, he said that there would be degradation of bottom waters, because of the release of toxic elements. He also said that it appeared there would also be a loss of habitat, as the animals associated with the deposits would be in a toxic environment. Nevertheless, the animals around active vents had been thriving in that environment, so Professor Scott did not see where toxic elements produced by mining would have a big effect on the animal community. According to Professor Scott, mining would not occur in hydrothermally active areas; because it would destroy the equipment. He therefore said that inactive deposits that would be the targets for mining. He noted however, that mining would have an impact on the organisms associated with inactive deposits.

In his presentation on "Proposed exploration and mining technologies for cobalt-rich crusts," Dr. Rahul Sharma, a scientist at India's National Institute of Oceanography in Dona Paula, Goa said that exploration for crusts deposits was similar to sulphides exploration, with the exception that cobalt-rich crusts tended to occur on the sides of seamounts. He said that the slopes of seamounts often had an incline of greater than 15%, which had implications for mining technology. He noted that suspended sediments produced as part of the commercial recovery of crusts were expected to have the same effect as those produced by polymetallic nodule mining but added that the areas where crusts and sulphides were found were often associated with lower than normal amounts of sediment cover. Therefore, he said that the effect of sediments on the environment in these areas might be of less concern than that produced from polymetallic nodule mining.

Dr. Sharma stated that, in his opinion, the Hawaiian Marine Mining plan was the most detailed study on a possible mining scenario for cobalt-rich crusts.[2] He noted that the report contained chapters covering all activities including prospecting, exploration, mining and processing. He further noted that the report estimated that the Hawaiian Archipelago and Johnston Island had a mean coverage of crusts on seamounts of 40%, creating a deposit of about 350 million tons with varying compositions and quantities of different metals.

According to Dr. Sharma, there are many unanswered questions, including the choice of a mining system. As such, Dr. Sharma said it was not possible to determine the impacts of mining on the environment in the absence of knowledge of the processes that would be involved. Dr Sharma informed participants that various groups had conducted a number of experiments to assess the impact of crusts mining on the environment. He noted, however, that these experiments were at scales significantly less than commercial mining scale. He concluded that experiments to monitor the impact of mining cobalt-rich ferromanganese crusts on the environment should simulate the activity at the scale at which mining would occur. In this connexion, he further noted that it would not be possible to extrapolate all the "what ifs", until the scale of the experiment is relevant to the environmental disturbance created.

A full day was devoted to polymetallic sulphides deposits. Presentations made included the physical and biological environments of these deposits, along with presentations by the Census of Marine Life and InterRidge, two international bodies promoting cooperation in marine scientific research related to hydrothermal systems that are often associated with polymetallic sulphides.

In his presentation on "An Introduction to hydrothermal vents and associated polymetallic sulphides deposits in the area with a special emphasis on the chemical environment", Professor Peter Herzig, Director of IFM-GEOMAR in Kiel, Germany emphasized that the magma chamber not only drove the seafloor spreading process, but that it also drove seawater hydrothermal convection systems. Professor Herzig said that the magma chamber is a large circulation system responsible for the formation of massive sulphides deposits and hydrothermal systems, at and beneath the seafloor. He said that a lot of sulphur in massive sulphides is from hydrothermal fluids leaching it from the surrounding rocks. Sulphur and other metals would be transported in solution up to the seafloor, together with hydrogen sulphide. There, these materials would form iron sulphides, copper sulphides, zinc sulphides and lead sulphides in response to the mixing of this high temperature hydrothermal fluid with ambient seawater. The product was sulphides mineralization below the seafloor. Professor Herzig described the process as stockwork remineralization, and said that mixing also created massive sulphides at the seafloor.

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2 Hawaii. Department of Planning and Economic Development. Business and Industrial Development Division. Ocean Resources Branch. *Mining Development scenario for cobalt-rich manganese crusts in the exclusive economic zones of the Hawaiian archipelago and Johnston Island*. Honolulu: 1987.

Professor Herzig stated that the mineralogical composition of seafloor massive sulphides deposits was relatively simple, with base metals occurring as sulphides of zinc, copper, lead and iron. In some areas, Professor Herzig said that exotic elements and minerals, such as native mercury and gold are associated with the sulphides deposits. He pointed out that from a commercial perspective, the revenue to support the operation would come from the base metals; the gold would be a valuable by-product. Professor Herzig noted that recently discovered deposits in the Southwest and West Pacific Ocean were extremely interesting with regard to their metal content. He said that in both Oceans, these deposits contain relatively high amounts of lead and zinc sulphides and, in places, a relatively high amount of gold. He further noted that these deposits were most similar to the massive sulphides currently mined on land.

Professor Herzig informed participants that, of the known deposits, only two, a large seamount on the East Pacific Rise and the TAG deposits, were located in the Area. However, there was significant potential for further discoveries, particularly in the Area, highlighting a clear role for the International Seabed Authority to play. Professor Herzig said that there are large areas of oceanic ridges that have not been scientifically examined thus far, in particular, in the Southeast Pacific Rise, the South Atlantic and in the Indian Ocean outside the 200-nautical-mile zone, which would be under the jurisdiction of the Authority.

In his presentation on "The physical environment of polymetallic sulphides deposits, the potential impact of exploration and mining on this environment, and data required to establish environmental baselines in exploration areas”, Dr. Andreas Thurnherr, Doherty Associate Research Scientist at Columbia University, informed participants that the physical environment in the vicinity of polymetallic sulphides deposits was the typical deep ocean environment. He described the environment as dark, cold and characterized by high pressure. Dr. Thurnherr said that in this environment, the instantaneous velocity of water was generally in the order of a few centimetres per second with mean flow velocities a few millimetres per second over weeks and months. He stated that no effects on the the physical environment of sulphides deposits were expected by mining operations beyond the scales of mining. He noted that the exception would be with blasting techniques. He further noted that in this case, the scales would depend entirely on the amount and size of explosives.

Dr. Thurnherr noted that there were other possible indirect large-scale effects if density anomalies were introduced into the water column. For example, if large amounts of fresh water were pumped down to the seabed, some type of connected plumes would be formed and these would have the potential to drive large-scale circulations. Dr. Thurnherr felt that it was very important to consider larger scales than the physical scales of mining, because anything released into the water column during mining or during transport to the surface would be dispersed in the ocean by physical processes that would be larger than the scales of mining.

Dr. Thurnherr was of the view that the physical environment could be expected to have more impact on mining than vice versa, as complex physical processes associated with the deposits would affect how far any effects of the activity would spread. With regard to determining the effect of currents on the area of impact, Dr. Thurnherr said that a combination of current meter moorings and tracer dye experiments would be needed to fully assess dispersal, as one type of measurement could be misleading without the other.

In her presentation on "The biological environment of polymetallic sulphides deposits, the potential impact of exploration and mining on this environment, and data required to establish environmental baselines in exploration areas", Professor Cindy-Lee Van Dover of the Biology Department, College of William & Mary in Virginia explained that there were two types of polymetallic sulphides deposits - active and inactive. She said that their biological environments were different. Professor Van Dover pointed out that the major biological difference between the two deposits was that communities at inactive sites were relatively unknown and, as such, predicting any impacts of exploration and mining on them would be difficult.

Professor Van Dover noted that, when considering the impact of mining on the environment, it was necessary to identify the seafloor area where activities would cause impacts and to determine the response of animals to plume fallout. In this regard, she also noted that it was necessary to know the distribution of the habitat, the species composition, community structure and basic biology of the species. She said that it would be necessary to know something about the heavy metals that could affect the animals. Professor Van Dover informed participants that it was not necessary to know the full range of all organisms of a species, but stated that it was necessary to know whether any species were endemic to a region. Professor Van Dover said information on community structure was necessary, as was as the age of the sulphides deposit, because fossils in the deposits would give an insight into the history of some of the vents. In this regard, she said that although scientists could follow active vent fields for 10 to 15 years, the 100,000 to 200,000-year fossil record in the sulphides deposits might be lost during mining. She suggested that there might be a way of studying the fossil record during mining or protecting deposits that were rich in fossils that might require protection. She also suggested modelling as a means to determine the effects of scaling as exploitation increased.

Professor Van Dover stated that in addition to the sulphides deposits themselves, impact assessment studies should also include surrounding areas that might be affected by the fallout resulting from the physical regime around the deposits. She recommended that preservation zones be established, since the organisms at hydrothermal sites may have biotechnological importance.

In his presentation on 'The work of InterRidge and its potential relevance to the establishment of environmental baselines, including the voluntary code of conduct for scientific research at hydrothermal vents, and potential collaborations with the Authority", Professor Colin Devey, Chairman of InterRidge introduced the organization as an international and interdisciplinary group. He said that InterRidge is concerned with all aspects of mid-ocean ridges, where polymetallic sulphides deposits are to be found. Professor Devey said that InterRidge comprised 27 member countries. He also said that financing for the activities of InterRidge is through contributions from its member countries. Professor Devey informed participants that InterRidge has a little less than 2,800 researchers from the 27 member countries; adding that not all of the researchers were Western Europeans or North Americans. He said that InterRidge is actively trying to involve countries that might not have the resources to do expensive research but that probably needed to do it. Professor Devey said that this was especially true in the context of the discussions at the workshop. In this regard, he noted that for example, while the back-arc basins in the West Pacific Ocean are areas that people were interested in exploiting, many of the countries close to them did not have the resources to do so.

Professor Devey said that in order to get many people working together, there needed to be community building. He said that InterRidge supported this process through a newsletter it published and which it made available to all interested parties. Professor Devey said that the newsletter contains information about the work of InterRidge, and that it is not a scientific publication.

Professor Devey informed participants that InterRidge is also involved with science policy and representation. He stated that InterRidge tries to be a mouthpiece for all researchers, adding that this was quite an important role. With regard to some of the other activities of InterRidge, Professor Devey said that in 2000, InterRidge convened a workshop on the management and conservation of hydrothermal vent ecosystems in Canada. He noted that the biological working group of InterRidge was responsible for this workshop as well as the "Code of Conduct for the conduct of scientific research on Marine Hydrothermal Vent Sites".

Dr. Lúcia de Siqueira Campos of the Institute of Biology, Department of Zoology, of the Federal University of Rio de Janeiro, Brazil informed the workshop that the Biogeography of Chemosynthetic Ecosystems (ChEss) project was part of the Census of Marine Life (CoML) programme. By way of introduction, she said that CoML was a "growing global network of researchers in more than 70 nations engaged in a ten-year initiative to assess and explain the diversity, distribution and abundance of marine life in the oceans".

According to Dr. Campos, the main objectives of CoML are to document diversity, distribution and abundance of marine organisms. She said that experts in different fields from over 70 nations around the globe assisted CoML in meeting its objectives. Dr. Campos said that CoMl had identified several key questions to meet its objectives, and is conducting research to address them over the next 10 years.

Dr. Campos said that the ChEss project is concerned with determining the biogeography of chemosynthetic communities found in various ocean areas, including at hydrothermal vent sites. She informed participants that chemosynthetic communities are often associated with polymetallic sulphides deposits. Dr Campos also told participants that ChEss is creating a database of chemosynthetic communities, including species found at each site, which would facilitate the determination of species ranges of organisms associated with polymetallic sulphides deposits. She pointed out that this information would be vital when establishing impact and preservation zones, as well as during monitoring programmes. Dr. Campos stated that ChEss is a very useful advisory body.

The following day was devoted to cobalt-rich feromanganese crusts deposits. Presentations were given on the chemical, physical and biological environments, along with a presentation by the relevant group from the Census of Marine Life.

The first presentation on the environment of deposition of cobalt-rich ferromanganese crusts deposits was on "The physical environment of cobalt-rich ferromanganese crust deposits, the potential impact of exploration and mining on this environment, and data required to establish environmental baselines". During his presentation, Professor Aike Beckmann of the Division of Geophysics, University of Helsinki in Finland noted that the physical conditions around seamounts vary, depending on the geometry and topography of the seamount and the ambient physical regime of the area. Through the use of a series of models, Professor Beckmann indicated how different conditions could produce very different current patterns. He said that the ingredients for physical environments at seamounts were the same, but that the relative contribution of each of these depended on many parameters related to the seamount, such as its geometry, the smoothness of topographic features and other parameters, such as the direction of the incident flow relative to a non-symmetric seamount. However, Professor Beckmann pointed out that general physical factors were the same at most seamounts and that seamounts were often associated with low levels of sedimentation, strong upward and downward mixing along the slope, and boundary currents which may prevent impacts on the seamount spreading to other seamounts. He said that the negative effect of these physical factors was that any sedimentation and pollution would not be diluted and would increase the localized impact. He noted that surrounding seamounts should not be affected.

Professor Beckmann noted that more knowledge of seamount geometry and a good way of describing the shape, height and steepness of the slopes of seamounts is required. In this regard, he pointed out that while it is easy to describe the geographical latitude of the seamount, information on the stratification of the water column and ambient ocean currents is required. Professor Beckmann informed participants about numerical methods, which had been available for ten years that are useful to determine, from selected short-term simulations, what the typical physical environment would be at a given seamount. In addition, he said that the numerical model is useful to determine the consequences of flow fields, such as where transport occurred, and to determine whether particles would be retained in the near field, and the amount of vertical upwelling. Professor Beckmann said that this information would provide a good basis for establishing baselines for the physical environment around seamounts.

In his presentation on “The chemical environment of cobalt-rich ferromanganese crust deposits, the potential impact of exploration and mining on this environment, and data required to establish environmental baselines in the exploration areas”, Professor Huaiyang Zhou of the Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, People’s Republic of China focussed on the chemical composition of crusts and the methods used for crusts exploration. Professor Zhou said that the methods used to explore for crusts were similar to those used for sulphides. He pointed out that the major impacts from crusts exploitation would be sediment plumes, and the accumulation of crusts fragments and debris at the base of the seamounts and in the surrounding abyssal plains. He also noted that mining may result in increased dissolved nutrients in the water column, which could have a positive impact if it occurred in areas where low concentrations of trace metals limited primary productivity.

In his presentation on “The biological environment of cobalt-rich ferromanganese crust deposits, the potential impact of exploration and mining on this environment, and data required to establish environmental baselines”, Dr. Anthony Koslow, Senior Principal Research Scientist at CSIRO Marine Research, Wembley, Western Australia pointed out the limitations of available studies. He explained that, while there had been some work done to investigate the biological environment of seamounts, there had been no faunal studies undertaken on crust communities. He therefore stressed the need for such investigations. Dr. Koslow said that, as a result of this deficiency, a major assumption was that communities found on crusts were the same as those found on seamounts. He pointed out that, due to enhanced currents associated with seamounts and their topographic isolation, endemism is very high, with the result that the species found on a region of a single seamount may be limited to that region.

Dr. Koslow showed a map highlighting about 250 sites of sampled seamounts. He compared the 250 sites with the thousands of seamounts known in the oceans, particularly in the Pacific Ocean, and concluded that a great deal of further sampling is necessary. With regard to the sampled seamounts, Dr. Koslow said that the map was misleading, in that adequate sampling has not occurred since more often than not, the concerned investigator had only been interested in one item, such as fish. With regard to the most likely geographic area of interest for cobalt-rich crusts in the Equatorial Pacific, Dr. Koslow said that it was for this reason that there are no biological data.

Dr. Koslow stated that, in some studies, no species were found in common between seamount chains and there was a much higher level of endemism than had been previously thought. This had led scientists to refer to seamounts as “The Galapagos of the Deep”.

Dr. Koslow discussed the potential impact of crusts mining on the environment. He said that mining crusts would result in stripping large areas of a seamount, and the loss of epifauna. He also noted the potential impact of enhanced sedimentation or the release of metals, which could have an effect on the benthic fauna of regions adjacent to the seamount, and on water column processes, such as primary productivity. Dr. Koslow thought that this was a key issue because if the crusts turned out to have relatively poor fauna, if there were richer fauna above the crusts, mining could have an impact on them.

Dr. Koslow believed that the key questions were the risk of extinction of endemic seamount species and the timescale for recovery, both for mined portions of seamounts and adjacent areas.

Dr. Koslow said that it was unclear what the potential impacts on the water column might be. There were a number of potential pluses and minuses. There could be enhanced micronutrients, such as iron, which could enhance primary productivity. On the negative side, Dr. Koslow said that bringing up a lot of material and releasing it in the upper water column could decrease the light available for primary productivity and interfere with grazers. In addition, he said that there would be a mix of trace metals released in the water. He noted that some of trace metals might enhance primary productivity; others might poison it.

Dr. Malcolm Clark, Principal Scientist, Deepwater Fisheries, National Institute of Water & Atmospheric Research in Wellington, New Zealand, made a presentation on a proposed CoML programme on seamounts, called CenSeam. Dr. Clark noted that, while the oceanographic definition of seamounts was quite specific with smaller protrusions from the seafloor called "knolls" or "pinnacles", more recently, "seamounts" is the term given to all three types of features. He said that for environmental coniderations the definition used has to be clear. On the basis of the traditional definition, Dr. Clark said that there were approximately 50,000 seamounts in the world's oceans. If the more general term was used, he said, the number rose to the millions. Dr. Clark said that the general term was also more appropriate when referring to crusts, as they were not restricted by the size of the "seamount". He pointed out that the CenSeam programme had closely followed the questions that had been posed during the workshop and that they would be addressed by the programme.

Dr. Clark said that other aspects of the CenSeam programme were to increase collaboration with other organizations, and to produce databases. He also said that the programme was a potential link between scientific research, the needs of the Authority in determining baseline information, and the strong international component and global overview offered by CenSeam.

In addition to the presentations outlined above, scientists from concerned countries made additional presentations on other programmes of relevance to the establishment of baselines, to the development of appropriate databases and to an increased understanding of the natural variability of polymetallic sulphides and cobalt-rich crusts ecosystems.

Professor Elva Escobar-Briones, Professor and Head, of the Biological Oceanography, Biodiversity and Deep-Sea Department of the Autonomous University of Mexico presented relevant work by the University on polymetallic nodules, polymetallic sulphides and cobalt-rich crusts in the Mexican exclusive economic zone. Other topics of relevance were also discussed, including the establishment of priority marine areas in Mexican waters and national marine conservation strategies. At the request of some participants, Dr. Escobar provided information on known marine mineral resources in the Gulf of Mexico.

Professor Escobar-Briones informed participants that Mexican scientists had documented transects along the abyssal plain and into venting sites in collaboration with IFREMER. Specimens of communities occupying the inactive structures had been collected and the research revealed that bacteria colonized some of the residual minerals and components of the inactive venting structures. Another result of the research is that invertebrates, such as shrimp, feed on the bacteria.

According to Professor Escobar-Briones, implementation of Mexico's national conservation strategies is by a Mexican conservation agency called CONABIO. Dr Escobar said that with the support of a foundation, Mexican authorities have designated a priority mining area within Mexico's marine jurisdiction. She said that the implementation of conservation strategies for hydrothermal vents, polymetallic nodule bearing areas and seeps is by different agencies of the Mexican Government. She said that the purpose of the conservation agency is to preserve biological diversity in different environments including terrestrial and aquatic habitats.

Dr. Baban Ingole, a Scientist in the Biological Division of the National Institute of Oceanography in Dona Paula in India stated that, Indian scientists had mapped seamounts, which had the potential for cobalt-rich crusts deposits, and the mid-ocean ridge system, which had potential for hydrothermal sulphides in the Indian Ocean. He said that for the past 20 years, there had been studies of areas in the abyssal basin, but that research on the ridges was relatively recent and with sampling of the seamounts in the planning stages.

Dr. Tomohiko Fukushima, a researcher at the Ship and Ocean Foundation in Tokyo, Japan stated that Japan had been conducting a survey of deep-sea mineral resources in its exclusive economic zone as a part of the Japanese International Technical Cooperation Project. The survey, initiated in 1985, is ongoing. It had produced various results related to polymetallic nodules, cobalt-rich crusts and polymetallic sulphides. He noted the use of deep-sea cameras by Japanese scientists during prospecting for marine mineral resources. He further noted that the still photographs and video recordings could be used for other purposes, such as megabenthos observation.

Dr. Fukushima presented participants with the differences observed in megafaunal communities at polymetallic nodule deposits, polymetallic sulphides deposits and cobalt-rich crusts deposits. He pointed out the need for intercallibration between researchers and contractors.

Dr. Fukushima stated that Japanese work in polymetallic nodules took place between 1975 and 1999, and said that environmental research took place from 1990 to 1997. He said that research on cobalt-rich ferromanganese crusts is underway and noted that while prospecting for polymetallic sulphides commenced in 1985, the associated environmental research is yet to start.

After all the presentations had been made, the participants divided themselves into three working groups to consider the main aim of the workshop, which was to prepare suggestions for the Legal and Technical Commission regarding the information that should be acquired by contractors for cobalt-rich ferromanganese crusts and polymetallic sulphides exploration to establish environmental baselines for a monitoring programme. Following a few hours of discussion within the working groups, all the participants met again in plenary, so that each working group could present the results of its deliberations and obtain feedback from the other working groups. Since some participants had already departed, owing to the threat of the impending hurricane, no one met on the fifth day of the workshop. In this regard, a decision was taken that the working groups should carry out the remainder of their work via email and presents their final recommendations to the Legal and Technical Commission through the Secretariat.

When the reports of the three working groups were completed, the Authority convened a meeting with the three working group chairpersons and David Heydon, the Chief Executive Officer of Nautilus Minerals, who had been unable to attend the workshop. At that meeting, working group leaders compared the reports of their respective groups and, based on these, a single document, entitled "Recommendations of the workshop on polymetallic sulphides and cobalt crusts: their environment and considerations for the establishment of environmental baselines and an associated monitoring programme for exploration" was produced and presented to the Legal and Technical Commission for its consideration in August 2005, as document ISBA/11/LTC/2.

CHAPTER 1 IMAX PRESENTATION ENTITLED "VOLCANOES OF THE DEEP SEA" AND ENVIRONMENTAL BASELINES AT DEEP SEABED POLYMETALLIC SULPHIDE MINE SITES IN THE AREA

Professor Peter A. Rona, Institute of Marine and Coastal Sciences, Rutgers University, New Brunswick, New Jersey, United States of America

Introduction

Polymetallic sulphides deposits of the Area form in the most remote, difficult-to-access regions of the oceans hidden beneath kilometres of water. At this early stage in exploration of the oceans, we already know that these regions of the deep ocean are the most spectacular, dynamic parts of our planet and host both non-living and living resources. A giant screen (IMAX) film that premiered in 2003, *Volcanoes of the Deep Sea* (*www.volcanoesofthedeepsea.com)*, exposes these regions for everyone to see clearly for the first time. Described as "remarkable as much for its technical accomplishments as for its scientific revelations" (*Variety*), and "an in depth IMAX stunner" (*New York Daily News*), the award-winning film illuminates the dark world of hot springs (hydrothermal vents) where polymetallic sulphides form and of other-worldly life forms "as never before" (*New York Times*).

The film achieves this new view by using high-technology lighting and cameras developed by the Hollywood movie industry, guided by cutting-edge science. The deep submergence vehicle (DSV) *Alvin* with a specially designed lighting array and high-resolution cameras was used to film the most spectacular vent sites known in the deep Pacific and Atlantic oceans. The thread that ties the film together is the story of the search to solve the mystery of one of the oldest living fossils on Earth, Paleodictyon that has survived for tens of millions of years in this region of the ocean with implications for biodiversity (Rona, 2004). The film was made by a team of ocean explorers which includes James Cameron of *Titanic* fame as Executive Producer, Stephen Lowe as Director, Professor Richard Lutz of Rutgers University as Science Director; and Professor Peter Rona, also of Rutgers University, as Associate Science Director. Major support was received from the U.S. National Science Foundation and Rutgers, the State University of New Jersey. The purpose of this paper is to build on the perception of viewers to highlight features revealed by the film relevant to formulation of environmental baselines at polymetallic sulphide sites in the Area. Sites of polymetallic sulphides associated with volcanic island chains that lie within the 200 nautical mile wide exclusive economic zones, like those of the island States of the western Pacific, are outside the scope of this paper.

Seafloor Setting of Polymetallic Sulphides

Polymetallic sulphides deposits in the Area are concentrated by processes at sites along the axis of a largely submerged volcanic mountain range, “the ocean ridge system,” that extends some 60,000 kilometres through all the ocean basins of the world (Figure 1). Although mostly underwater, this submerged mountain range of the ocean ridge system is the largest geographic feature on Earth. It is also the place where the outermost shell of the Earth, about 100 kilometres thick beneath the ocean basins, is continuously being created by the process of seafloor spreading. Hot molten rock (magma) rises from the Earth’s interior at sites along the axis of the ocean ridge, cools, solidifies, and accretes to form the layer of lithosphere that moves to either side of the ridge axis like two conveyor belts diverging at a rate of centimetres per year in the process of seafloor spreading.

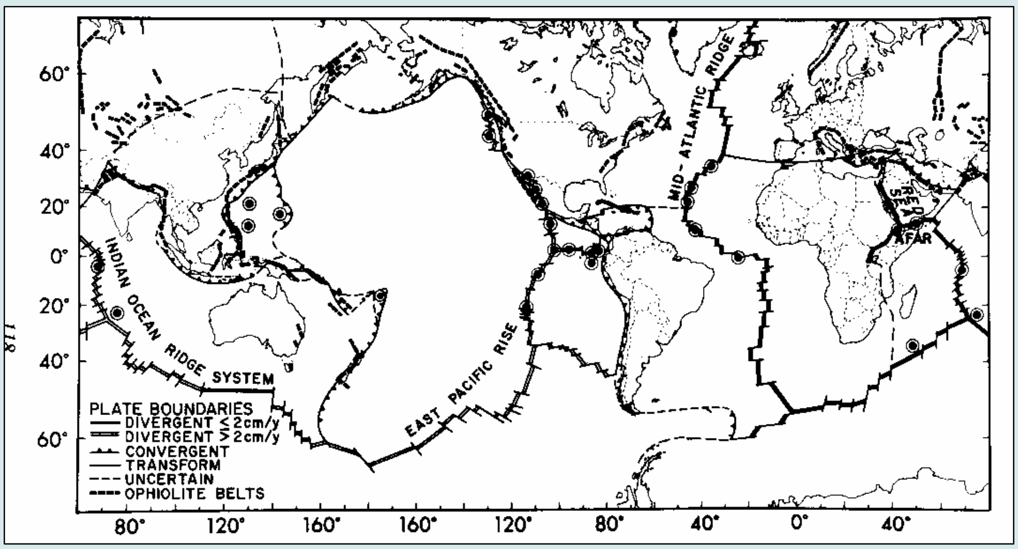

Figure 1: Global map showing plate boundaries and selected sites of polymetallic sulphide deposits (dots) at ocean ridges (divergent plate boundaries; from Rona, 1985). Ocean crust at and away from the axes of ocean ridges comprising some 40% of the Earth’s surface is prospective for polymetallic sulphide deposits.

The morphology and volcanic activity of ocean ridges generally varies with rate of seafloor spreading (Figure 2), although exceptions exist. The film shows sections of a fast-spreading ocean ridge (full spreading rate to both sides of the ridge axis up to 18 centimetres per year) in the eastern equatorial Pacific Ocean (latitude 9^0N on the East Pacific Rise) and of a slow-spreading ocean ridge (full spreading rate about 2 centimetres per year) on the Mid-Atlantic Ridge in the central north Atlantic Ocean. Fast-spreading ocean ridges, such as those in the Pacific Ocean, are generally gentle linear rises produced by a combination of thermal expansion of underlying hot rocks and construction by superimposition of successive lava flows. As shown in the film, volcanic eruptions occur on a timescale of years to tens of years on fast-spreading ocean ridges. The volcanic eruptions can destroy an ecosystem of animals living at and around hydrothermal vents. However, magma underlying the seafloor that accompanies an eruption provides the heat to re-establish the hydrothermal vents and associated organisms within several years of the eruption. This does not mean that if a vent community is destroyed by mining the vent ecosystem would re-establish itself. It is the replenishment of heat in the natural cycle of a volcanic eruption that is critical in rejuvenating the vents and the associated vent community.

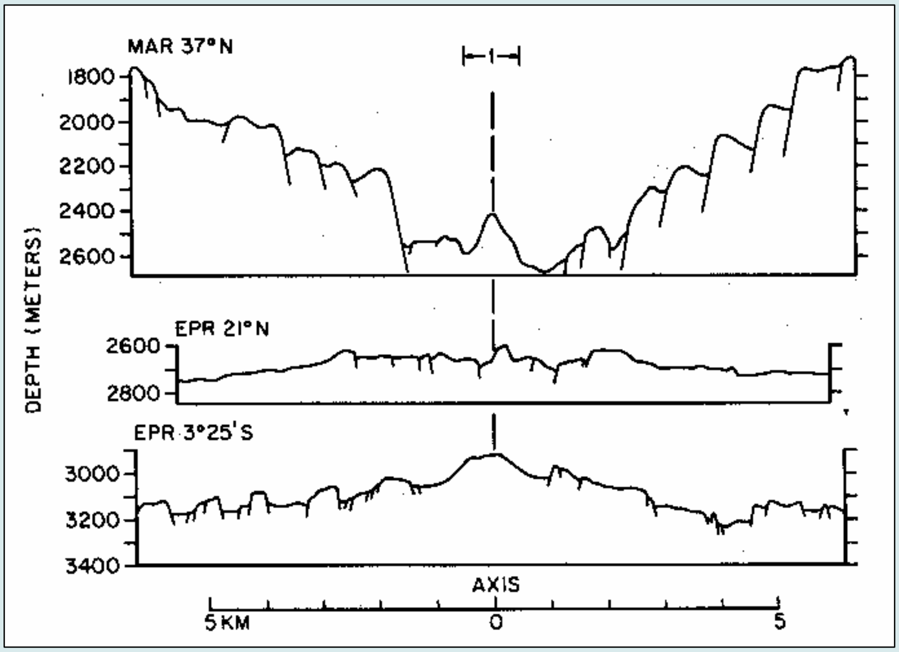

Figure 2: Profiles to show the difference in morphology of the seafloor across fast-spreading (East Pacific Rise [EPR] 3°25'S and 21°N) and slow-spreading (Mid-Atlantic Ridge [MAR] 37°N; from Rona, 1985).

In place of the rise along the axis of fast-spreading ocean ridges, slow-spreading ocean ridges, such as those in the Atlantic and Indian Oceans, generally have deep valleys, termed "rift valleys", with high walls. This characteristic form of slow-spreading ocean ridges is produced by less thermal expansion and more extension by seafloor spreading than at fast-spreading ridges. Volcanic eruptions on slow-spreading ocean ridges generally occur at intervals of hundreds to thousands of years. It was initially thought that polymetallic sulphide deposits would be larger and more numerous at fast-spreading, than at slow-spreading ocean ridges related to more frequent volcanic activity at the former. In fact, it has been found that, in general, fewer but larger polymetallic sulphide deposits occur at sites on slow-spreading, rather than on fast-spreading ocean ridges.

Once formed at the axis of an ocean ridge, a polymetallic sulphides deposit is transported away from the axis by the process of seafloor spreading (Figure 3). Other processes, such as cementing by silica-rich solutions, tend to preserve the deposits; still other processes, such as faulting, which breaks up a deposit, and microbial activity, which can degrade the deposit, tend to destroy the deposits; and there are yet other processes, such as lava flows and accumulation of sediment, that bury a deposit. Burial both preserves and hides an off-axis deposit. A characteristic signature of a low in magnetic intensity is produced when hydrothermal solutions erase the magnetic properties of ocean crust by alteration of magnetic minerals in the crust under a deposit (Rona, 1978). The magnetic signature resides with the deposit as seafloor spreading transports the deposit away from the axis (Rona, 1978; Tivey et al., 1993, 1996). The magnetic signature can be used as an exploration method to find off-axis deposits. The ocean crust that is away from the axes of ocean ridges constitute some 40% of the Earth's surface largely within the international Area and has significant potential for future discoveries of polymetallic sulphides deposits.

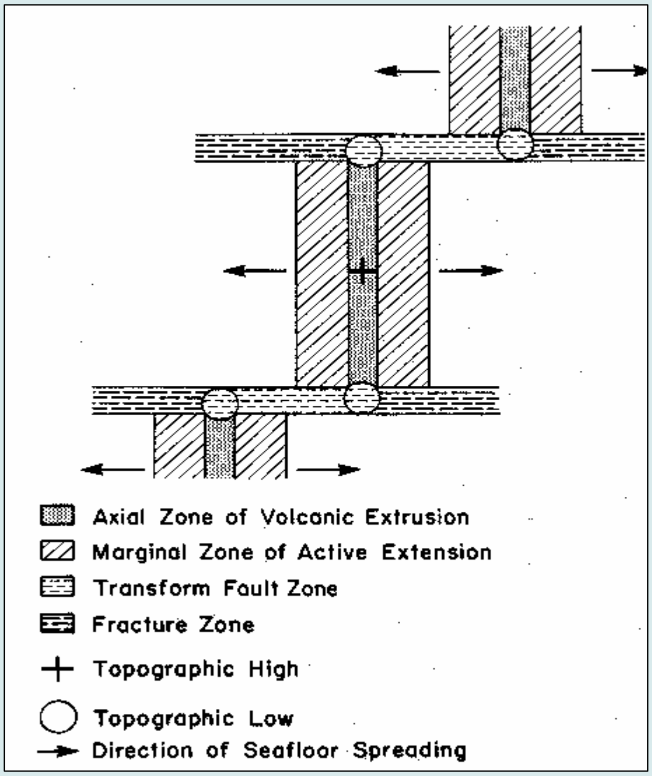

Figure 3: Schematic plan view of the axis of an ocean ridge to show how seafloor spreading could transport a polymetallic sulphide deposit formed at the axis away from the axis to either side (from Rona, 1985).

Hydrothermal Ore Forming Processes

The ocean basins are leaky containers for the oceans. Dense, cold seawater penetrates kilometres downward through fractures in the Earth's crust underlying the seafloor and, in most places, is assimilated into the Earth's interior. However, where magma is rising beneath ocean ridges, the downwelling dense, cold seawater is heated by flow near the hot rocks, thermally expands, becomes lighter, and buoyantly rises (Figure 4). As the heated seawater rises, it dissolves metals present in tiny quantities in the volcanic rocks of ocean crust and concentrates the metals as polymetallic sulphide deposits beneath and on the seafloor. Remaining metal-rich hot hydrothermal solutions are discharged through mineralized chimneys as "black smoker" vents on the seafloor at sites along the axis of the ocean ridge system.

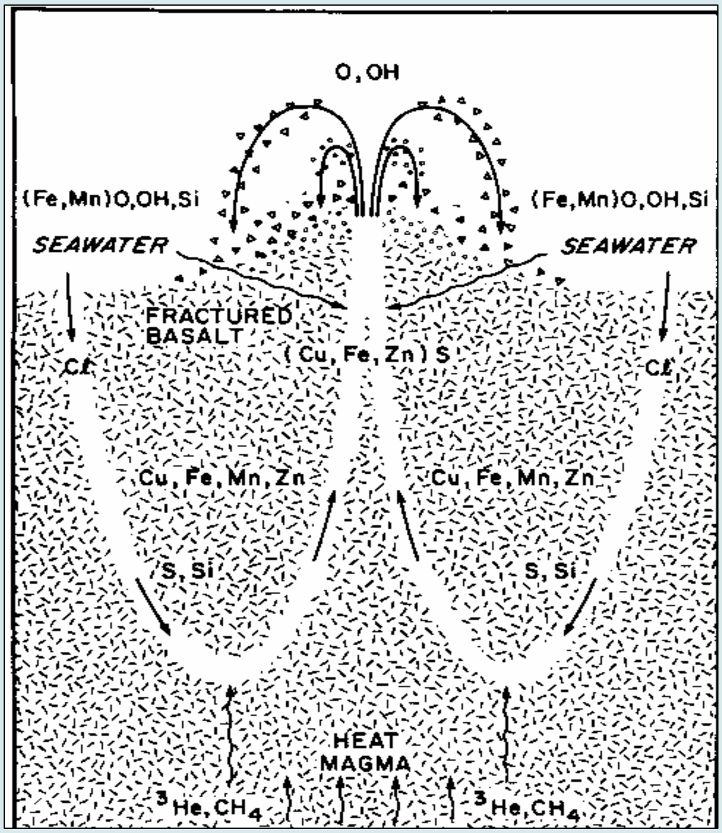

Figure 4: Schematic cross-section though the axis of an ocean ridge showing an ore-forming hydrothermal circulation system (from Rona, 1984). Chemical abbreviations are shown for metallic and other elements that are transferred between the seawater, the ocean crust and the magma to form a polymetallic sulphide deposit beneath and on the seafloor.

It was initially thought that the number and size of such deposits would increase with the rate of seafloor spreading, so that the largest deposits would occur at sites along the fast-spreading East Pacific Rise. In fact, fewer but larger deposits are being found at sites along slow-spreading ocean ridges such as those in the Atlantic (Rona, 1988). Exceptions to this generalization are expected.

The mineralized chimneys at seafloor hydrothermal vents have been observed to grow rapidly, attaining heights of tens of metres in months to years. This observation has promulgated the myth that seafloor polymetallic sulphides are renewable resources. In fact, large seafloor polymetallic sulphide deposits in the size range of millions of tonnes take thousands to tens of thousands of years to form for two reasons, namely:

1. Hydrothermal vent systems do not run continuously, but are episodic, turning on and off in concert with the volcanic eruptions that supply heat to drive the hydrothermal circulation. Large deposits are the product of multiple cycles of deposition;

2. Polymetallic sulphides deposits undergo a slow internal cooking process called "zone refinement " that tends to concentrate the interesting metals (copper, zinc, silver, and gold) into zones only metres thick at the top of the deposit, and leaves iron-rich minerals (the iron sulphide mineral pyrite) in most of the volume of the deposit underlying the surface zone of enrichment.

An example of these processes is the actively venting sulphides mound in the TAG hydrothermal field on the slow-spreading Mid-Atlantic Ridge. The TAG mound contains nearly 5 million tonnes of sulphide with interesting metals concentrated in the upper 10 metres below the seafloor (Rona et al., 1986; Hannington et al., 1995). Radiometric dating of the deposits reveals a record of short intervals of hydrothermal activity (tens of years) separated by long intervals of quiescence (thousands of years; Lalou et al., 1995).

Minerals and Microbes

Chemosynthetic microbes are at the base of the food chain that supports ecosystems of animals new to science at seafloor hydrothermal vents. The film shows how microbes use chemicals dissolved in the same metal-rich hydrothermal solutions that concentrate the polymetallic sulphides as an energy source to manufacture carbohydrates to nourish themselves. In turn, the microbes are consumed by the larger vent animals. Therefore, the microbes and the vent ecosystems that they support are literally hosted in the actively forming polymetallic sulphide deposits in active seafloor hydrothermal fields. Microbes may also use metallic sulphide minerals in inactive polymetallic sulphides deposits as a source of chemical energy to manufacture their food.

The microbes are important both scientifically and economically. Scientifically, certain of the microbes possess genetic characteristics that place them at the base of the tree of life. These primitive microbes are being investigated as a key to the origin of life. Economically, certain of the microbes are yielding enzymes and compounds that are proving commercially valuable in a spectrum of industrial and medical applications. Indeed, Lyle Glowka (1996) has characterized this situation where the newly discovered living resources have proven economically valuable before the mineral resources as "the deepest of ironies".

Biodiversity

The film shows spatial biodiversity with vent ecosystems dominated by giant tubeworms and clams at the Pacific site and by a new variety of vent shrimp at the Atlantic sites (Williams and Rona, 1986). The striking six-sided form slightly larger than a poker chip shown living on the seafloor is a living representative of the fossil form Paleodictyon preserved in sedimentary strata deposited on the seafloor tens of millions of years ago and uplifted in exposures on the north coast of Spain and other places. This living fossil represents another kind of biodiversity. Whether the living Paleodictyon is part of or separate from the vent ecosystem, its presence shows that the deep ocean is a sanctuary for survival of ancient life forms. Biodiversity at and around seafloor vent sites may therefore relate both to diversity in space and to survival in time.

SUMMARY AND CONCLUSIONS

Vent ecosystems and polymetallic mineral deposits are inextricably linked at active sites along the axes of ocean ridges. Seafloor hydrothermal systems are episodic, exhibiting relatively short periods of active venting (years to tens of years) primarily driven by input of magmatic heat associated with volcanic eruptions, and longer intervening periods of quiescence. These intervening periods may last up to thousands of years at seafloor hydrothermal systems situated on slow-spreading ocean ridges, such as those in the Atlantic, Indian, and Arctic Oceans. It is only when seafloor spreading carries a polymetallic sulphide deposit away from volcanic heat sources at the axis of an ocean ridge that the deposit becomes permanently inactive. Seafloor spreading separates the polymetallic sulphide deposits from vent ecosystems that require venting to survive. A magnetic signature that resides with polymetallic sulphides deposit is a method that can be applied to explore for polymetallic sulphides deposits in ocean crust away from the axes of ocean ridges. This off-axis area of the ocean crust covers some 40% of the Earth's surface and constitutes a vast province within the international Area that is a challenge for future ocean exploration. We are at an early stage in exploration of the oceans and regimes for recovery of the interrelated living and non-living marine resources should remain flexible to accommodate unanticipated discoveries.

ACKNOWLEDGEMENTS

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SUMMARY OF PRESENTATION

Professor Rona presented the recent IMAX film entitled "*Volcanoes of the Deep Sea*", which he had been involved with, and informed workshop participants that the movie clearly illuminated, for the first time, the very setting that was being considered at the workshop, specifically, the setting of polymetallic sulphides deposits and the ecosystems in the deep sea. He also informed participants that the Executive Producer had been James Cameron, the Producer of the blockbuster film "*Titanic,*" and that the film had been directed by the award-winning IMAX Director, Stephen Lowe. Professor Rona then highlighted some points from the film that he considered relevant to the workshop.

With regard to the occurrence of polymetallic sulphides on the seabed, Professor Rona said that the basic processes were the same at all ocean ridges. There was an upwelling of magma, which solidified as it adhered to either side of the break and formed a layer of lithosphere which moved on either side of the ridge axis like two conveyor belts diverging in opposite directions. Cold, heavy sea water seeped through fractures in the seafloor and descended kilometres through the volcanic rocks in the ocean crusts, where it was heated and dissolved metals from those rocks as it buoyantly rose back through the fractures. Professor Rona pointed out that this resulted in deposits both beneath the seafloor and on the seafloor as the dissolved metals precipitated. He further explained that discharges were also seen as black smokers, but that these occurred at specific sites, not continuously along the ridge system. He noted that, although the basic processes on the ocean ridge system were similar everywhere, the ocean ridges differed with reference to spreading rate. The film showed both a fast-spreading ridge in the Pacific Ocean with rates of up to 18 cm/year and a slower-spreading ridge in the Atlantic Ocean with rates about one-tenth of those in the Pacific Ocean. The intermediate- to fast-spreading ridges of the Pacific Ocean produced a constructional volcanic high, and thermal expansion from the heat in the underlying rocks formed a very low rise, such as the East Pacific Rise. In the Atlantic Ocean, where the rates were slower, there was less heat so there was less thermal expansion and less magma, leaving a gap called the rift valley, with walls that could be kilometres high.

Professor Rona said that, in the film, it was possible to see a sealing of a lava flow, with the flow destroying the vent ecosystem, which was composed primarily of giant tubeworms and other fauna. This had been observed by DSV *Alvin* in 1990. One of the important questions was how long it would take to re-establish the community and how often these lava flows occurred. With regard to lava flows, Professor Rona noted that eruptions on the fast-spreading ridges in the Pacific were quite frequent, and that they could occur on a timescale of years to tens of years. He provided an example of an ecosystem that had re-established itself in less than two years.

Professor Rona suggested that some people might use this as evidence to prove that it was possible to disregard the effect of destroying the ecosystem by marine mining because the system was resilient and the biodiversity would recolonize the area. He said that this was not true, because when lava flow destroyed an ecosystem, all the seeds of rejuvenation (the heat and organisms) were still present. He emphasized that this situation was different from destroying a system by tearing the bottom out with mining.

Professor Rona described the frequency of the eruptions on fast-spreading ridges as the other special factor and explained that, when hydrothermal systems were first found in the deep ocean, in the Pacific Ocean in the late 1970s, it was thought that the size of polymetallic sulphide deposits would be directly proportional to the spreading rate. For that reason, much of the early exploration was concentrated on the East Pacific Rise. He observed that this had been found to be false, and that there were very few large deposits on the East Pacific Rise. Although some scientists continued to investigate the slower spreading ridges in the Atlantic and Indian Oceans, it was doubted at that time that there could be hydrothermal systems on those systems.

Professor Rona stated that at the base of the hydrothermal vent systems of the Pacific and the Atlantic Oceans were the chemosynthetic microbes, which did not only lie on, but also beneath, the seafloor. He said that there was a whole sub-seafloor biosphere that had to be considered, particularly because these microbes were significant in terms of the origin of life, and their use for practical applications in industrial and medical products.

Professor Rona told participants that in the Atlantic Ocean, there were two aspects of biodiversity, namely, biodiversity in space and biodiversity in time. With regard to biodiversity in space, there was the basic process of chemosynthesis, where microbes at the base of the food chain were similar, but there were different forms of organisms. In that regard, Professor Rona pointed out that the hydrothermal vents found in the Atlantic Ocean lacked the tubeworms and the giant clams of the Pacific Ocean, but were dominated by new varieties of shrimp. With regard to biodiversity in time, he pointed out that this had been brought out by the search for Paleodictyon that was shown in the film. He said that Paleodictyon was a little larger than a poker chip. An experiment recently carried out had revealed that, beneath the surface expression of the holes, arranged in a six-sided pattern found on the seafloor, was also a network of tunnels just like those found in the fossil. Professor Rona informed participants that this was the time dimension of biodiversity. He further noted that sites on the deep seafloor at this ocean ridge system were sanctuaries for many ancient forms of life, such as Paleodictyon, that had somehow survived the many environmental catastrophes that had affected and extinguished some of the biodiversity both in shallower water and on land.

Professor Rona remarked that the hydrothermal solutions coming up through the seafloor supporting the chemosynthesis of the microbes at the base of the food chain were the same solutions that formed the ore deposits through the metals they contained. He then remarked that the microbes and the minerals were closely linked and that the microbes and vent ecosystems were hosted in the polymetallic sulphide deposits. Professor Rona said that, not only were there hydrothermal deposits in the slow-spreading ridges, but they tended to be larger than those on the faster-spreading ridges. In this regard, he gave an example of a deposit in the Atlantic Ocean that had been referred to as the Houston Astrodome, because it was the size and shape of that athletic stadium. He also noted that, while the process of seafloor spreading continued, scientists tended to concentrate on the processes right at the ridge axis where everything was active, where these polymetallic sulphides formed and where the vent ecosystems coexist.

Describing the system, Professor Rona said that a polymetallic sulphide deposit and the associated ecosystem which it hosted formed together directly at the axis where the process of seafloor spreading brought up heat and hot water. As the seafloor continued to spread, the deposit would be carried away from the axis to either side, but the organisms would remain at the axis. He further noted that polymetallic sulphide deposit could become partially buried by lava flows, broken up by faulting, but could continue to move away from the ridge axis by seafloor spreading at a rate of centimetres a year (the approximate rate of growth of finger nails). Over geologic time, the deposit would be carried farther and farther away, but would no longer be active. He explained that in a section of the South Atlantic, this process had continued for over 120 million years and in the North Atlantic, it had been going on for some 200 million years. While most of the scientific work had been concerned with occurrences at the ridge axis, there was a potential for deposits to occur at the seafloor away from the ridge crest. While such deposits would undergo some alteration, they would be carried away from the ridge axis and become part of the ocean crust itself. Describing the search process as a real exploration challenge, Professor Rona said that a method had been developed which was very promising. The earth's magnetic field reverses polarity periodically, so although current polarity caused compass needles to point north, a hundred thousand years ago, they may have pointed south and, before that, they would have pointed north, and so on. As the seafloor spread and solidified, it acted like a magnetic tape recorder and recorded the magnetic field at that time. It had been noticed that at the large deposit on the Mid-Atlantic Ridge, referred to as the Astrodome, there was a magnetic signature that implied that the magnetic tape had been essentially erased by the event of deposition of the polymetallic mineral deposit. This magnetic signature could be used to assist in the search for other off-axis deposits.

In concluding his presentation, Professor Rona pointed out that, if scientists learned how to explore for the larger deposits, ancient deposits would be found on the seabed away from the ecosystems at the active ridge crest. He noted that the present state of knowledge was just the beginning of the age of ocean exploration and that what had been found thus far was less than what remained to be discovered. He said that much more would be found in the future and that the environmental guidelines should remain flexible so as to incorporate research emanating from such discoveries.

SUMMARY OF DISCUSSION

Professor Rona stated that the magnetic prospecting techniques used for prospecting active deposits were developed as a result of work carried out at the TAG mound and on Red Sea metalliferous deposits. He said he had written some papers on the subject and could supply them if required. Professor Rona stated that Mauritius had used the techniques on the Endeavour Ridge to discover new deposits. One participant stated that this process had been used on land to find metal deposits in Japan that were associated with magnetic lows.

Asked whether the inactive vent structures shown in the film had specialized bacteria living within the crevices, Professor Rona said that this was the problem that occurred when looking at vents near the axis, since the vents turned on and off. He said that just because the system was not currently venting did not mean that the vent was inactive. He also said, however, that the deposits off axis were more likely to be inactive, as they had been carried away from the heat source.

Finally, in response to the question of whether the bubbling sound heard in the video had been recorded at the vents, Professor Rona said that the sounds had been superimposed on the film. He informed participants that experiments to try to record the sound of vents had met with limited success.

Part I

LEGAL, TECHNICAL AND ECONOMIC FRAMEWORK FOR POLYMETALLIC SULPHIDES AND COBALT-RICH FERROMANGANESE CRUST EXPLORATION AND MINING IN THE AREA

Chapter 2 Draft regulations for prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts deposits produced by the Legal and Technical Commission (ISBA/10/C/WP.1)

Mr. Albert J. Hoffmann, Chairman of the Legal Technical Commission and Chief Director, Legal Affairs, Department of Foreign Affairs, South Africa

Chapter 3 Proposed exploration and mining technologies for polymetallic sulphides

Professor Steven Scott, Professor and Department Chair, Department of Geology, University of Toronto, Ontario, Canada

Chapter 4 Proposed exploration and mining technologies for cobalt-rich ferromanganese crusts deposits

Dr. Rahul Sharma, Scientist, National Institute of Oceanography, Dona Paula, Goa, India

CHAPTER 2 DRAFT REGULATIONS FOR PROSPECTING AND EXPLORATION FOR POLYMETALLIC SULPHIDES AND COBALT-RICH FERROMANGANESE CRUSTS DEPOSITS PRODUCED BY THE LEGAL AND TECHNICAL COMMISSION (ISBA/10/C/WP.1)

Mr. Albert J. Hoffmann, Chairman of the Legal Technical Commission and Chief Director, Legal Affairs, Department of Foreign Affairs, South Africa

Introduction

At its last meeting during the tenth session of the International Seabed Authority held in May/June 2004, the Legal and Technical Commission (LTC) completed new draft regulations for the prospecting and exploration for polymetallic sulphides and cobalt-rich crusts in the international seabed area (Area). The draft regulations were submitted to the Council which decided to continue its examination thereof at the eleventh session next year, so as to allow Council members time to study the document and to consult with their Governments.

The draft regulations are the product of some three years of deliberations within the LTC and follow on the earlier elaboration by the Commission, and the eventual adoption by the Assembly in July 2000, of the Regulations for Prospecting and Exploration for Polymetallic Nodules in the Area.

The Commission completed its deliberations of the draft regulations on the general understanding that, as far as practicable, the new regulations should follow the framework of the regulations for polymetallic nodules and conform to the provisions of the Convention and the Agreement relating to part XI. In fact, the Commission used this as a basis for the new draft the regulations for polymetallic nodules, including the contract for exploration and the standard clauses relating thereto.

Nevertheless, significant adjustments had to be made in order to reflect not only the difference in nature and distribution of nodule deposits from that of crust and sulphide deposits, but also the fact that each of these latter deposits was of a different character. Note was also taken that different political and economic considerations apply.

The most significant differences in the new regime relate to definition of blocks, size of the area for exploration, and relinquishment. It is also proposed that, because of the different distribution of these resources, a contractor could, in addition to the site banking system, elect to participate in an equity interest, joint venture or production sharing arrangement with the Authority.

Based on these discussions, the Commission felt that, despite differences in geometry and dimensions of the two types of deposits, estimations of the likely mineable ore indicated that the total size of the exploration area would be the same for each deposit. Accordingly, the Commission proposed a size of exploration area for both resources of 10,000 square kilometres, consisting of 100 contiguous blocks, of approximately 10 x 10 kilometres each. This would have the potential for localizing a mineable area with at least 40 million tonnes of ore for each resource and a mining operation lasting 20 years. It was further recognized that the likelihood of large areas of poor resources within an exploration area would suggest that a high relinquishment percentage is appropriate.

Another important feature of the draft regulations is the provisions relating to the protection and preservation of the marine environment during prospecting and exploration. In developing environmental regulations relating to nodule exploration, the Commission had been dealing with an "*ex post facto*" situation. This was not the case with respect to crusts and sulphides and, given the lack of scientific information on these deposits, the Commission had some scope for reviewing the obligations of contractors in relation to the protection and preservation of the marine environment. In this context, the Commission considered it appropriate to reflect in the draft regulations the developments in international environmental law since the adoption of the Convention in 1982.

Discussions in the Commission on environmental considerations had indicated a lack of adequate knowledge of seamount and vent communities. It was pointed out that biological communities varied according to position on the seamount, the depth of the oxygen minimum zone in reference to the seamount, and on the substrate on which they lived. There also seemed to be a great deal of variation between seamounts that made it difficult to predict the impact that research on one seamount could have on another.

One particular topic that had been discussed was whether mining for polymetallic sulphides would only occur at inactive vent sites. Most work had suggested that extraction would only occur at inactive sites, as the technology would not make activities at active sites possible. Inactive sites appeared to be less at risk from human interaction, but there was much less knowledge available on inactive sites than on active sites to substantiate such an assumption.

Given the highly speculative nature of seabed exploration, it was realized that the new regulations should have a strong environmental focus, aimed primarily at ensuring that contractors progressively develop environmental baselines against which to assess the likely impact of future mining activities. As matters currently stand, potential seabed miners would face particular challenges with respect to environmental issues because of the relatively undefined nature of the deposits and the systems to be used to mine them, as well as the fact that the biodiversity of the deep seabed was far greater and more complex than had been thought up to now. In these circumstances, it was considered essential to begin the process of environmental regulation at an early stage, with a view to ensuring that the critical decisions that would have to be made in the future were made on the basis of adequate scientific information, using consistent methods of analysis and environmental characterization.

It is apparent, therefore, that the regulatory framework for exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts needs to contain provisions relating to the collection of baseline data and information on the biological characteristics of areas under exploration. This should include information on species composition and community structure and information on the basic biology of species found in such areas, as well as procedures for environmental impact assessment.

The functions of the LTC include making recommendations to the Council with regard to the protection of the marine environment, taking into account the views of recognized experts in the field. With this in mind, an exercise similar to the current workshop took place in respect of the regulations for prospecting and exploration for polymetallic nodules. Based on the outcomes of a workshop devoted to the development of environmental guidelines, which the Authority organized with the participation of experts in 2001, the Commission adopted recommendations for the guidance of the contractors for the assessment of the possible environmental impacts arising from exploration of polymetallic nodules in the Area. The purpose was to describe the procedures to be followed in the acquisition of baseline data, and the monitoring to be performed during and after any activities in the exploration area with the potential to cause serious harm to the marine environment. The aim was further to define the biological, chemical, geological and physical components to be measured and the procedures to be followed by contractors to ensure the effective protection of the marine environment from harmful effects which may arise from the activities in the Area and to provide guidance to potential contractors in preparing work plans in conformity with the Convention and the regulations.

Shortly after the Commission had issued its recommendations for the guidance of contractors, the Authority convened another workshop to assist the LTC to standardize the environmental data and information that contractors have to submit in accordance with the regulations for polymetallic nodules and the guidelines. The workshop proposed standards for the measurement of the biological, chemical, geological and physical components of the marine environment in nodule-bearing provinces that are essential for establishing baselines and for environmental impact assessment. It made recommendations on general sampling designs for the acquisition of environmental baseline data and for conducting monitoring tests. It also made recommendations on appropriate standardization strategies for ongoing efforts in taxonomy, sample processing and field collection of data. Strategies were further proposed to convert relevant data and information that had been acquired by contractors and concerned international scientific institutions into the standards proposed, thereby enabling the Authority to create a central database of provinces such as the Clarion Clipperton Zone, for subsequent use in managing impacts from polymetallic nodule mining. Those recommendations will be subject to review by the LTC in the next two years.

During the LTC deliberations on the draft regulations for polymetallic sulphides and cobalt-rich ferromanganese crusts at the May session, it had the benefit of advice from three scientific experts, namely, Peter Herzig, Jim Hein and Kim Juniper, who are internationally renowned for their expertise and work on these minerals and the deep-sea environment. They assisted the Commission by giving presentations on the current level of knowledge relating to these two mineral deposits.

Jim Hein described the main properties and distribution of cobalt-rich ferromanganese crusts and associated seamounts, emphasizing the high porosity, extremely high surface area and slow growth rate of crusts and the very high endemism, making any generalization of species distribution impossible.

Peter Herzig, who is again here to make another presentation, described the main characteristics of seafloor polymetallic sulphides associated with hydrothermal vent systems and their occurrence along mid-oceanic ridges, and indicated the critical factors for mining polymetallic sulphides.

Kim Juniper focused on the biology of the hydrothermal vent systems and the intimacy between vent fauna and mineral deposits, and suggested that any new regulations should leave room to incorporate new knowledge, as it became available.

The three experts also reviewed the draft regulations and were consulted on matters relating to the size of the exploration area, the system of exploration to be recommended in the light of the experience with the system for polymetallic nodules, and related options.

The Commission was very appreciative of the experts' inputs and advice, which not only assisted members in clarifying some questions and concerns, but also helped to broaden their understanding of some of the key issues involved.

Overview of the Draft Regulations for Polymetallic Sulphides and Cobalt Crusts

With this introduction as background, I now turn to the draft regulations prepared by the LTC and currently with the Council for its consideration and approval. I intend to highlight those provisions dealing with the protection and preservation of the marine environment, including data and information requirements, which should be relevant for our discussions over the next few days.

The draft regulations comprise nine parts and contain 43 regulations and four annexes.

The preamble sets out the objective of the regulations, namely, to provide for prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area.

Part I covers the use of terms and the scope of the regulations. It is made clear that the regulations shall not affect the freedom of scientific research nor the right to conduct marine scientific research in the Area pursuant to the provisions of the Convention. It is also stated that the regulations may be supplemented by further rules, regulations and procedures, in particular on the protection and preservation of the marine environment.

Part II deals with prospecting, how it shall be conducted and the obligations on prospectors with regard to the protection of the marine environment, consideration by the Secretary-General of notifications to engage in prospecting, as well as the submission of annual reports by prospectors.

Part III deals with exploration and sets out the details of applications of plans of work and the consideration thereof by LTC and approval by the Council. It also provides that the total area covered by each application is not to exceed 100 blocks; the size of a block being approximately 10 x 10 kilometres, and that, for both sulphides and crusts, the exploration area shall consist of contiguous blocks. As indicated earlier, the applicant can also elect to contribute to a reserved area or offer an equity interest or enter into a joint venture arrangement with the Authority.

Part IV requires that, following its approval by the Council, a plan of work for exploration be in the form of a contract between the Authority and the applicant. The contractor enjoys exclusive rights to explore an area covered by a plan of work, which shall be approved for a period of 15 years. Provision is also made for a process of relinquishment of allocated blocks. Provision is further made for the training of personnel of the Authority and developing States by contractors and their sponsoring States, as well as for a periodic review of the implementation of the plan of work. It also addresses the question of responsibility and liability.

Part V contains provisions for the protection and preservation of the marine environment and requires the Authority, in accordance with the Convention and Agreement, to establish and keep under review environmental rules, regulations and procedures to ensure effective protection of the marine environment from harmful effects which may arise from activities in the Area. Of particular importance in this regard is the application of the precautionary approach, as well as the establishment of environmental baselines, monitoring and reporting. This is an important part of the draft regulations for the purposes of our discussion and we will look into these provisions in more detail.

Part VI deals with confidentiality provisions to protect proprietary data and information submitted by the contractor to the Authority, with the exception of such data and information necessary for the formulation of rules and regulations to protect the marine environment. It requires the Secretary-General to establish procedures consistent with the Convention that would govern the handling of confidential information.

Part VII contains general procedures, including a provision that the LTC may issue recommendations of a technical or administrative nature for the guidance of contractors to assist them in the implementation of the Authority's rules, regulations and procedures.

Part VIII provides for the settlement of disputes concerning the interpretation and application of the regulations.

Part IX requires the prospector or contractor to notify the Authority in the event of the discovery of resources in the Area other than polymetallic sulphides or cobalt-rich ferromanganese crusts, which shall be the subject of new rules and regulations to be adopted by the Authority.

The annexes to the draft regulations provide detailed requirements for the notification to engage in prospecting, the application for approval of a plan of work for exploration to obtain a contract, the contract for exploration and the standard clauses to be included in the contract.

It is noteworthy that, of the 43 regulations, 9 are concerned with and specifically provide for the protection and preservation of the marine environment from activities in the Area. These are: regulation 5 in part II, regulations 20 and 23 in part III, regulations 33, 34, 35 and 36 in part V, regulation 38 in part VI and regulation 41 in part VII. Of these, regulation 33 (protection and preservation of the marine environment), regulation 34 (environmental baseline and monitoring) and regulation 41 (recommendations for the guidance of contractors) are considered to be the most pertinent to the objectives of this workshop.

Prospecting

For the purposes of the draft regulations, prospecting "means the search for deposits of polymetallic sulphides or cobalt crusts in the Area, including estimation of the composition, sizes and distributions of deposits of polymetallic sulphides or cobalt crusts and their economic values, without any exclusive rights" (regulation 1(g)).

The provisions relevant to the protection of the marine environment during prospecting are contained in regulations 2, 5 and 6.

"Regulation 2: Prospecting

1. ...

2. Prospecting shall not be undertaken if substantial evidence indicates the risk of serious harm to the marine environment.

3. …
nor may there be prospecting in an area which the Council has disapproved for exploration because of the risk of serious harm to the marine environment.

4. ...”

The term “serious harm to the marine environment” means any effect from activities in the Area on the marine environment which represents a significant adverse change in the marine environment determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally recognized standards and practices (regulation 1(h)).

In turn, “marine environment” is described to include the physical, chemical, geological and biological components, conditions and factors which interact and determine the productivity, state, condition and quality of the marine ecosystem, the waters of the seas and oceans and the airspace above those waters, as well as the seabed and ocean floor and subsoil thereof (regulation 1(e)).

These provisions are in accordance with article 162 of the Convention and are identical to those provisions in the regulations for polymetallic nodules, except of course for the different types of minerals involved.

It has been suggested that the Authority may wish to clarify the term “substantial risk”, as it is not defined in the Convention nor in the regulations and, in particular, how it should be interpreted in the light of the application of the precautionary principle.

An important provision with regard to the protection and preservation of the marine environment during prospecting is contained in regulation 5.

“Regulation 5: Protection and preservation of the marine environment during prospecting

1. Each prospector shall take necessary measures to prevent, reduce and control pollution and other hazards to the marine environment arising from prospecting as far as reasonably possible using for this purpose the best practicable means at its disposal. In particular, each prospector shall minimize or eliminate:

   (b) Adverse environmental impacts from prospecting; and

(c) Actual or potential conflicts or interference with existing or planned marine scientific research activities, in accordance with the relevant future guidelines in this regard.

2. Prospectors shall cooperate with the Authority in the establishment and implementation of programmes for monitoring and evaluating the potential impacts of the exploration and exploitation of polymetallic sulphides and cobalt crusts on the marine environment.

3. A prospector shall immediately notify the Secretary-General in writing, using the most effective means, of any incident arising from prospecting which poses a threat of serious harm to the marine environment. Upon receipt of such notification the Secretary-General shall act in a manner consistent with regulation 35."

This is a new regulation proposed by one of the informal working groups established within the LTC to look at the environmental considerations in the draft regulations. The regulation seeks to prevent or control adverse environmental impacts arising from prospecting by imposing obligations on prospectors to take the necessary measures and also to cooperate with the Authority in the establishment and implementation of programmes to monitor and evaluate the potential impacts of exploration and exploitation on the environment. It also addresses the question of conflicts or interference with existing marine scientific research and the care that prospectors have to exercise in this regard in accordance with guidelines that are still to be created. Prospectors also have the obligation to notify the Secretary-General of incidents arising from prospecting which poses a threat of serious harm to the marine environment. The term "poses a threat of serious harm" used throughout the draft regulations replaces the term "causes serious harm" that is used in the regulations for polymetallic nodules, to bring it more in line with the precautionary approach.

"Regulation 6: Annual reporting

1. A prospector shall, within 90 days of the end of each calendar year, submit a report to the Authority on the status of prospecting. Such reports shall be submitted by the Secretary-General to the Legal and Technical Commission. Each such report shall contain:

(d) ...

(e) Information on compliance with the undertakings referred to in regulation 3, paragraph (4)(d); and

(f) Information on compliance with the relevant future guidelines in this regard.

2. ...”

In this regulation, prospectors are required to provide information on compliance with the future environmental guidelines. The working group proposed some tentative environmental guidelines for prospecting but the Commission decided not to include it in the regulations, but rather, to await the outcome and recommendations from the present workshop.

As part of the notification of intention to engage in prospecting that is required under regulation 3 and annex I, the proposed prospector shall provide a written undertaking to comply with those requirements and to make available to the Authority such data as may be relevant for the protection and preservation of the marine environment.

Exploration

For the purposes of the draft regulations, exploration “means searching for deposits of polymetallic sulphides or cobalt-rich ferromanganese crusts in the Area with exclusive rights, the analysis of such deposits, the use and testing of recovery 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 exploration.”

The provisions relevant to environmental protection are contained in regulations 20 and 23.

“Regulation 20: Data and information to be submitted for approval of the plan or work for exploration

1. Each applicant shall submit, with a view to receiving approval of the plan of work for exploration in the form of a contract, the following information:

2.

(a) ...

(g) A description of the programme for oceanographic and environmental baselines studies in accordance with these Regulations and any environmental rules, regulations and procedures established by the Authority that would enable an assessment of the potential environmental impact of the proposed exploration activities, taking into account any recommendations issued by the Legal and Technical Commission;

(h) A preliminary assessment of the possible impact of the proposed exploration activities on the marine environment;

(i) 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;

i. …”

These provisions are important elements of an environmental protection regime if it were to function as an integral component of the regulatory regime for deep-seabed activities.

As part of the application for approval of a plan of work for exploration, it is critical that the Authority be provided with as much data and information as possible, including, as is stated in the said regulation, a description of the programme for environmental baseline studies. The purpose of environmental baseline studies is to establish the initial state of the marine environment before the occurrence of activities that have the potential for causing harmful effects on the environment. Such data and information, as well as that relating to a preliminary environmental impact assessment and measures to be proposed for the prevention and control of other hazards and possible impacts on the marine environment, are important tools that would enable the Authority to assess the potential environmental impact of the proposed exploration activities and to take an informed decision as to whether or not to allow the application.

“Regulation 23. Consideration by the Legal and Technical Commission”.

2. Upon receipt of an application for approval of a plan of work for exploration, the Secretary-General shall notify the members of the Legal and Technical Commission and place consideration of the application as an item on the agenda for the next meeting of the Commission.

…

3. The Commission shall, in accordance with the requirements set forth in these Regulations and its procedures, determine whether the proposed plan of work for exploration will:

…

(b) Provide for effective protection and preservation of the marine environment;

...

6. The Commission shall not recommend approval of the plan of work for exploration if part or all of the area covered by the proposed plan of work for exploration is included in:

...

(c) An area disapproved for exploitation by the Council in cases where substantial evidence indicates the risk of serious harm to the marine environment.

…"

The role of the LTC as the competent body of the Authority to consider applications for approval of plans of work for exploration, in particular with regard to the protection of the marine environment, and to make recommendations to the Council relating thereto, is once again derived from the Convention. The relevant provisions state that the Commission also has competence to prepare assessments of the environmental implications of activities in the Area, and to make recommendations to the Council on the protection of the marine environment, taking into account the views of recognized experts in the field (see article 165, paragraphs 2 (d) and (e)).

Protection and Preservation of the Marine Environment

The draft regulations contain extensive provisions dealing with the protection and preservation of the marine environment, some of which have already been referred to in the context of the provisions relating to prospecting and exploration. Part V contains specific provisions relating to environmental protection and requires the Authority to establish and keep under review environmental rules, regulations and procedures to ensure effective protection of the marine environment from harmful effects which may arise from activities in the Area. For the purposes of our discussion, this part of the draft regulations, and more specifically regulations 33 and 34, read together with regulation 41 in part VII, require closer scrutiny.

"Regulation 33: Protection and preservation of the marine environment".

1. The Authority shall, in accordance with the Convention and the Agreement, establish and keep under periodic review environmental rules, regulations and procedures to ensure effective protection of the marine environment from harmful effects which may arise from activities in the Area.

2. In order to ensure effective protection for the marine environment from harmful effects which may arise from activities in the Area, the Authority and sponsoring

States shall apply a precautionary approach, as reflected in principle 15 of the Rio Declaration, to such activities. The Legal and Technical Commission shall make recommendations to the Council on the implementation of this paragraph.

3. Pursuant to article 145 of the Convention and paragraph 2 of this regulation, each contractor shall take necessary measures to prevent, reduce and control pollution and other hazards to the marine environment arising from its activities in the Area using for this purpose the best practicable means at its disposal.

4. 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. When required by the Authority, such programmes shall include proposals for areas to be set aside and used exclusively as impact reference zones and preservation reference zones. "Impact reference zones" means areas to be used for assessing the effect of activities in the Area on the marine environment and which are representative of the environmental characteristics of the Area. "Preservation reference zones" means areas in which no mining shall occur to ensure representative and stable biota of the seabed in order to assess any changes in the flora and fauna of the marine environment."

These provisions reflect what is required in article 145 of the Convention, namely, 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."

It further states that: "the Authority shall adopt appropriate rules, regulations and procedures for inter alia:

(a) the prevention, reduction and control of pollution and other hazards to the marine environment, including the coastline, and of interference with the ecological balance of the marine environment, particular attention being paid to the need for protection from harmful effects of such activities as drilling, dredging, excavation, disposal of waste, construction and operation or maintenance of installations, pipelines and other devices related to such activities;

(b) the protection and conservation of the natural resources of the Area and the prevention of damage to the flora and fauna of the marine environment."

The 1994 Agreement also provides that the adoption of rules, regulations and procedures incorporating applicable standards for the protection and preservation of the marine environment are amongst the matters that the Authority should concentrate on between the entry into force of the Convention and the approval of the first plan of work for exploitation (see annex, section 1, paragraph 5 (g)).

In accordance with these requirements, the Authority had developed a comprehensive environmental protection regime, which was incorporated into the regulations for polymetallic nodules. Similar provisions are now contained in the draft regulations.

In regulation 33 (2) there is an obligation on the part of both the Authority and sponsoring States to apply a precautionary approach, as reflected in principle 15 of the Rio Declaration, to activities in the Area.

Principle 15 states:

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

It is noted that neither the Convention nor the 1994 Agreement expressly provides for the application of the precautionary principle. The regulations for polymetallic nodules first introduced the "precautionary approach as reflected in principle 15" which is exactly the same formulation now contained in regulation 33 (2). As recalled by Professor Dr. Tullio Scovazzi in a paper presented at the special session of the Assembly during the celebration of the tenth anniversary of the establishment of the Authority in May 2004, "the incorporation of the precautionary approach proved to be a delicate issue during the negotiations for the Mining Code. On the one hand, some coastal States were concerned that dredging and other exploration activities might cause unpredictable harm to living organisms. On the other, potential miners believed that environmental disturbances prior to the exploitation activities were only minor. The Code (regulations) tries to combine the two approaches by providing a compromise solution." [1]

In a consultancy report prepared by Daniel Owen for the Authority in 2002, after providing an analysis of the precautionary principle in relation to activities in the Area, and as reflected in the regulations for polymetallic nodules, he suggested that the Authority may wish to take a different approach to the precautionary principle in respect of future regulations for other resources in the Area (i.e. polymetallic sulphides and cobalt crusts). The purpose of the report, as he stated, is to inform LTC on the possible applications of the precautionary approach when it makes recommendations to the Council on the implementation of regulations such as regulation 33 (2).

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1 "Future directions for the Authority." Prof. Dr. Tullio Scovazzi. In Proceedings of the tenth anniversary commemoration of the establishment of the International Seabed Authority 25-26 May 2004.

Unfortunately, it is not possible to deal with the findings of the report in this presentation but, as it is considered to be a very useful document, I trust that the organizers have included it in the resource material for consideration at the present workshop.

Another important provision is that contained in regulation 33 (4), which obliges contractors, sponsoring States and other interested States or entities to cooperate with the Authority in establishing and implementing programmes to monitor and evaluate the impacts of deep-seabed mining on the marine environment. For this purpose, the Authority may set aside areas to be used as impact reference zones and preservation reference zones. These are important environmental protection tools that would enable the Authority to monitor and assess the effect of activities in certain designated areas on the marine environment, as compared to areas where no mining activities occur.

Similar provisions are contained in the regulations for polymetallic nodules, and in the recommendations for the guidance of contractors for the assessment of the possible environmental impacts arising from exploration for polymetallic nodules, issued in 2001 by LTC, proposals are made as to when and where these zones should be selected and how they should be monitored.

"Regulation 34: Environmental baselines and monitoring".

1. Each contract shall require the contractor to gather environmental baseline data and to establish baselines, taking into account any recommendations issued by the Legal and Technical Commission pursuant to regulation 41, 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. The recommendations issued by the Commission may, inter alia, list those exploration activities which may be considered to have no potential for causing harmful effects on the marine environment. The contractor shall cooperate with the Authority and the sponsoring State or States in the establishment and implementation of such monitoring programme.

2. The contractor shall report annually in writing to the Secretary-General on the implementation and results of the monitoring programme referred to in paragraph 1 and shall submit data and information, taking into account any recommendations issued by the Commission pursuant to regulation 41.

3. Pursuant to article 165 of the Convention, the reports referred to in paragraph 2, together with such other environmental data and information as the Commission may require in order to carry out its functions, shall be transmitted to the Commission for its consideration."

This is an extremely important regulation and constitutes the core of what is considered to be an environmental assessment and monitoring regime. It provides the legal framework for the establishment of environmental baselines and monitoring programmes but leaves it to the Commission (and experts in this field) to develop detailed guidelines and to implement the regime.

Each contractor shall be contractually obligated to: gather environmental baseline data; establish environmental baselines against which to assess the likely effects of activities under the plan of work on the marine environment; and monitor and report on such effects.

The contractor is further obliged to submit annual reports on the implementation and results of the monitoring programme, as well as any other data and information that may be required. The objective of these monitoring and reporting requirements is not to unduly burden the contractors with unnecessary requirements, but rather, as the Secretary-General remarked in a statement to the United Nations General Assembly, "to establish a mechanism whereby the Authority, and particularly the Legal and Technical Commission, can be provided with the information necessary to carry out its responsibilities under the Convention and the Agreement to ensure the protection of the marine environment from harmful effects arising from activities in the Area."

These responsibilities or functions of the Commission, which have already been referred to in the context of the discussion of some of the other regulations, require it to, inter alia, make recommendations to the Council on the protection of the marine environment; take into account assessments of environmental implications when formulating rules, regulations and procedures; and make recommendations to the Council regarding the establishment of monitoring programmes.

Under this competency, which is derived from article 165 (2) of the Convention, regulation 41 enables 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."

Such recommendations are subject to the approval of the Council, are particularly relevant to the establishment of environmental baselines, impact assessment, monitoring and reporting and must be adhered to by the contractors. As stated, the recommendations are for the guidance of contractors, to assist them in discharging their obligations under the regulations and also to enable LTC to carry out its functions.

Regulations 35, 36 and 38 are also relevant to the protection of the marine environment, but they are not so pertinent to the objectives of this workshop.

Regulation 35 deals with emergency action that the Secretary-General can take in the event of an incident resulting from or caused by a contractor's activities in the Area that poses a threat of serious harm to the marine environment. Such action may include the taking of immediate measures of a temporary nature to prevent, contain and minimize the threat.

Regulation 36 protects the rights of coastal States and requires any such State with grounds for believing that any activity in the Area by a contractor is likely to cause a threat of serious harm to the marine environment under its jurisdiction or sovereignty to notify the Secretary-General thereof. If there are clear grounds for believing that serious harm to the environment is likely to occur, the Secretary-General shall act in accordance with regulation 35. It also places an obligation on contractors to take measures to ensure that their activities are conducted in such a way as not to cause damage (by pollution) to the marine environment under the jurisdiction or sovereignty of coastal States.

Regulation 38 refers to the confidentiality of data and information submitted or transferred by the contractor to the Authority pursuant to the regulations and in terms of its contractual obligations. An important exception is contained in regulation 38 (2), namely, that "data and information that is necessary for the formulation by the Authority of rules, regulations and procedures concerning the protection of the marine environment and safety, other than equipment design data, shall not be deemed proprietary."

Conclusion

As was the case with the regulations for polymetallic nodules, it will be necessary with respect to the draft regulations for polymetallic sulphides and cobalt-rich ferromanganese crusts, to consider and, if necessary, to elaborate on the above-mentioned environmental requirements and to develop guidelines for the assessment of the possible environmental impacts arising from exploration for these minerals in the Area. This should include procedures to be followed by contractors in the acquisition of baseline data and the establishment of environmental baselines, the monitoring of exploration activities and the reporting of these activities to the Authority.

As we have heard, the main objective of this workshop is to assist the Authority to develop such environmental guidelines for future exploration for deposits of polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area. For this purpose, we believe it is essential to determine what is currently known about the environments in which these minerals are found, what needs to be done to assess the likely impact that exploration and mining activities would have on the state of the environment, and what further measures need to be taken to ensure the effective protection of the marine environment from harmful effects that such activities may have.

It is expected that the recommendations of this workshop would be submitted to the LTC to assist it in formulating recommendations for the guidance of contractors who may in future wish to engage in exploration activities for these minerals.

Finally, the Commission has benefited greatly in the past from workshops similar to this one in its effort to fulfil the mandate given to it by the Convention, the Agreement and the regulations. We value your contributions, your expertise and collective wisdom and your collaboration with the Authority and are certainly looking forward to working with you and to receiving, in due course, the results of this workshop.

SUMMARY OF PRESENTATION

Mr. Hoffman said that, whereas scientists made discoveries, lawyers, diplomats and policy makers were called upon to translate that into regulatory mechanisms that would enable mankind to benefit from such endeavours. In other words, scientists made the discoveries and lawyers and diplomats made the rules. This was exactly what the Legal and Technical Commission (LTC) had been doing over the past few years - trying to make rules - but it was important to get the scientists on board to help to improve knowledge and understanding. Mr. Hoffman observed that his task was to present the draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area prepared by the LTC. He said that his presentation would emphasize those provisions of the draft regulations relating to the protection and preservation of the marine environment, including the data and information requirements that were relevant to the objective of the workshop.

Mr. Hoffman said that at the tenth session of the International Seabed Authority held in June 2004, new draft regulations for the prospecting for polymetallic sulphides and cobalt-rich ferromanganese crusts in the international seabed area were completed. The draft regulations had been submitted to the Council, and it had been decided that examination of them should be continued at the eleventh session, in 2005, so as to allow Council members time to study the document and to consult with their respective Governments. The draft regulations were the product of two or more years of deliberations within the Commission. They followed on the earlier drafting by the LTC, and the eventual adoption by the Assembly in July 2000, of the regulations for prospecting and exploration for polymetallic nodules in the Area. The Commission had completed its deliberations on the draft regulations on the general understanding that, as far as practicable, the new regulations should follow the framework of the regulations for polymetallic nodules and, more importantly, should be in conformity with the provisions of the Convention and the Agreement relating to part XI. The Commission had used the regulations for polymetallic nodules, including the contract for exploration and standard clauses relating thereto, as a basis for the new draft.

Nevertheless, according to Mr. Hoffman, significant adjustments had had to be made, in order to reflect not only the differences in nature and distribution of nodule deposits from those of cobalt-rich ferromanganese crusts and polymetallic sulphides deposits, but also the fact that each of these latter deposits was different from the others. He also noted that different political and economic considerations applied.

Mr. Hoffman observed that the most significant differences in the new regime related to the definition of blocks, size of the area for exploration, and relinquishment. He also proposed that, in view of the different distribution of these resources, the contractor could elect to participate in an equity interest, joint venture, or production-sharing arrangement with the Authority, in addition to the site banking system. Based on these discussions, Mr. Hoffman said that the LTC felt that, despite differences in geometry and dimensions of the two types of deposits, the total size of the exploration area would be the same for each deposit. Accordingly, the Commission proposed an exploration area size for both resources of 10,000 square kilometres, consisting of 100 contiguous blocks of approximately 10 x 10 kilometres each. The LTC felt that this size exploration area would have the potential of localizing a mineable area with at least 14 million tons of ore for each resource and a mining operation lasting 20 years. Mr. Hoffman said that the LTC further recognized that the likelihood of large areas containing poor resources within an exploration area would suggest that a higher relinquished percentage was appropriate. Mr Hoffman noted that another important feature of the draft regulations was the provisions relating to protection and preservation of the marine environment during prospecting and exploration. In developing environmental regulations relating to nodule exploration, Mr. Hoffman said that the LTC had been dealing with an *ex post facto* situation. He called the attention of participants to the pioneer regime, during which pioneer investors had been working in pioneer areas for some time before the regulations on nodules were adopted, resulting in a situation in which not much of the methods that they used could be changed. He explained that this was not the case with respect to cobalt-rich ferromanganese crusts and polymetallic sulphides. Mr. Hoffman said that because of the lack of scientific information on these deposits the Commission had some scope for reviewing the obligations of contractors in relation to the protection and preservation of the marine environment. In this context, Mr. Hoffman informed participants that the LTC considered it appropriate to reflect developments in international environmental law since the adoption of the Convention in 1982 in the draft regulations.

Mr. Hoffman stated that discussions in the LTC on environmental considerations indicated a lack of adequate knowledge of seamount and vent communities. In this regard, Mr. Hoffman noted, *inter alia*, information that biological communities varied according to position on the seamount, the depths of the oxygen minimum zone in reference to the seamount, and the substrate on which they lived. Other information seemed to suggest a great deal of variation between seamounts, which made it difficult to predict the impact that research on one seamount would have on another. Mr. Hoffman said that a particular topic discussed in the LTC was whether mining for polymetallic sulphides would only occur at inactive vent sites. Mr. Hoffman informed participants that the information available suggested that extraction could occur at both inactive and active vent sites, as the technology would make activities at both sites possible. He also noted that while it is generally assumed that inactive sites were less at risk from human interaction, there was much less knowledge available on inactive sites than on active sites to substantiate such an assumption. Given the highly speculative nature of seabed exploration, Mr. Hoffman said that the LTC realized that the new regulations should have a strong environmental focus aimed primarily at ensuring that contractors developed environmental baselines against which to assess the likely impact of future mining activities.

According to Mr. Hoffman, as matters currently stood, potential seabed miners would face particular challenges with respect to environment issues because of the relatively undefined nature of the deposits and the systems to be used to mine them, as well as the fact that the biodiversity of the deep seabed was far greater and more complex than had previously been thought. Mr. Hoffman stated that, in these circumstances, it was considered essential to begin the process of environmental regulation at an early stage, with a view to ensuring that the critical decisions that would have to be made in the future were made on the basis of adequate scientific information using consistent methods of analysis and environmental characterization. It was apparent, therefore, that the regulatory framework for exploration for polymetallic sulphides and cobalt crusts needed to contain provisions relating to the collection of baseline data and information on the biological characteristics of areas under exploration, including information on species composition and community structure and acquisition of information on the basic biology of species found in such areas, as well as procedures for environmental impact assessment.

Mr. Hoffman noted that the Commission's functions included making recommendations to the Council with regard to the protection of the marine environment, taking into account the views of recognized experts in the field. With this in mind, he described an exercise similar to the current workshop that had taken place in 2001 regarding the regulations for prospecting and exploration for polymetallic nodules in the Area. Based on the outcomes of that workshop, Mr. Hoffman informed the workshop that the LTC had adopted recommendations for the guidance of contractors for the assessment for the possible environmental impact arising from the exploration for polymetallic nodules in the Area.

Mr. Hoffman stated that the purpose of the recommendations was to describe the procedures to be followed in the acquisition of baseline data and the monitoring to be performed during and after any activities in the exploration area with potential to cause serious harm to the marine environment. Shortly after the LTC had issued its recommendations for the guidance of contractors, the Authority convened another workshop to assist the LTC to standardize the environmental data and information required to be submitted by contractors in accordance with the regulations for polymetallic nodules and the guidelines.

Mr. Hoffman noted that the 2001 workshop had also made recommendations on appropriate standardization strategies for ongoing efforts in taxonomy, sample processing and field data collection. He recalled that the workshop had proposed strategies to convert relevant data and information that had been acquired by contractors and concerned international scientific institutions into the standards proposed, thereby enabling the Authority to create a central database of provinces such as the Clarion Clipperton zone. He said that this was for subsequent use in managing impacts from polymetallic nodule mining. He informed participants that the 2001 workshop's recommendations would be subject to review by the Commission by 2006.

According to Mr. Hoffman, during its deliberations on the draft regulations for polymetallic sulphides and cobalt-rich ferromanganese crusts at the Authority's session in May 2004, the Commission had had the benefit of advice from three scientific experts. These were Professor Peter Herzig (Lehrstuhl fur Lagerstattenlehre, Institut fur Mineralogie, Brennhausgasse, Germany), Dr. James Hein (United States Geological Survey, Santa Cruz, California, USA) and Professor S. Kim Juniper (University of Quebec at Montreal, Montreal, Canada), who were internationally renowned for their expertise on these minerals and the deep-sea environment. He said that they had assisted the LTC by giving presentations on the current level of knowledge related to the two minerals. Mr. Hoffman said that Dr. Hein had described the main properties and distribution of cobalt-rich ferromanganese crusts and associated seamounts emphasizing the high porosity, extremely high surface area and slow growth rates of crusts and the very high endemism, making any generalization of species distribution impossible. Mr. Hoffman said that Professor Herzig had presented the main characteristics of seafloor polymetallic sulphides associated with hydrothermal vent systems and their occurrence alongside the oceanic ridges, indicating the critical factors for mining polymetallic sulphides. Mr. Hoffman also said that Professor Juniper had focused on the biology of hydrothermal vent systems and the intimacy between the fauna and mineral deposits, suggesting that any new regulations should leave room to incorporate new knowledge as it became available. He concluded this part of his presentation informing participants that these experts had also reviewed the draft regulations and had consulted on matters, including the size of the exploration area. Mr. Hoffman expressed the appreciation of the Commission for their inputs and advice, which had not only assisted in clarifying some questions and concerns but had also helped to broaden the understanding of some of the key issues involved.

Mr. Hoffman then moved on to the draft regulations prepared by the LTC which were under consideration by the Council for approval. He highlighted the provisions dealing with the protection and preservation of the marine environment, including the data and information requirements that should be relevant to the discussions at the workshop.

Mr. Hoffman explained that the text of the draft regulations was in nine parts containing 43 regulations and 4 annexes. The preamble set out the objectives of the regulations, namely to provide for prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crust in the Area. He then continued to outline each section in detail, as follows.

Part 1 outlined the use of terms and the scope of the regulations. It also made it clear that the regulations should not affect the freedom of scientific research or the right to conduct marine scientific research in the Area pursuant to the provisions of the Convention. It also stated that the regulations may be supplemented by further rules, regulations and procedures, in particular, on the protection and preservation of the marine environment.

Part 2 dealt with prospecting, how it should be conducted and the obligations on prospectors with regard to the marine environment. It also dealt with the consideration by the Secretary-General of notifications to engage in prospecting as well as the submission of annual reports by prospectors.

Part 3 dealt with exploration and set out the details of applications for plans of work and the consideration thereof by the Commission and approval by the Council. It also provided that the total area covered by each application should be no more than 100 blocks, the size of a block to be approximately 10 x 10 kilometres, and that for both polymetallic sulphides and cobalt-rich ferromanganese crusts, exploration should consist of contiguous blocks. The applicant could also elect to contribute a reserved area or offer an equity interest or enter into a joint venture arrangement with the Authority.

Part 4 required that, after a plan of work for exploration had been approved by the Council, it would take the form of a contract between the Authority and the applicant. The contractor would enjoy exclusive rights to explore an area covered by the plan of work, which should be approved for a period of 15 years. Provision was also made for a process of relinquishment of allocated blocks. Provision was further made for training of personnel both of the Authority and developing States by contractors and their sponsoring States, similar to the case with polymetallic nodules, as well as for a periodic review of the implementation of the plan of work. The question of responsibility and liability was also addressed.

Part 5 contained provisions for the protection and preservation of the marine environment and required the Authority, in accordance with the Convention and the Agreement, to establish and keep under review environmental rules, regulations and procedures to ensure effective protection of the marine environment from harmful effects which may arise from activities in the Area. Of particular importance in this regard was the application of the precautionary approach, as well as the establishment of environmental baselines for monitoring and reporting. This was an important part of the draft regulations for the purposes of the current workshop and Mr. Hoffman stated that he would look at these provisions in more detail.

Part 6 dealt with confidentiality provisions to protect proprietary data and information submitted by the contractor to the Authority, except such data and information necessary for the formulation of rules and regulations to protect the marine environment.

Part 7 contained general procedures, including a provision that the LTC issue recommendations of a technical or administrative nature for the guidance of contractors to assist them in the implementation of the Authority's rules, regulations and procedures.

Part 8 provided for the settlement of disputes concerning the interpretation and application of the regulations.

Part 9 required the prospector or contractor to notify the Authority in the event of the discovery of resources in the Area other than polymetallic sulphides and cobalt crusts, which should then be on the subject of new rules and regulations to be adopted by the Authority.

The annexes to the draft regulations provided detailed requirements regarding the notification to engage in prospecting and the application for approval of the plan of work for exploration (annex I) and to obtain a contract (annex II). Annex III dealt with the contract for exploration and annex IV contained the standard clauses to be included in such a contract.

Mr. Hoffman felt that it was noteworthy that, of the 43 regulations, 9 concerned the protection and preservation of the marine environment from activities in the Area.

According to Mr. Hoffman, for the purposes of the draft regulations, prospecting means the search for deposits of polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area, including estimation of their composition, sizes and distribution, and their economic value, without any exclusive rights. This was contained in regulation 1G.

Mr. Hoffman stated that the provisions relevant to the protection of the marine environment during prospecting were contained in regulations 2, 5 and 6 and he went on to discuss them in more detail, as follows.

He informed the participants that regulation 2, paragraph 2, stated that "prospecting shall not be undertaken if substantial evidence indicates the risk of serious harm to the marine environment." The first part of paragraph 3 reads "prospecting shall not be undertaken in an area covered by an approved plan of work or in a reserved area", and "nor may there be prospecting in an area which the Council had disapproved for exploration because of the risk of serious harm to the marine environment."

Mr. Hoffman said that the term "serious harm to the marine environment" meant any effect from activities in the Area which represented a significant adverse change in the marine environment determined according to the rules and regulations adopted by the Authority on the basis of internationally-recognised standards and practices." He said that this definition was taken from regulation 1H of the draft.

The term "marine environment" included the physical, chemical, geological and biological components, conditions and practice which interact and determine the productivity state, condition and quality of the marine ecosystem, etc., and could be found in regulation 1E.

Mr. Hoffman noted that these provisions were in accordance with article 162 of the Convention and that it was very important to ensure that the draft conformed to the provisions of the Convention and the part XI Agreement. These provisions were also identical to those in the regulations for polymetallic nodules, with the exception that they applied to different mineral resources.

Mr. Hoffman suggested that the Authority might wish to clarify the term "substantial risk," as it had neither been defined in the Convention nor in the regulations. In particular, Mr. Hoffman said that an indication as to how to interpret this term in the light of the application of the precautionary principle was needed. An important provision in regard to the protection and preservation of the marine environment during prospecting was contained in regulation 5. Mr. Hoffman said that it was important that each prospector take the necessary measures to prevent and reduce harm to the environment using the best possible practical means at its disposal. In addition, Mr. Hoffman said according to the regulations; each prospector shall minimize or eliminate adverse environmental impacts from prospecting and actual or potential conflicts of interference with existing marine research activities.

According to Mr. Hoffman, prospectors were required to cooperate with the Authority in the establishment and implementation of programmes for monitoring and evaluating the potential impact of exploration and exploitation of polymetallic sulphides and cobalt-rich ferromanganese crusts on the marine environment. The prospector should also immediately notify the Secretary-General, in writing, of any incident arising from prospecting which posed a threat of serious harm to the marine environment. Mr. Hoffman explained that this was a new regulation - it was not in the regulations for polymetallic nodules - proposed by one of the informal working groups established within the LTC to look at the environmental considerations in the draft regulations.

Regulation 6 stipulated that, to prevent and control adverse environmental impact arising from prospecting, prospectors have to take necessary measures and to cooperate with the Authority in the establishment and implementation of programmes to monitor and evaluate the potential impact of exploration and exploitation on the environment. It also addressed conflicts such as interference with existing marine scientific research.

Regulation 6 also dealt with annual reporting. Prospectors should annually submit a report to the Authority on the status of prospecting. As part of that requirement, they would also have to include information on compliance with the relevant future guidelines in that regard.

Mr. Hoffman noted that the informal working group had proposed some tentative environmental guidelines for prospecting, but that the Commission had decided not to include it in the draft regulations, but rather to await the outcome and recommendations of the 2004 workshop.

Mr. Hoffman said that, as part of the notification of intent to engage in prospecting required in regulation 3 and annex I, the potential prospector should provide a written undertaking to comply with those requirements and to make available to the Authority such information and data as may be relevant for the protection and preservation of the marine environment.

Turning to the part of the regulations dealing with exploration and plans of work, Mr. Hoffman said that, for the purposes of the draft regulations, exploration meant searching for deposits of polymetallic sulphides or cobalt-rich ferromanganese crusts in the Area with exclusive rights. It also included the analysis of such deposits, the use and testing of recovery systems and equipment, processing facilities and transportation systems, and the carrying out of studies for the environmental, technical, economic, commercial and other appropriate factors that must be taken into account in exploitation. The provisions that were relevant to the protection of the environment during this phase were contained in regulations 20 and 23.

Mr. Hoffman explained that regulation 20 concerned the data and information to be submitted for approval of the plan of work for exploration. Each applicant should submit for approval the programme for oceanographic and environmental baselines studies in accordance with the regulations, and environmental recommendations that would enable an assessment of the potential environmental impact of the applicant's proposed exploration activities. It also required a preliminary assessment of the possible impact of the proposed exploration activities on the marine environment and a description of proposed measures for the prevention, reduction and control of pollution and other hazards.

Mr. Hoffman was of the view that these provisions were important elements of an environmental protection regime if it were to function as an integral component of the regulatory regime for deep seabed activities. He said that as part of the application for the approval for the plan of work, it was critical that the Authority receives as much data and information as possible. He also said that the purpose of environmental baseline studies would be to establish the initial state of the marine environment before the commencement of activities that have a potential for causing harmful effects on the environment. Such data and information, as well as that relating to preliminary environmental impact assessment, were important tools that would enable the Authority to assess the potential environmental impact of the proposed exploration activities and to make an informed decision as to whether or not to allow the application.

In discussing regulation 23, which dealt with the consideration by the Legal and Technical Commission of an application for approval of a plan of work for exploration, Mr. Hoffman said that, upon receipt of an application for approval, the Secretary-General would notify the members of the Legal and Technical Commission of the application. The Secretary-General would then place it on their agenda for consideration. In paragraph 4, it was stated that the Commission should, in accordance with the requirements set forth in the regulations, determine whether the proposed plan of work for exploitation would provide for effective protection and preservation of the marine environment.

Mr. Hoffman noted that the Commission should not recommend approval of the plan of work for exploration if part or all of the area covered by the proposed plan of work for exploration were included in an area that was not approved for exploration by the Council, such as an area where substantial evidence had indicated a risk of serious harm to the marine environment.

According to Mr. Hoffman, the role of the LTC as the body of the Authority with competence to consider applications for approval of plans of work for exploration, in particular, the protection of the marine environment and to make a recommendation to the Council thereon, had, once again, been derived directly from the Convention. The provision stated that the LTC also had competence to prepare assessments of the environmental implications of activities in the Area and to make recommendations to the Council on the protection of the marine environment, taking into account the views of recognized experts in the field. Mr. Hoffman directed the participants to article 165, paragraphs 2D and 2E, of the Convention, for further information.

Mr. Hoffman then came to the fifth part of his presentation, which he viewed as perhaps the most important for the purposes of the workshop. The draft regulations contained extensive provisions dealing with the protection and preservation of the marine environment, some of which had been referred to in the context of the provisions. Part 5 of the draft regulations contained specific provisions relating to environmental protection and required the Authority to establish and keep under review environmental rules, regulations and procedures to ensure effective protection of the marine environment from harmful effects which may arise from activities in the Area.

For the purposes of discussion at the workshop, Mr. Hoffman felt that this part of the draft regulations and, more specifically, regulations 33 and 34, read together with regulation 41, in part 7, might require close scrutiny. Regulation 33, paragraph 2, read "In order to ensure effective protection for the marine environment from harmful effects which may arise from activities in the Area, the Authority and sponsoring States shall apply the precautionary approach, as reflected in principle 15 of the Rio Declaration, to such activities. The Legal and Technical Commission shall make recommendations to the Council on the implementation of this paragraph."

Paragraph 4 stated that contractors, sponsoring States, and other interested States or entities should 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. In addition, when required by the Authority, such programmes should include proposals for areas to be set aside and used exclusively as impact reference zones and preservation reference zones. According to Mr. Hoffman, the paragraph contained a description of each of these zones.

Mr. Hoffman noted that the 1994 Agreement provided that the adoption of rules, regulations and procedures, incorporating applicable standards for the protection and preservation of the marine environment, were among the matters that the Authority should concentrate on between the entry into force of the Convention and the approval of the first plan of work for exploitation. In accordance with these requirements, the Authority had developed a comprehensive environmental protection regime which had been incorporated into the regulations for polymetallic nodules. Similar provisions were now contained in the draft regulations.

Mr. Hoffman had mentioned that, in regulation 33, paragraph 2, there was an obligation for contractors and sponsoring States to apply a precautionary approach, as reflected in principle 15 of the Rio Declaration, to activities in the Area. In principle 15, it was stated that, in order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there were threats of serious or irreversible damage, lack of full scientific certainty would not be used as a reason for postponing cost-effective measures to prevent environmental degradation.

Mr. Hoffman wished for it to be noted that neither the Convention nor the 1994 Agreement expressly provided for the application of the precautionary principle. The regulations for polymetallic nodules first introduced the precautionary approach as reflected in principle 15, which was exactly the same formulation now contained in regulation 33 (2).

Mr. Hoffman quoted the following statement made by Professor Scovazzi in a paper presented at the special session of the Assembly during the celebration of the tenth anniversary of its establishment, held in May 2004: "The cooperation of the precautionary approach to the delicate issue here in the negotiations for the mining code which was also the polymetallic nodule regulations. On the one hand, some coastal States were concerned that dredging and other exploration activities might cause unpredictable harm to living organisms. On the other, potential miners believe that environmental disturbance prior to the exploitation activities were only minor. The code tried to combine the two approaches by providing a compromise solution."[2]

Mr. Hoffman also mentioned an internal report discussed by the Legal and Technical Commission that had been prepared by Daniel Owen, which included an analysis of the precautionary principle in relation to activities in the Area and, as reflected in the regulations for polymetallic nodules, suggested that the Authority may wish to enter a different approach to the precautionary principle.

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2 "The future of the Authority" *Op Cit*

Mr. Hoffman believed that another important provision was the one contained in regulation 33, part 4, which advised contractors, sponsoring States and other interested States or entities to cooperate with the Authority in establishing and implementing programmes to monitor and evaluate impacts of deep seabed mining on the environment. For that purpose, the Authority may set aside areas to be used as impact reference zones and preservation reference zones. Impact reference zones were defined as areas representative of the environmental characteristics of the region, to be used for assessing the effect of activities on the marine environment. Preservation reference zones were areas in which no mining should occur to ensure the maintenance of representative and stable biota of the seabed, in order to assess any changes in the flora and fauna. These areas were important environmental protection tools that would enable the Authority to monitor and assess the effect of activities in certain designated areas on the marine environment, compared to areas where no mining activities occur.

Mr. Hoffman then discussed regulation 34, which he believed was also very important, as it dealt with environmental baselines and monitoring. It stipulated that the contractor was required to gather environmental baseline data and to establish baselines, taking into account the recommendations by the LTC pursuant to regulation 41. It also required that the contractor cooperate with the Authority and a sponsoring State or States in the establishment and implementation of such monitoring programmes.

According to Mr. Hoffman, paragraph 2 required a contractor to report annually, in writing, on the implementation and results of the monitoring programme referred to in paragraph 1 and to submit data and information, taking into account the recommendations of the Commission. He believed this to be an extremely important regulation and that it constituted the core of what was considered to be an environmental assessment and monitoring regime. It provided the legal framework for the establishment of environment baselines and monitoring programmes, but left it to the LTC and experts in this field to develop detailed guidelines and to implement the regime. Each contractor should be contractually obligated to establish environmental baselines against which to assess the likely effects of activities under the plan of work on the marine environment and monitor and report on such affects. Mr. Hoffman wished to note that the objective of the monitoring and reporting requirements was not to unduly burden the contractors, but rather, as was remarked by the Secretary-General in a statement to the United Nations General Assembly, "To establish a mechanism whereby the Authority and particularly, the Legal and Technical Commission can be provided with the information necessary to carry out its responsibilities under the Convention and the Agreement to ensure the protection of the marine environment from harmful effects arising from activities in the Area."

Mr. Hoffman announced that the functions of the LTC, which he had already referred to in the context of the discussion of some of the other regulations, required the Commission, *inter alia*, to make recommendations to the Council on the protection of the marine environment, taking into account assessments of the environmental implications when formulating rules, regulations and procedure, and to make recommendations to the Council regarding the establishment of monitoring programmes. Under this competency derived from article 165, paragraph 2, of the Convention, regulation 41 enabled the LTC 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. Such recommendations, which were subject to the approval of the Council, were particularly relevant to the establishment of environmental baselines, impact assessment, monitoring and reporting, and had to be adhered to by all contractors.

Mr. Hoffman said that, while not so pertinent to the current workshop, regulations 35, 36 and 38 were relevant to the protection of the marine environment. In regulation 38 (2), it was stated that, with the exception of equipment design data, data and information necessary for the formulation by the Authority of rules, regulations and procedure concerning the protection of the marine environment and safety should not be deemed proprietary.

In conclusion, Mr. Hoffman stated that, as was the case with the regulations for polymetallic nodules, it would be necessary with respect to the draft regulations for polymetallic sulphides and cobalt-rich ferromanganese crusts to consider and, if necessary elaborate on, the above-mentioned environmental requirements. Subsequently, to develop guidelines for the assessment of the possible environmental impacts arising from exploration for these minerals in the Area. This should include procedures to be followed by contractors in the acquisition of baseline data and the establishment of environmental baselines, the monitoring of exploration activities and the reporting of these activities to the Authority. As Mr. Hoffman understood it, the main objective of the workshop was to assist the Authority to develop such environmental guidelines for future exploration for deposits of polymetallic sulphides and cobalt-rich crusts. For that purpose, the Commission believed it was essential to determine what was currently known about the environment in which these minerals occurred, what was required to assess the likely impact that exploration and mining activities would have on the environment and what further measures needed to be taken to ensure the effective protection of the marine environment from harmful effects which may arise from such activities. It was expected that the recommendations of the workshop would be submitted to the LTC to assist it in formulating recommendations for the guidance of contractors, who may wish to engage in exploration for these minerals in the future.

Finally, Mr. Hoffman noted that the LTC had, in the past, benefited greatly from workshops similar to the current one when fulfilling the mandate given to it by the Convention, the Agreement and the regulations. He said that the Commission valued the contributions, expertise and collective wisdom of scientists and their collaboration with the Authority and closed by saying that the Commission looked forward to working with the scientists and receiving the results of the workshop.

SUMMARY OF DISCUSSION

One participant noted that there were others who had done studies similar to those outlined in Mr. Hoffman's presentation, including The International Marine Minerals Society, which had drafted an ethics code for ocean mining, and the Government of Papua New Guinea, which had a green paper which, in Fiji subsequently became a live paper in relation to ocean mining. In reply to a query as to whether the LTC had used these studies in their preparations, Mr. Hoffman said that it had not. The participant expressed the view that those documents should be considered and, in reply, Mr. Hoffman stated that experts had been involved in the preparation of the LTC documents and their involvement had included being allowed to make suggestions and comments on the proposed regulations.

Mr. Hoffman was asked why two types of resources had been put into one set of regulations, given the fact that they were very different in both their economic and environmental settings. He replied that this was something that the LTC had discussed and decided that, as the basis for the regulations for both cobalt-rich ferromanganese crusts and polymetallic sulphides were the regulations for polymetallic nodules, it would not be a problem to put them into one document. However, he said that the Council would have to decide whether this was an acceptable approach, as it was just a suggestion by the LTC. He said that it was important that there be a balance between development and protection.

One attendee requested clarification of the term "substantial risk", as perception could vary between individuals. The response was that this was one of the issues that would hopefully be discussed at the workshop, as the Authority relied on the opinion of experts, and hence, held workshops such as the present one. Mr. Hoffman said that he did not expect to have all the answers by the end of the workshop but hoped that those received would move the LTC in the right direction.

CHAPTER 3 PROPOSED EXPLORATION AND MINING TECHNOLOGIES FOR POLYMETALLIC SULPHIDES

Professor Steven Scott, Professor and Department Chair, Department of Geology, University of Toronto, Ontario, Canada

Introduction

Marine polymetallic iron-copper-zinc-lead-silver-gold sulphides (PMS) deposits are found in back arcs, mid-ocean ridges and seamounts. Back arcs are the most prospective but are almost exclusively in territorial waters. The Area contains most but not all mid-ocean ridge sites and hundreds of prospective seamounts. Basically, PMS deposits can form anywhere in the oceans where there is the right combination of a heat source within a few kilometres of the seafloor to drive the circulation of seawater through the rocks; sufficient permeability to allow deep penetration of the fluid enabling chemical exchanges with a large volume of hot rock; fractures to focus selectively the discharge of large volumes of metalliferous hydrothermal fluid onto the seafloor; and an efficient means of precipitating metallic sulphides from the discharging hydrothermal fluid (Figure 1). If the deposits are to be preserved from oxidation and erosion, there must be a sufficient flux of volcanic or sedimentary material to bury them.

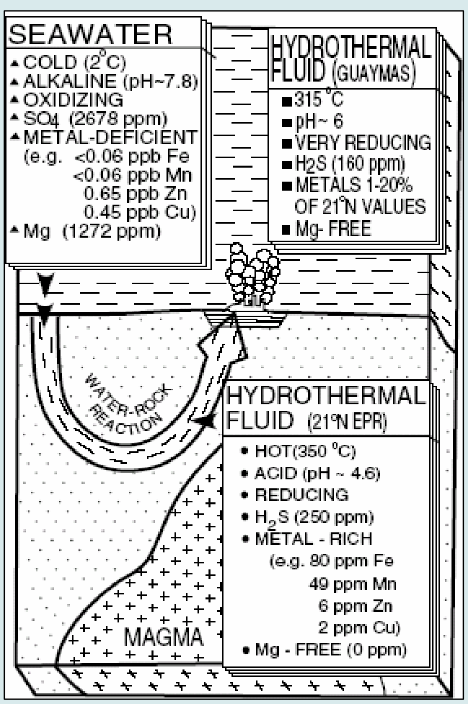

Figure 1: Schematic vertical section of a hydrothermal circulation system (modified from Scott, 1997).

Discharge of the hot (typically 200-350ºC) metalliferous fluid onto the seafloor produces the familiar "black smoker" chimneys (Figure 2).

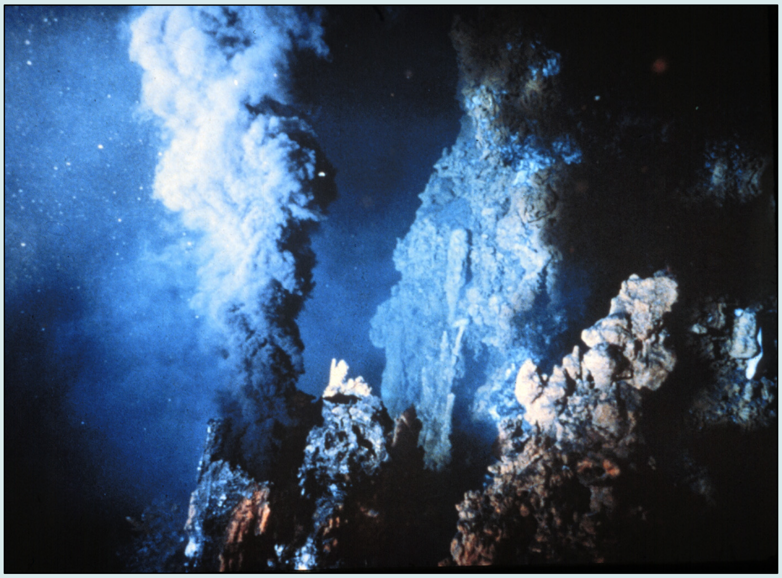

Figure 2: "Black smoker" from 13ºN East Pacific Rise (courtesy of Roger Hekinian). Mineral laden hydrothermal fluid is exiting from a sulphide-sulphate chimney at 350ºC and a velocity of 1-2 m/sec. It looks like a dirty industrial smoke stack. The "smoke" is fine predominantly iron sulphide precipitates that colour the rapidly rising plume black. Accumulations of sulphides surround the smoker.

The hot vent fluid escaping from the chimneys mixes turbulently with the cold (typically 2ºC) ambient seawater and produces a rapidly rising, billowing plume. The mixing produces fine precipitates of predominantly iron sulphide imparting a black colour. The plume rises a few hundred metres to a level of neutral buoyancy in the seawater column where it spreads laterally for hundreds of metres according to the vagaries of local currents. The growing chimneys can reach tens of metres in height. Eventually, being gravitationally unstable and probably aided by earthquakes, the chimneys collapse and their debris produces a mound of PMS (Figure 3).

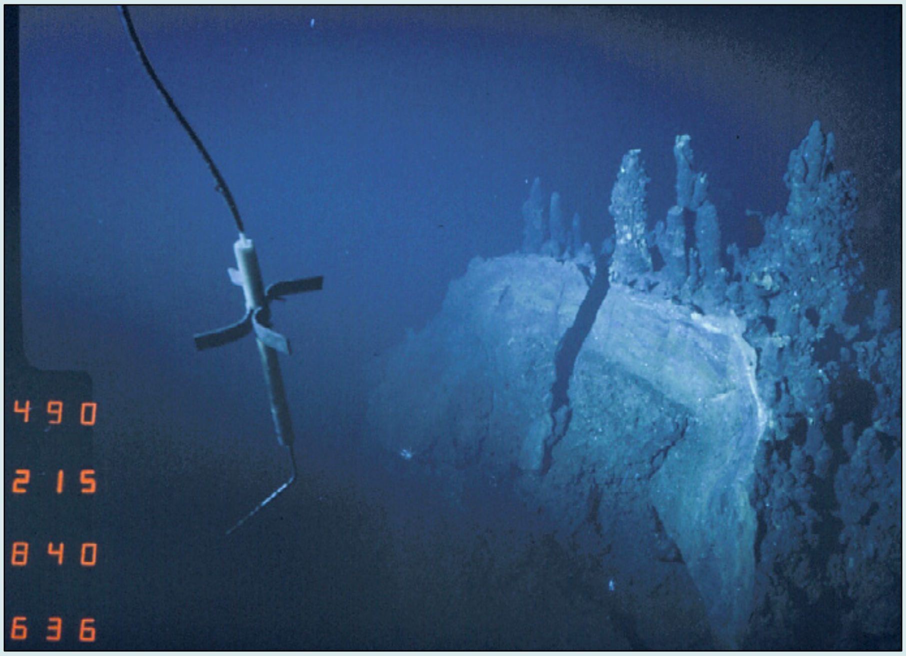

Figure 3: Small sulphide mound at 13ºN EPR split in half by a fault (courtesy Roger Hekinian).

When a mound becomes large enough, hydrothermal fluid circulating within it recrystallizes the minerals and either enriches or depletes the contained metals. The modern seafloor PMS are good analogs for ancient base and precious metal PMS that are mined on land.

Exploration Methodologies

Scientific research cruises have been responsible for the discoveries to date of seafloor polymetallic sulphides and all deposits are prominently exposed and visible on the seafloor. Seemingly, everywhere we looked, we found deposits.

Exploration has largely relied on methods such as detailed bathymetric mapping, high resolution sidescan sonar, tracing hydrothermal particulate plumes to their source using transmissometers, dredging, seafloor photography and submersible traverses. All except dredging are passive and inflict no serious environmental damage.

Close inspection of high-resolution swath bathymetric and sonar maps can usually reveal the most prospective sites in the axial valley, and sometimes off-axis, of mid-ocean ridges and in the calderas of young, volcanically active seamounts. Tops of magma chambers have been imaged seismically beneath individual segments of ridge axes by recognition of a "bright spot" in multi-channel reflection records. A good example is from 8°50'N to 13°30'N (most notably at 9°30'N) along the East Pacific Rise (Detrick et al., 1987). Here, the interpreted top of the magma chamber can be traced, with some uncertainty, for tens of kilometres along the ridge axis at depths of 1.2 to 2.4 kilometres beneath the seafloor. Harding et al. (1989) have interpreted the seismic data from 13°N East Pacific Rise to represent a shallow small axial magma at the pinnacle of a much larger zone of hot and only partially molten basalt. Such pinnacles probably occur intermittently along a ridge segment and would be loci for hydrothermal venting, as is presently occurring at 13°N. The closest approach of the axial magma chambers tends to be near the middle of an individual seafloor-spreading segment. Here, because of excessive volcanism and thermal expansion of the volcanic rocks, the spreading segment tends to display a minimum in its bathymetry. Because of the high heat flow at the bathymetric minimum, this is where hydrothermal vents tend to be found as was pointed out a long time ago by Ballard and Francheteau (1982). This principle guided the discovery of the large PMS deposits at Explorer Ridge off Canada's west coast, for example (Scott et al., 1990).

The most successful method for locating actively forming PMS deposits is to find their particulate plume and tracing it to its source. The typical method is by using a transmissometer that measures absorption of light by the particles within the water column. Figure 4 depicts a transmissometer lowering through a particulate plume, in this case a double plume.

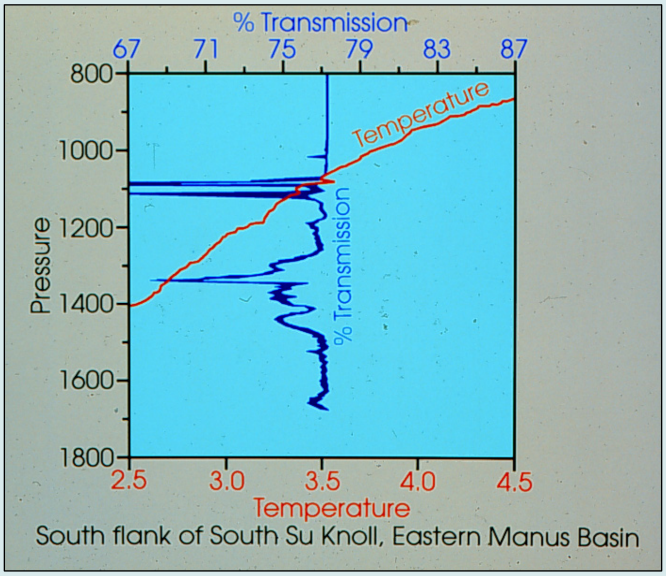

Figure 4: Typical light transmission (inversely proportional to the concentration of particles) and temperature profile through a hydrothermal plume. Pressure is equivalent to depth in metres. Note the temperature anomaly in the uppermost plume indicating close proximity to the source.

Typically, an instrument package measuring conductivity (salinity), temperature (in millidegrees), depth and light absorption with water samplers aboard is towed at slow speed behind a ship and is lowered and raised within the expected depth interval for a particulate plume. Data are recorded in real-time and water is sampled within any plume that is encountered. Particles are filtered from this water onboard ship and later analyzed for pathfinder elements such as copper, zinc and barium that might indicate a PMS-forming hydrothermal system. Suspected sources of plumes (Figure 5) are dredged, photographed or inspected by submersible.

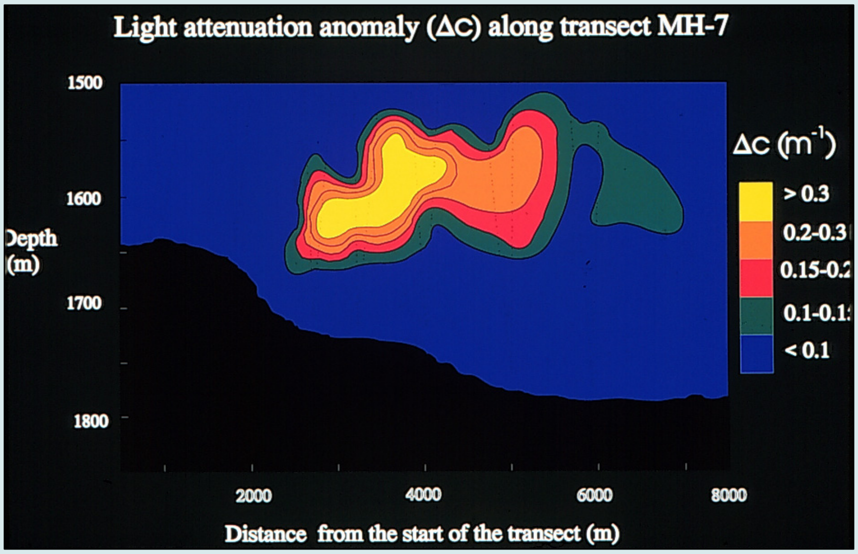

Figure 5: Transmissometer (light attenuation) anomaly caused by a hydrothermal particulate plume along a ridge. The source of the plume is obvious.

The technology to discover older deposits that are now hidden under sediments is lacking at present. These older PMS deposits must surely be present, as they are in the ancient geological record, because the relentless slow movement of tectonic plates would have carried them away from their place of origin at a ridge axis. Constant marine sedimentation of a few centimetres or decimetres per thousand years results in the thickness of sediment in the ocean basins increasing steadily with distance away from volcanic centres so that the oldest sulphides deposits would be the most deeply buried. Various electrical methods such as self-potential and electromagnetics (resistivity, conductivity), magnetics and perhaps gravity hold some promise as geophysical prospecting tools for these buried deposits. Electro-magnetic, both airborne and ground, and self-potential surveys are standard exploration methods for PMS on land. At sea, these methods require dragging electrodes on the seafloor. This is viable in heavily sedimented terrains without destroying the electrodes but not in rugged volcanic terrains. Magnetic surveys rely on the weakening of the remnant magnetic field in the vicinity of a PMS deposit caused by the destruction of magnetic iron oxide (magnetite) in the underlying basalts by the ascending metal-laden hydrothermal fluid when the deposit was being formed. Such haloes have been mapped at the TAG site in the Mid-Atlantic Ridge (Tivey et al., 1993, 1996). The Japanese Kuroko PMS deposits have similar haloes around them, on land where magnetite has been converted to pyrite (iron sulphide). High-resolution gravity surveys that would pick out the higher density of PMS, compared to the host volcanic rocks or sediments, are painfully slow and are thus not likely to be effective.

Once a sizeable mound has been located, coring of close-spaced and accurately positioned drill holes is required in order to determine with a considerable degree of confidence the deposit's content of metals and its tonnage. As is the case for land deposits, such information is critical for determining whether mining is economically viable and for determining the best methods for metallurgical processing. Near total core recovery is required in holes that may be only a few metres apart. Coring can be accomplished either using a bottom-deployed autonomous drill (Figure 6) or a drill operated from a remotely operated vehicle (ROV).

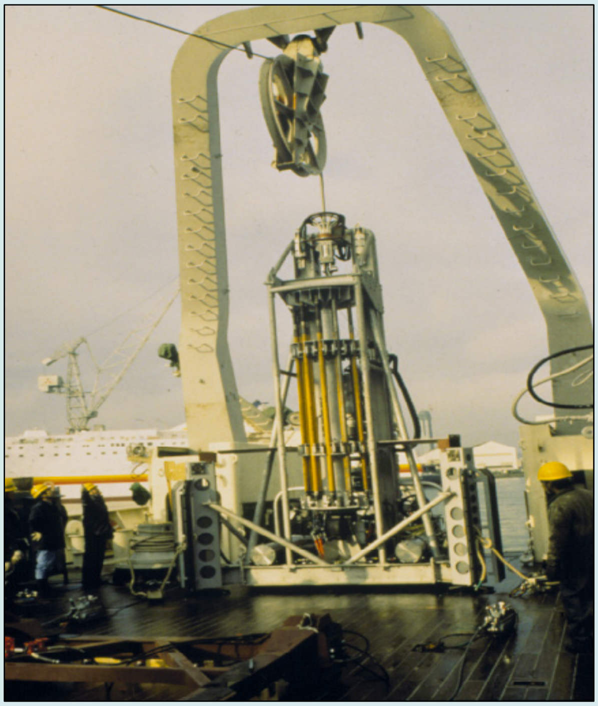

Figure 6: Australian PROD drill for coring tens of metres into the seafloor. The drill assembly is deployed from the ship to the seafloor. Final positioning is achieved by means of thrusters. A new core barrel is rotated into position as the preceding one is filled.

Prospects for Ocean mining of Polymetallic Sulphide

I believe that the largest of the known seafloor PMS deposits could be an economic resource in its own right and have made this case in several articles over the past 17 years (Scott, 1987, 1992, 1995, 2001). Other researchers who have made similar cases are Binns and Decker (1998), Herzig (1999), and Dekker and McConachy (2000). There are seafloor deposits of apparent size and grade which, if they were on land, would definitely be targets for further evaluation. Most of these are in territorial waters. An example is the Atlantis II Deep in the Red Sea, which contains 94 million metric tons (Mustafa et al., 1984) and rivals the size of analogous "giant" ore bodies on land although at 0.5% copper, 2% zinc, 39 g/t silver and 0.5 g/t gold it is of lower grade than mineable land deposits. Most marine deposits are very much smaller, but have an apparent high unit value that makes them attractive (e.g., Sunrise in the Izu-Bonin arc, 9 million metric tons with 44 analyses averaging 5.6% copper, 20.3% zinc, 2.1% lead, 1,197 g/t silver, 18.4 g/t Au; Iizasa et al., 1999). The only known PMS in the Area of sufficient size to be of potential interest is TAG on the Mid-Atlantic Ridge (Rona et al., 1993; Humphries et al., 1995). The main mound (there are several additional "Mir" mounds nearby) and underlying subsurface stockwork mineralization totals about 3.9 million metric tons but, like the Atlantis II Deep, it too appears to have a low metal content.

The American Geological Institute defines an "ore" as a "naturally-occurring material from which a mineral or minerals <u>can be extracted at a profit</u>". The only seafloor deposit for which the grade is known is the Atlantis II Deep, which was cored on closely spaced centres. The Ocean Drilling Program (ODP) has drilled some deposits, such as Middle Valley on the Juan de Fuca Ridge and TAG on the Mid-Atlantic Ridge, but the information is not sufficient for an economic evaluation. For all other deposits, there are only random samples taken typically from chimneys or the surface of a mound. Such samples may not be representative of the interior of a mound as was found, for example, when ODP cored the TAG mound. The metal content in most of the cores was disappointingly lower than in samples taken by a submersible from the surface of the mound. The *in situ* value of the metals in the Sunrise deposit could be about $US 770 per metric ton at 3 September 2004 metal prices, based on the average analysis of 44 samples. Extrapolating this over the 9 million tons that has been estimated for Sunrise gives a potential in situ value of $6.93 billion, but these 44 samples are probably not representative of the entire deposit. Regardless, the average metal content ("grade") of a deposit is only one of the many factors that determine whether an accumulation of sulphides is an "ore". Whether or not Sunrise is an "ore" will depend on not only its true grade and tonnage, but also on how much of it is recoverable, mining costs, metallurgical recoveries and costs, and a host of other considerations.

That these deposits are under several hundred to a few thousand metres of water is of no particular concern. Deep marine technology is up to the challenge. The oil industry moved offshore in the mid-twentieth century, despite there being no particular need because of huge resources remaining onshore and the technology for marine recovery of oil not having been perfected. Today, about one third of the world's oil production is from the offshore and is growing. Oil exploration is extending to >3000 metres water depth, about the maximum depth at which potentially viable mineral deposits have been found.

The conventional mining industry is not likely to attempt ocean recovery of polymetallic sulphides. Disillusioned by the $650 million failure in the 1970s and 1980s of polymetallic nodule mining (which interestingly is again in vogue in Korea, Japan and China), it is reluctant to try again. Systematic surveys in the search for mineable deposits were made by government-subsidized organizations in the 1990s. A German company, Preussag, on behalf of the Red Sea Commission, systematically evaluated the Atlantis II Deep and conducted trial mining of the metalliferous mud using a modified drill ship. Full mining was deemed to be uneconomic. The Metal Mining Agency of Japan and associates carried out extensive seafloor surveys in the exclusive economic zones of some Pacific island nations and elsewhere in the Area during the 1990s but did not pursue mining. Currently, two small entrepreneurial companies based in Australia, Nautilus Minerals and Neptune Resources, are betting that there is a market for marine polymetallic sulphides. Nautilus has an exploration permit from the Government of Papua New Guinea covering 2,458 square kilometres of the Manus Basin. Neptune has an exploration permit from the Government of New Zealand covering about 8,000 square kilometres of the Havre Trough north of North Island. A United States of America company, Deep Sea Minerals, with their partner, Phelps Dodge, had several applications for exploration permits pending, but the company has been unable to raise the necessary capital and appears to be defunct.

Economics of Polymetallic Sulphides Ocean Mining

Large-scale ocean mining for PMS will have high start-up costs, perhaps as much as $300 million (all values are in current US dollars) phased in over several years through stages of exploration, evaluation and mining. This cost must be seen in the light of discovery and development costs for new land mines that are typically of the same order of magnitude. For example, approximately $200 million is required to find and develop a PMS deposit in the Abitibi region of western central Quebec (G. Riverin, Inmet Mining Corporation, personal communication, 2001) and Noranda is spending about $200 million to develop 30 million metric tons of ore between 2,000 and 3,000 metres depth in its Kidd Creek mine. The anticipated start-up cost for ocean mining of PMS is favourable, relative to the $650 million spent on the failed attempt to mine manganese nodules.

Ocean mining may have some economic advantages over conventional land mining. Unlike ocean mines, land mines require expensive permanent installations such as shafts ($3,500-7,500 per metre) and tunnels ($1,200-2,300 per metre), if an underground mine; extensive excavations if an open pit mine; power lines; roads; and, in some cases, even a town site, all of which are left behind when an ore body on land is exhausted. Recent costs for developing a mine site from a green field condition have ranged from $130 million for a modest size gold mine with a ramp in Nevada to $240 million for a large base metal mine with a 900-metre deep shaft in the

Abitibi region of Quebec (W. Shaever, Dynatec Corporation, personal communication, 2001). Since these costs have to be amortized over the life of a mine, small deposits have to be near existing infrastructure to be economic. A deposit that is remote from areas of existing infrastructure has to be very large and/or very rich to be mined. Ocean mining, on the other hand, would involve an entirely reusable infrastructure. An ocean mining platform would be moved easily from site to site, so that much smaller deposits could be recovered than is possible on land. Shipping of ore or concentrates to smelters would be largely or entirely by sea and therefore at a relatively low cost.

Companies, such as Deep Sea Minerals, have looked at the economics of a large-scale ocean mining programme for PMS. Calculations of costs must include the development and building of specialized equipment, ship time, days lost to weather (particularly acute in higher latitudes of the Area), processing of raw material, shipping, marketing, etc. The details of these analyses are proprietary but, as a first approach, it is clear that a large-scale effort will require a high daily recovery of PMS from the seafloor, as it does for land mining, perhaps 10 to 15,000 tons per day depending on the contained value of the ore. A 10-million-ton deposit would take 700 to 1,000 days to recover, or about 3.5 to 5 years, with 200 operating days per year. The valuable minerals, being copper, zinc, lead and silver sulphides, plus gold, typically constitute about 20 % of a deposit, or 2 million tons, in this example. About 8 million tons would be waste and would remain on the seafloor.

Possible Mining Technologies

Although the technology does not exist for recovering seafloor PMS, some schemes that were developed by Namco for recovering diamonds in the relatively shallow offshore of Namibia and by the Lockheed Corporation for recovering manganese nodules in deep ocean basins, such as robotic bottom-mining vehicles and lift systems (Welling, 1981), can probably be adapted to sulphide mining. Small operations, such as that envisaged by Nautilus Minerals, might use television-guided grabs. The Namco vehicle, which has suffered serious mechanical failures, is a bottom crawler with a suction head. The sulphides are at shallower water depth than nodules and are relatively soft so should be easy to break up. The subsurface stockwork mineralization is typically of lower metal content than the massive sulphides and is harder, so would require excavation. These are unlikely to be recovered unless by solution mining or bio-leaching. For the softer surface deposits, Scott (1992) envisaged a robotic continuous miner (Figure 7) with a cutting blade, much as is used in coal and potash mines, that would extract, grind and preconcentrate the desired minerals, lift these to surface in a slurry (air lift or pump) and leave the waste minerals on the seafloor.

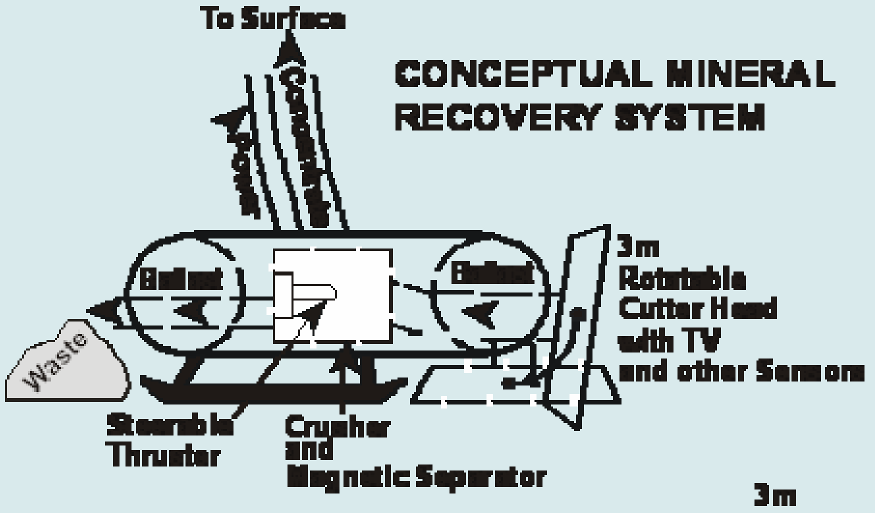

Figure 7: Conceptual continuous mining machine with magnetic separation of waste (Scott, 1992).

A television-guided grab, such as that envisaged by Nautilus for lifting chimneys to surface in Manus Basin, can never be more than a small operation. Grabs are deployed at 60 metres per minute and the water depth at the main PACMANUS site is about 1,800 metres. Assuming, optimistically, half an hour for manoeuvring to find a chimney, each grab would take 90 minutes. Only 36 tons can be recovered per day if the capacity of the grab is 2 tons, 180 tons with a 10-ton capacity, etc.

Leaving the 80% rejects on the seafloor, instead of lifting them to surface and concentrating them there, would reduce recovery costs substantially. Alton et al., (1989) demonstrated in bench tests that a strong magnet is as effective as conventional froth flotation in separating sulphides from their gangue minerals. Scaling up to a mining operation would require a superconducting magnet operating at seafloor temperatures of around 2°C. Such a magnet does not yet exist, but operating temperatures for superconductors are rising with continuing research in this field. Magnetic separation has the advantage over flotation of being simple to operate and not being affected by ship's roll. It also has attractive environmental advantages because, as shown by research on manganese nodule recovery (Thiel et al., 1991), dumping the waste from surface would spread fine particles over a wide area. In addition, magnetic separation would not use noxious chemicals, such as Na_2S, that would be a source of pollution if flotation were done at sea and the waste returned to the seafloor. A disadvantage of magnetic processing, unlike flotation, is that copper cannot be separated from zinc. This would have to be done onshore.

Simply piping the 350°C metalliferous solutions from the hydrothermal vents to surface and precipitating the metals is not realistic. The metalliferous solutions are very corrosive, rich in hydrogen sulphide and contain only a few parts per million (ppm) of the desired metals.

Furthermore, the hot fluids would boil vigorously as the confining pressure is released on the ascent to surface causing minerals to precipitate, most of which such as anhydrite, pyrite or pyrrhotite and silica, are undesirable and would clog the pipe in similar manner to the build-up of scale in geothermal fields.

Environmental Considerations

Small-scale mining tests of manganese nodules, also applicable to sulphide mining in sedimented areas, suggest that the resuspension of the fine sediment may do ecological damage well outside of the mining area as the sediment plume is carried across the seafloor by currents and settles out on the gills of filter feeding animals (Thiel et al., 1991). It is expected, however, that the affected areas would eventually be repopulated, as the species concerned are widespread. Most of the known sulphide deposits within the Area occur in volcanic areas (spreading ridges and seamounts) that are relatively free of sediment, other than that produced by the disaggregation of the sulphides during mining and recovery. However, this local suspension of particles in the water column probably has no lasting effect on the biota. For example, as pointed out by Binns and Dekker (1998), the Manus site occurs in an area of very strong and frequent earthquakes that must stir up the bottom and there are dense clouds of mineral precipitates in the water column resulting from the hydrothermal venting. Neither of these has affected the masses of healthy organisms. By preconcentrating the metals on the seafloor, rather than at surface, not only would operating costs be reduced, but there would be no pollution of the water column caused by dumping the waste back to the seafloor. Organisms densely populate areas of active hydrothermal venting, but such areas would be avoided during mining in any case because of the deleterious effects of the hot corrosive vent fluid on the mining equipment.

There may actually be some environmental advantages of marine mining over land mining for polymetallic sulphides. Three of the greatest adverse environmental consequences of land mining are acid mine waters produced by exposing iron sulphide to the atmosphere, large surface excavations of open pit mines, and unsightly piles of waste rock from surface or underground excavations. The alkaline seawater quickly neutralizes acids produced by submarine weathering. The surficial sulphide deposits are mounds sitting on the seafloor, so there would be no excavations and no waste rock piles. The separation process would produce waste, amounting to some 80% of the mined material, but this could be done on the seafloor and the residue would simply reoccupy the space from which it was originally extracted.

Mining may release into the water column toxic elements such as mercury, arsenic, antimony and selenium, which occur in very low concentrations in the sulphides. The hydrothermal venting process is releasing these continuously and the amount added by mining is expected to be relatively minimal. Besides, as pointed out by Binns and Dekker (1998), the resident animals not only survive, but actually thrive in this naturally-occurring, toxic environment. Undoubtedly, there would be some loss of habitat of some marine organisms, at least temporarily, and biologists would be called upon to determine whether mining would result in permanent loss of some species (i.e., environmental impact assessments and monitoring). All of these anticipated consequences of ocean mining could be tested by well-designed experiments (Scott 1992), such as that illustrated in Figure 8, that would monitor the dispersal of particulates as simulated mining is carried out.

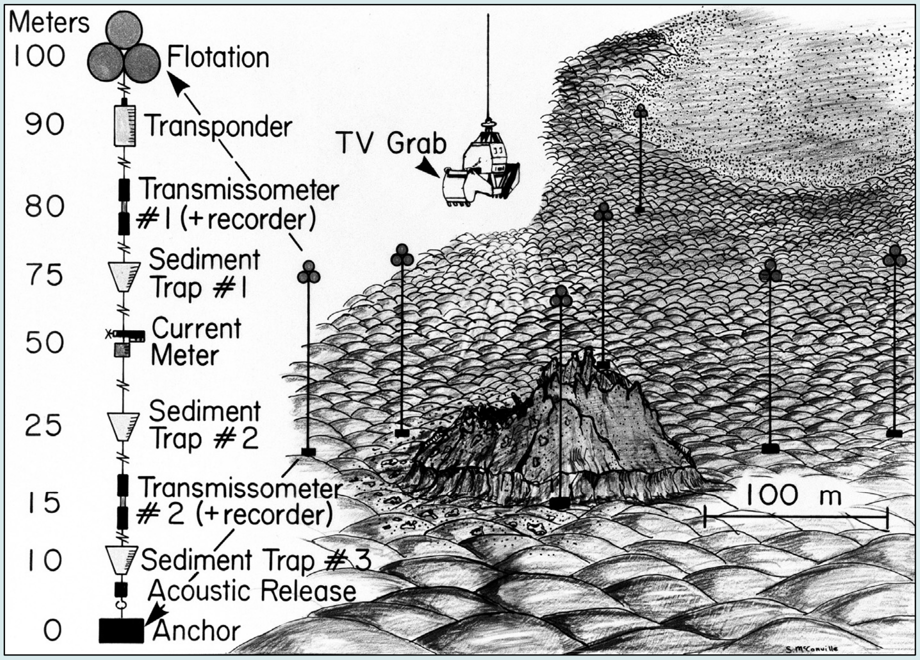

Figure 8: Simulated mining experiment for observing environmental consequences.

In the experiment, the vicinity of an isolated, hydrothermally- inactive, small sulphides mound would be instrumented with moorings to monitor the fluxes and dispersal patterns of particulates before, during and after the disaggregation of the mound by a television-guided grab. The concentration of particulates would be measured with optical transmissometers and some of the particles would be recovered in traps to give further information on their concentrations, composition and size. Dispersal patterns outside of the instrumented area could then be predicted from the measured size and density of the trapped particles and knowledge of the bottom currents.

The NEPTUNE fibre-optic cabled observatory network scheduled for launching on the Juan de Fuca Plate in 2007 would provide an ideal test bed for the mining experiment. One node of the network will be in the Endeavour Segment of the Juan de Fuca Ridge in Canadian territorial waters, where isolated mounds of the type needed for this experiment are known.

Instruments could be monitored and responses of fauna to the simulated mining continuously observed from anywhere that has access to the Internet. The experiment would provide essential information for assessment of environment consequences of ocean mining within the Area. Potential contractors should share the cost of the experiment. The work should be coordinated by the International Seabed Authority, in order to assure compliance with regulations and to avoid unnecessary duplication of effort.

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SUMMARY OF PRESENTATION

Professor Scott said that he would speak about exploration and mining technologies, which had been around for a very short time because, although exploration technologies were fairly well-developed - at least in terms of scientific exploration - mining technologies for polymetallic sulphides were non-existent; they were just conceptual ideas. He said that he would explain how the deposits were formed, include some quantitative information which might be relevant to biologists, and then discuss the reasons why there might be interest in ocean mining of these deposits. He said that, as the chief scientist of an ocean mining company called Deep Sea Minerals, he had some experience and insider knowledge on ocean mining. Unfortunately, he could not share it because it was proprietary information, but he could say that decision making on whether to mine were not just made by collecting a few samples and analysing them; a great deal of data, an assessment of risks and further discussions were involved before a decision was made. Professor Scott said that he was a geologist and would propose an experiment that might be done to quantitatively measure what the environmental effects might be. It was a very simple experiment, but it was going to cost money and the question was, who was going to pay for it.

According to Professor Scott, polymetallic sulphide deposits contained iron, which has no commercial value. The commercially viable metals were copper, zinc, sometimes lead, silver and gold. The deposits in the Area were very lead-poor; but lead was not one of the more valuable metals. They were a product of hydrothermal processes and resulted in the production of chimneys.

Professor Scott explained that the process started with cold oxidising sea water at 2^0C that contained hardly any metals. Because of circulation, it reacted with hot rock and heating to approximately 350^0C to become an acidic, reducing liquid containing a lot of hydrogen sulphide. However, the important thing from the point of view of mining was the production of a fluid relatively metal-rich in comparison to what it contained initially. Black smokers were produced during the process and spread laterally resulting in an accumulation of sulphides on the seafloor. It was thought that this happened because the chimneys grew and tended to be tall and narrow, making them unstable. They fell over, producing a pile of chimneys through which hot water could continue to pass. This may add more metals to the deposit and change its characteristics.

Professor Scott noted that Endeavour Segment was the world's first deep-water park and a marine-protected area; it had been established in 2003 in about 2,300 metres of water off the coast of Canada. He noted further that when Yellow Stone National Park was first established in the United States, no one could get there and so some considered that there was no need to create it. However, at the time of the workshop, it was no longer considered remote and the same might be said for the oceans in the future; hence the need to set up the Endeavour Segment.

The Professor said that, in the ancient geological record, there were many examples of sulphide deposits called volcanogenic massive sulphide deposits. In the younger deposits, fossil chimneys could be seen on their sides on the tops of the mounds. Underneath those deposits was a stockwork zone and hydrothermal alteration pipe. Professor Scott presented this because he intended to make some comparisons with the ancient geologic record and the modern seafloor in terms of metal contents and sizes, etc. There were approximately 200 of these occurrences on the seafloor, of which only a few were large. They occurred primarily along the middle of the spreading ridges, but also in back-arc environments, primarily the western Pacific, although there were some in the Mediterranean. Back arcs formed behind volcanic islands, such as Papua New Guinea, North of Fiji and Tonga, and were richer than the mid-ocean ridge deposits. Professor Scott believed that these were the deposits that were going to be primarily targeted by the companies involved in ocean mining, mainly because they would not have to deal with the United Nations if they were going to mine them. Papua New Guinea and Tonga were countries that were enlightened when it came to ocean mining. Another reason was that the water would be very sheltered behind islands and it would thus be easy to work there.

Professor Scott informed the participants that one of the mining companies concerned with polymetallic sulphides deposits was called Nautilus and had two exploration licences in the Manus Basin. They were seriously entertaining the possibility of mining the polymetallic sulphides in a few areas. Another company, Neptune Resources, had an exploration licence in Havre Trough from the Government of New Zealand for about 8,000 square kilometres. Professor Scott noted that there were known hydrothermal sites on seamounts in this area but it was not known how large or rich they were. It was noted that these companies had permits but not the money. The company that Professor Scott was involved in had been rejected four times by investors, not because they didn't think the idea was good, but because the financers could not assess the risk involved.

Professor Scott said that these deposits were being considered because industry needed large copper reserves. To that end the second largest copper producer in the world was a partner in Deep Sea Minerals. They did not invest money but they did invest the expertise they had regarding metallurgical processes. Another partner of Deep Sea Minerals was Halliburton. It had assured Deep Sea Minerals that the planned mining procedure was feasible because much bigger problems were dealt with by the oil industry. Since the oil industry drilled holes in the seafloor at 3,000 metres water depth, Professor Scott did not believe there would be any technological problems for what was planned for sulphide mining in shallower water.

Professor Scott mentioned that the reusable infrastructure had financial implications. In land mining, it was necessary to build roads, power lines, maybe power plants, sometimes a small town, shafts and underground workings, which were huge costs that must be amortised over the life of the mining because it would be impossible to move them and their cost must be recovered. However, with ocean mining, the mining apparatus could be easily moved to the next site, so there would not be any permanent installations on the seafloor. There was a big cost advantage to ocean mining because of the reusable infrastructure.

Professor Scott noted that ocean mining was governed by two questions, namely, "can we?" and "should we?" He said that, while "should we" was an environmental and philosophical question, "can we" was a technology question. One of the concepts that had been recognized was that sulphide deposits occurred along the axes of spreading ridges although sometimes they are found off the axes. In addition, since deposits occurred anywhere that there was heat and fracturing for sea water to circulate through, sulphide deposits could also be found on seamounts. Not all seamounts would contain actively-forming sulphide deposits but seamounts often hosted deposits formed in the past.

Therefore, said Professor Scott, there were two areas of interest, the spreading ridges, of which he believed everyone was aware, including where they were located around the world, and seamounts about which less was known. There were maps produced from satellite gravity measurements that showed where the bigger seamounts were, but there were a lot of small ones that would not show up on that kind of survey.

Professor Scott stated that there was a strong structural control on where sulphide deposits were found. There were faults that dip in towards the ridge axis and they were very permeable so fluids could rise up through them very easily. Actively-forming deposits were found not just on the ridge axis, but also on the "stair-like steps" going up the axis. Caldera was a seamount on a volcano on the Juan de Fuca ridge. Caldera was 21 kilometres long and 7 kilometres wide and contained several hydrothermal vent fields, some of which were covered by lava flow. It was very clear to Professor Scott that it was the faults that formed this Caldera controlling area where the fluids were coming up. Professor Scott noted that the same process occurred in the Havre Trough where Neptune was interested. He stated that this would not surprise an ore deposit geologist, as it had also been seen in the ancient geology record. Basic geology was one way to find the deposits. Deposits had been found at Explorer Ridge off the west coast of Canada in 1984 using the principle of Bathymetric Minimum. Within two days of surveying, the Bathymetric Minimum sulphide deposits had been found.

Professor Scott said that one of the best ways to find active deposits was by observing the hydrothermal plume, which reached a point of mutual buoyancy and spread out over hundreds of metres, if not a few kilometres, using sophisticated equipment called CTD-X, which comprised a set of instruments that can measure, among other things, temperature, pressure (to determine depth), connectivity and concentration of particulate matter in the water, called the plume. It would be lowered through the water column and the hydrothermal plume would be indicated by an increase in temperature and particulate matter. The temperature change is not seen if sampling is too far away from the source, but a sharp temperature spike indicated a nearby source. The equipment could be towed behind a ship to survey an area. Professor Scott had performed surveys this way and found sulphide deposits forming.

The bigger problem was how to find older deposits that were covered with sediment. Professor Scott explained that as the seafloor spread there was a constant raining down of sediment. It was a slow process, but after a while the deposit would be buried. The only way Professor Scott thought that it would be possible to find these deposits was by means of geophysics. There were various electrical methods whereby electrodes could be put on the seafloor to detect a signal that would indicate a change in the electrical connectivity that could be caused by sulphides. Magnetics could also be used to find them. According to Professor Scott, the problem with magnetic techniques was that there was a lot of noise in the data. If a deposit were known then it could be seen on a magnetic trace, but finding new deposits using this method was not easy. Gravity had been suggested as another technique for doing this but a gravity survey required an incredibly stable platform. It would also be a very slow process, which Professor Scott did not think viable, as it would not be cost-effective. He felt that the best option was using electrical methods, and noted that there were people working on this, not necessarily for the purpose of finding sulphide deposits, but the research they were doing was directly applicable to exploring for sulphides in sedimented areas. Professor Scott emphasized sedimented areas because if this method were tried in very rough, volcanic terrain the equipment would be damaged.

Professor Scott said that in land mining companies drilled holes through deposits every few metres or every ten metres, for two reasons: they wanted to know the exact dimensions and tonnage of the deposit and they wanted to know the grade, which was the average metal content of the entire deposit and would not be obtained from random samples. Complete cores through the deposit would be required in order to know what was there. A drill would be required to sample a deposit found at sea and three candidates for this were shown. Closely-spaced holes would be needed just as on land in order to assess the economic value of the deposit.

Professor Scott reminded the participants that the term “ore” was too loosely used, even by geologists. It was defined as a naturally-occurring material from which one or more minerals of economic value could be extracted at a reasonable profit. It was possible to have something that looked like a rich deposit, but when all of the costs were considered, including exploration, recovery, processing, shipping, sales, and dividends for investors, it may not be profitable enough to make it viable. Therefore, it was questionable whether some of the deposits discussed were ores.

Professor Scott said that there was a candidate in the Middle Valley site on the Juan de Fuca ridge. It had been drilled by the Ocean Development Programme. There were two major mounds, 100 metres by 150 metres and 103 metres thick, but it only contained 1.2 % zinc, 45% copper, a low silver value and practically no gold. There was a richer deposit, called OPD mound, which was a lot smaller. This had a very high copper value, but Professor Scott did not think that it would be mined as an ore, first, because he thought that the grade was too low and second, because it would be very difficult to excavate below the seafloor, especially in a sedimented area. A technique called solution mining might work in the future, but current mining technology would not recover it economically. Thus, although it was a large deposit, Middle Valley was not an ore.

Professor Scott said that the Sunrise Deposit in Myojiri Knoll, Isu-Bonin Arc might be an ore. It was about 300 kilometres south of Tokyo – close to Japan - in a volcanic complex in a back arc. Some 44 samples had been taken randomly from the surface. Professor Scott noted that averages of random samples could be very misleading but they had revealed 5.6% copper, 20% zinc, 2% lead, 40 ounces of silver per ton, and the gold was about 2/3 an ounce per ton, which was huge for this kind of kinds of deposit; typically, gold occurred at 1-5 g per ton. It was estimated that there was about 9 million tons of minerals at the site. This deposit might have been an ore, but the danger was that these samples had been taken just from the surface and might not be indicative of the deposit as a whole.

Professor Scott gave examples of real ores, such as that found in Cyprus, which was of a type likely to be found on the seafloor, and the Kuroko deposits in Japan, which were from a different kind of volcanic extreme. The grade of the Cyprus deposit was 4 % copper, .5 % zinc, 3-9 g silver and gold. The danger was that some analyses were samples taken from chimneys and from the surface but the metal content within a body may be a lot less, which was why deposits needed to be drilled before they could be classed as an ore.

According to Professor Scott, the Atlantis II Deep was the only deposit that had been drilled, in the sense that a mining company would accept the numbers, and it was 94 million tons. This was equivalent to some of the biggest ore deposits on land. However, 0.5 % copper, 2 % zinc, 39 g per ton silver and 0.5 % g per ton gold was not economical. The Middle Valley site was large, but it did not have a high enough metal content. The TAG deposit was also large, but the ODP drilling showed that it was not metal rich inside. The Sunrise deposit was 9 million tons. At a particular site in Quebec, deposits ranged in size from 771 tons to 54 million tons; so some of those on the seafloor are certainly commensurate with that. On a world-wide basis, the data collected by a mining company for more than 800 deposits that they looked at indicated the median value was only 1.25 million tons. Deposits on the seafloor were in this range. The Atlantis II deposits in the Red Sea were huge compared to that.

The advantages of ocean mining included the movable mining operation and lower shipping costs. The cheapest way to transport something was on a ship, across water. Mining underwater meant moving the material ashore was cheaper. Professor Scott also thought that it was less polluting than land mining.

Professor Scott then discussed costs. Deep Sea Minerals thought that more than US$ 300 million was needed to do a full mining venture (i.e. to develop all the equipment, to do all the surveys, to pay all the pertinent costs). There were four serious investors.

Professor Scott said that mining was a high-risk business. To find and develop a mine on land, just for comparison, cost about US$ 300 million. Exploration cost was maybe about 20 % of the total cost. To find a copper/zinc/silver/gold deposit in the Abitibi, just 300 kilometres north of Montreal, was costing US$ 200 million to develop 30 million tons of ore between the 2,000 and 3,000-metre level. This equated to US$ 27 per ton but a lot of money ws being spent to develop that ore. Costs of land mining were high, and Professor Scott felt that ocean mining needed to be put into that perspective.

According to Professor Scott an important question was how the deposit would be mined. He noted that a lot of the US$ 650 million spent in the manganese nodule projects was used in trying to develop some sort of technology for recovery of the nodules. He felt that the technique that would have been the most successful was Conrad Mullings' idea of using a robotic vehicle that had blades that pick up the nodules off the surface. The other was similar to that used by the Namssol Diamond Mine being used off the coast of Namibia. The process involved a vehicle crawling along the bottom, sucking up the gravel and then piping the diamonds up to the surface. Although this was in less than a hundred metres water depth, the concepts were very similar for the deep sea. Professor Scott felt that the diamond mining concept was the one that would be used for mining but it would need to be on a larger scale.

Professor Scott stated that a company had proposed using a TV-guided grab for collecting chimneys and bringing them to the surface. The grab had a capacity of about two tons and would be deployed at 60 metres a minute. Assuming a water depth of about 1,800 metres it would take a minimum of 90 minutes for one return trip with a chimney, meaning that it would be possible to recover 36 tons a day doing this. If the *in situ* value was US$ 1,000 a ton, then that equated to US$ 36,000 a day. A typical land mine with grades containing probably two times the copper and silver, and five times the gold in it was only worth approximately US$ 321. The Sunrise deposit had been analysed with 44 samples and, assuming that the grades supplied were correct, had a net value of US$ 770 per ton. Professor Scott's point was that it was necessary to think big if mining was going to be economic.

Deep Sea Minerals worked out the economics of mining and, according to Professor Scott, taking into account metal content and the size of the deposits it decided on a daily production of 10,000 to 15,000 tons. That was about the same as in a difficult volcanogenic massive sulphide mine on land. This took into consideration all the costs, including down days due to mechanical problems, etc. Professor Scott said that a TAG size deposit of ten million tons, would take 700 to 1,000 days to mine. On the assumption that actual mining would occur 200 days a year, Professor Scott said that this equated to approximately three and a half to five years to recover the 10 million tons.

Professor Scott noted that 80 per cent of the recovered ore was not of interest. This part of the ore contained, among other materials, silica, calcium sulphate and iron sulphide. He said the 20 per cent of the ore of interest was the part that contained copper, zinc, lead, silver and gold. He also said that if possible, miners would not lift the unwanted 80 per cent to the surface because of unrecoverable costs. Professor Scott said that some people had suggested piping the hydrothermal fluid to the surface and recovering the metals that way. He stated that this was not possible because the fluid would be very hot - approximately 350 degrees. He informed participants that using this method, as soon as the fluid got to about 1,500 to 1,800 metres below the sea surface, the reduced pressure would cause it to boil and explode. He said that many of the metals in the fluid would precipitate at that point and clog or destroy the pipe. He also said that the hydrogen sulphide that would be part of the fluid would be a hazard, as it was poisonous. In addition, Professor Scott noted that this method required pumping a lot of fluid to the sea surface to recover the 20 per cent of interest. Professor Scott further noted that the method would not be economically viable. He suggested that it would be better to let the natural process occur and then recover what nature had accumulated.

Professor Scott presented his concept of a mining system. The proposed mining system would comprise a robotic vehicle with a rotating and steerable cutter head, and a magnetic separator to concentrate the valuable components. Professor Scott said that a magnet could remove much of the unwanted material, so that the recovered material consisted of only the 20 per cent of interest, thereby improving the economics of the venture. He pointed out that this is a method used in coal mining.

Professor Scott said that the standard way of separating metals in ores was by froth flotation. He said, however, that froth flotation did not work very well for seafloor ores. In this regard, he pointed out that a lot of calcium oxide was required to make froth flotation work, and since sodium sulphide is also required for this process, he envisioned a big risk of pollution at sea from the waste returned to the ocean. He identified the rolling action of the vessel as another drawback to froth flotation. He suggested therefore that magnetics seemed to be the best option. He noted that with a magnet it was possible to get a zinc and copper concentrate by removing the unwanted iron sulphide and sulphate. He said that recovery rates would be about the same as the rates obtained from froth flotation and that the method would be cost-effective. His opinion was that a magnet would be simple to operate, efficient for recovery, and that the rolling of the ship would not be a problem. He also said that it would be relatively inexpensive and non-polluting and no bulk chemicals would be involved.

According to Professor Scott, the two most significant environmental problems from land-based mining are acid drainage (rainfall on iron sulphides making sulphuric acid) and the degraded environment following mine closure. He pointed out that neither problem would occur from ocean mining for polymetallic sulphides, because no excavation is required or acid produced. He said however, that there were other problems, as mining would degrade the seabed and the tailings needed to be disposed of. He said that with his proposed system, the gangue material would stay on the seafloor. In relation to degradation, he said that the toxic elements released if processing occurred at the seabed would degrade bottom waters, as the animals would be in a toxic environment. Since the animals around active vents thrive in a toxic environment, Professor Scott said that he did not see that toxic elements produced by mining would have a big effect on the animal community. According to Professor Scott, mining would not occur at the hydrothermally-active areas, as it would destroy the equipment, so it would be the inactive deposits that would be mined, although there were organisms associated with these that would need to be investigated.

Professor Scott proposed an experiment to test the effect of mining, as follows: a small mound should be taken, instruments put around it and the mound and the surrounding environment should be monitored during simulated mining. It would be necessary to monitor the behaviour of any animals that were present, as well as the chemistry, physics and oceanography around the site. It should be a real-time experiment and the best way to do this would be to use a cable fibre-optic observatory such as that which was about to be put in the water on the Juan de Fuca plate of the West Coast of North America. The idea of this was to have fibre-optic and power cables out to approximately 27 node stations on the seafloor into which experiments/instruments could be connected. One of the nodes was the Endeavour Segment on the Juan de Fuca ridge. Instead of going out in a submersible to see what was going on, scientists could sit at their desk and watch, in real time, what was happening. Professor Scott said that this type of experiment had to be done and suggested that the International Seabed Authority take the lead.

In conclusion, Professor Scott said that there were deposits on the seafloor which were arguably easy to explain, but that mining had yet to begin.

SUMMARY OF DISCUSSIONS

One participant pointed out that there was a myth that polymetallic sulphides grew as fast as they could be mined and wanted that myth dispelled.

Another participant wanted clarification on the vertical distribution of mineable deposits since sulphides deposits below the surface were under investigation. In response, Professor Scott said that if there was just a small amount of sediment on top of the deposit mining might be feasible, but if there were metres of sediment covering the deposit, it would not be financially feasible. Professor Scott felt that the LTC should consider the extraction of deposits from below the seafloor, as it may be feasible in the future. However, Professor Scott pointed out that that this activity could have serious environmental implications because of the plumes that would be produced.

One delegate asked whether the budget proposed by Professor Scott included money for an environmental impact assessment and if so, how much. Professor Scott replied that an amount similar to that required for land-based deposits is under consideration.

It was suggested that there should be experiments to monitor the effect of mining for polymetallic sulphides along similar lines to those carried out for polymetallic nodule mining, but instead of setting up expensive experiments, the Authority could collaborate with one of the companies investigating the mining of polymetallic sulphides, such as Nautilus or Neptune.

CHAPTER 4 PROPOSED EXPLORATION AND MINING TECHNOLOGIES FOR COBALT-RICH FERROMANGANESE CRUSTS DEPOSITS

Dr. Rahul Sharma, Scientist, National Institute of Oceanography,
Dona Paula, Goa, India

Introduction

The occurrence of cobalt-rich ferromanganese crusts on seamounts has generated considerable interest as a potential source of cobalt and nickel in addition to manganese and iron (Cronan, 2000). Studies have reported on their occurrence around different islands in the Pacific Ocean (Hein et al, 1988; 1992), French Polynesia (Pichocki and Hoffert, 1987); Izu-Ogasawara Arc (Usui and Nishimura, 1992; Usui and Terashima, 1997), as well as on islands (Exon et al., 2002) and seamounts (Iyer and Sharma, 1990; Banakar et al., 2004) in the Indian Ocean.

Whereas the availability of cobalt- rich ferromanganese crusts at shallower depths and within the exclusive economic zones of some of the island countries are favourable considerations for their mining, their occurrence as coatings on hard substrates, such as rock outcrops, offers a technological challenge for mining them, when compared with mining loosely scattered deep-sea polymetallic nodules. A few studies have evaluated the influence of the distribution characteristics of cobalt crusts on mining (Keating, 1989; Yamazaki et al., 1994; Yamazaki and Sharma, 1998, 2000).

The present paper evaluates the mining scenario for cobalt-rich ferromanganese crusts and associated environmental considerations.

Resource Assessment

Although many studies have evaluated their metal contents and geological setting, a study under the Hawaii Department of Planning and Economic Development Marine (1987) addressed several aspects of the deposits, such as resource estimates, mining criteria, techno-economic feasibility and infrastructure requirements.[1]

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[1] *Mining Development scenario for cobalt-rich manganese crusts in the Exclusive Economic Zones of the Hawaiian Archipelago and Johnston Island*. Hawaii. Department of Planning and Economic Development. US Department of the Interior. Minerals Management Service,. January 1987

According to the study, the Exclusive Economic Zones of the Hawaiian Archipelago and Johnston Island contain 350 x 10^6 tonnes of crusts. The crusts are estimated to contain 2.5 x 10^6 tonnes of cobalt, 1.6 x 10^6 tonnes of nickel, 80 x 10^6 tonnes of manganese, and 58 x 10^6 tonnes of iron; based on average metal grades of 0.73% Co, 0.45% Ni, 23% Mn and 16.5% Fe. The study estimates the mean crust coverage as 40%, with crust thickness ranging from 0.5-2.5 cm in different areas, and with an average density of 1.95g/cm^3 (wet) or 1.34 g/cm^3 (dry).

The other assumptions in the study were as follows:

1. That technology similar to that used for surface continuous coal mining would be applicable. With this technology, a thin layer of crust would be "stripped" from the seamount using rotary cutting tools. This is an unconventional method for ocean dredging, and increases the level of engineering sophistication required for the design of the crusts miner.

2. With allowances for bad weather, system maintenance, and other lost productive time, a conservative estimate of 206 operational days per year (d/yr) is the basis for sizing the miner.

3. It would be optimum to convey only pure crust material to the surface ship, but this is highly unlike first generation systems. The miner will have to cut, gather, crush, and may partially separate the ore before it is lifted to the surface. Estimates of the fraction of substrate material that would be recovered with the ore, range from 25 to 50% of the recovered ore. This would be equivalent to 20 to 42% of the ore, after shipboard dewatering. The base-case scenario assumes the recovery of 25% substrate with the ore.

4. There will be disturbances near the miner, which will interfere with any benthic population that may be present.

The association between cobalt-rich ferromanganese oxide crusts and Pacific seamounts was taken into account in assessing the mineral resource potential of the oceans (Mero, 1965). Cronan (1977) also reported that the highest concentrations of cobalt occur in crusts and nodules recovered from seamounts in the Central Pacific Basin, including seamount provinces in the Hawaiian exclusive economic zone. Other studies by the U.S. Geological Survey (USGS) (Hein et al., 1985) and the German MIDPAC-81 expedition found that cobalt concentrations in ferromanganese crusts and nodules in the Mid-Pacific Mountain and Line Islands area increase consistently from less than 0.4% at water depths greater than 400 m to 1.1% on the tops and slopes of seamounts in water depths less than 2,500 m (Halbach and Manheim, 1984). It was also discovered that, whereas nodule coverage was variable in deep-sea areas (4,700-5,000 m), crusts and nodules were present on the slopes and tops of seamounts at water depths between 1,000 and 3,000 metres. Such occurrences and metal contents underline the potential of crusts to be mined as viable deposits of cobalt and other strategic metals.

Crusts Characteristics for Mining

The characteristics of crusts deposits that would influence mining (Table 1) include factors that are critical for resource estimation, such as the aerial extent (from few sq. m. to few sq. km.), crust thickness (0.1 to 10 cm), composition (Co+Ni+Mn+Fe = 30-40%) and average density (1.5-2.0 g/cm^3). The other factors that would determine the mineability of a deposit would include their depth of occurrence (500-5000 m), location (whether on axis or off axis), the slopes on which they occur (0-40^0) and microtopographic undulations (1-100 cm).

TABLE 1: CRUSTS CHARACTERISTICS FOR MINING

1.	Area	: Sq. m- Sq. Km.
2.	Depth	: 500-5000 m
3.	Crust thickness	: 0.1-10 cm
4.	Crust coverage	: 1-100 %
5.	Composition	: Co+Ni+Fe+Mn = 30-40%
6.	Location	: On axis / Off axis
7.	Slope/gradient	: 0-40 degrees
8.	Microtopography	: 1-100 cm
9.	Av. Density	: 1.5-2.0 gm/cm^3
10.	Environmental setting	: Physical, chemical, biological

Table 2 contains the values of these factors for the Hawaiian Archipelago and Johnston Island (Hawaiian Marine Mining Plan, 1987). The study reveals that the depth versus axis position relationships of Co, Ni, Mn, and Fe of both on- and off-axis sample locations showed minor variation for similar depth ranges. Further, metal concentrations of Co, Ni, and Mn increase with increases in latitude, whereas Fe decreases. Similarly, crusts on sediments have higher concentrations of Al and Cu, and lower concentrations of Mn, Co, and Zn than those on basalt substrates.

TABLE 2: RELATION OF METALS WITH LOCATION, DEPTH, LATITUDE AND SUBSTRATES

Location/metal	Co	Ni	Mn	Fe	Total
On-axis	0.71	0.37	20.3	15.2	36.5
Off-axis	0.63	0.33	18.6	18.7	38.0
Overall avg.	0.68	0.36	19.7	16.4	36.4

Metals v/s	Depth	Latitude	Substrate
Co, Mn, Ni	decrease	increase	high in basalts
Fe	increase	decrease	
Al, Cu			high in sediments

***Source*:** Hawaiian marine mining plan, 1987.

A detailed study on the occurrence of these deposits (Yamazaki and Sharma, 2000) has classified zones depending on seabed slopes, such as nodule dominant ($0-3^0$), sediment dominant ($3-7^0$), transitional zone ($7-15^0$), wherein crusts and nodules coexist at most locations, and crust dominant ($>15^0$) (table 3). Such a classification of the distribution of crust deposits on the seafloor provides critical inputs for designing the mining device and helps to optimize the capability of the mining system. Besides manoeuvrability on different seabed slopes, a mining device would also be required to negotiate the microtopographic undulations associated with different types of crusts surfaces, such as steplike (100-200 cm), large outcrops (50-100 cm), cobble type (20-50 cm), nodular (10-20 cm), nodules (1-10 cm) and sediments (0-5 cm). It has also been suggested that if buried crusts were also considered for mining, the resource potential could increase manyfold, hence improving the overall efficiency of the mining system (Yamazaki et al., 1994).

TABLE 3: DISTRIBUTION OF CRUST, NODULES AND SEDIMENTS WITH RESPECT TO SEABED SLOPES

Zone	Slope	Nodule coverage	Crust coverage	Sediment coverage
Nodule dominant	0-30	~70%	5-30%	2—30%
Sediment dominated	3-70	<20%	<30%	>60%
Transition	7-150	20-50%	10-60%	10-90%
Crust dominant	>150	<10%	80-100%	nil

Source: Yamazaki and Sharma, 2000.

Besides these, there are several geotechnical properties of crusts that would play a role in mining these deposits (Table 4). These include their density, hardness, porosity, void ratio, compressive and tensile strength (Hawaiian Marine Mining Plan, 1987). These properties would determine the collection mechanism of the mining device.

TABLE 4: SUMMARY OF CRUSTS PROPERTIES FOR MINING

Density (apparent)	1.31	[g/cm³]
Density (Solid)	2.81	[g/cm³]
Shore hardness	18	
Porosity	55	%
Void ration	1.15	
Compressive strength	8.36	[MPa]
Tensile strength	1.75	[Mpa]
Youngs modulus (static)	1.06	[Gpa]
Acoustic pulse Velocity (approximate)	2.26	[km/s]
Cohesive strength	2.9	[Mpa]
Angle of internal friction	42	[degrees]

***Source*:** Hawaiian marine mining plan, 1987.

Exploration Techniques

Various parameters need to be evaluated for resource estimation, as well as designing a suitable mining device, for which different techniques would have to be employed (Table 5). These include the occurrence of rock outcrops, sediment cover, slope distributions, geomorphology, and current patterns. All of these physical properties of the environment affect crust formation. Bottom photographs are useful in determining local distribution of crusts, sediments, and rock outcrops; depth sounding is useful for determining slopes; coring can be useful in interpreting sub-bottom structure, including buried crusts. Similarly, deployment of metres and conductivity, temperature, depth (CTD) sensors and collection of water samples at discrete depths would provide critical environment data for the operation of the mining system, as well as environmental impact prediction and assessment. Whereas, the weather recorder helps to track the meteorological conditions for optimizing mining duration during the year, the position-fixing instruments provide the basic location and navigation data.

TABLE 5: EXPLORATION TECHNIQUES

1.	Sounding	:	Bathymetry
2.	Seismic	:	Subbottom
3.	Dredging	:	Collection of exposed deposits
4.	Coring	:	Sampling of buried deposits
5.	Photography	:	Distribution characteristics
6.	Current meters	:	Water mass circulation
7.	CTD+water	:	Water column characteristics
8.	Weather recorder	:	Meteorological data
9.	GPS+acoustic	:	Navigation and position fixing

Mining Design Considerations

A possible scenario for ferromanganese cobalt-rich crusts mining would consist of a bottom crawling (tracked) vehicle attached to the surface mining vessel by means of a hydraulic pipe lift system and an electrical umbilical. The miner would have articulated cutting devices, which would allow the crusts to be fragmented while minimizing the amount of substrate collected. In addition, behind the cutter heads of the miner, there would be a series of parallel pick-up devices consisting either of articulated hydraulic suction heads or a mechanical scraper/rake device. Approximately 95% of the fragmented material would be picked up and processed through a gravity separator prior to lifting (Hawaiian Marine Mining Plan, 1987). Alternatively, the mining device would have self-propelled autonomous vehicles to collect or scrape the crusts and nodules, and offload them to a mid-water buffer, from where they could either be pumped through pipes or transported by the autonomous underwater vehicles (AUVs) to the surface platform. Bottom navigation would be done by means of acoustic transponders and accurate ship's position would be obtained by long baseline acoustic navigation.

The mining system would comprise two sets of components:

A. <u>Subsurface components</u>

1. Crust surface cutting mechanism
2. Hydraulic/mechanical pick-up devices
3. Ore lifting mechanism (absent if ROV)
4. Obstacle avoidance mechanism
5. Navigation device
6. Propulsion devices
7. Rescue/recovery devices

B. Surface components

1. Surface platform
2. Umbilical link (absent if ROV)
3. Transport vessels
4. Power generation
5. Processing plant

Estimation of Area to be Mined and Impacted

A number of individual crusts deposits will be required to sustain a commercial mining operation over a 15 to 20-year period. It is estimated that a 600 sq. km area would sustain one commercial mining operation for 15 to 20 years (Hawaiian Marine Mining Plan, 1987), which at the mining rate of 1 million tonnes per year, should comprise deposits with a total tonnage ranging from 15 to 20 million tonnes of recoverable ore. The Hawaiian study suggested that to estimate the tonnage of in-place crust resources in an area, the appropriate tonnage number should be multiplied by the permissive area. For example, for a seamount having an average crust thickness of 2.5 cm, 40 % coverage, and a permissive area of 425 $km^{2,}$ the total in-place crust resource would be:

Crust resource = 19,500 X 425 = 8,775,000 t (wet)

In addition, to determine the in-place metal content, multiply the appropriate number by a dry-density conversion factor (.6872), the permissive area and the decimal metal content.

However, considering the crust to substrate ratio of 70:30, 30% of the ore would be waste that (Table 6) would preferably be discharged at sea. In addition, considering an average 36% of metal content (Co+Ni+Mn+Fe) for 1 million tonnes of crust mined per year, the remaining 64% of gangue would be deposited on land after processing of the ore. These discharges should be made at carefully selected water depths or at locations on land, and monitored for possible repercussions on the ecosystem.

TABLE 6: MINING CONSIDERATIONS AND ESTIMATES

1.	Mining rate	:	1 million tonnes /year
2.	Duration	:	15-20 years
3.	Size of deposit(s)	:	15-20 million tonnes
4.	Days / year	:	~250 (20-21 days/month)
5.	Crust thickness	:	2.5 cm
6.	Wet density	:	1.95 g/ cm3
7.	Avg. coverage	:	40%
8.	Mined area	:	~600 sq km / year

Crust to substrate ratio = 70:30,

Thirty per cent of material will be discharged at sea

If total metal= 36%, gangue = 64 %,

Therefore, out of 1 million. Tonnes of ore mined per year, 640,000 tonnes will be waste on land.

Factors Influencing Environmental Impact

Certain factors that would play a critical role in minimizing environmental impact are as follows:

1. The depth of disturbance will have to be controlled in order to maximize efficiency and minimize impacts.

2. The dilution of the ore should be kept a minimum by reducing the substrate collected with it. The amount of substrate fragmented depends on substrate hardness, its cohesion to crust, thickness of crust, morphology of crust/ substrate interface and roughness of the crust surfaces (Hawaiian Marine Mining Plan, 1987).

3. The solids generated from re-suspension of associated sediment or discharge of substrate should be released as close to the seafloor as possible.

The potential environmental hazards from the operation of a mining device could be due to following reasons:

1. Quantity of substrate mined – thickness, cohesion
2. Suspended solids – due to miner movement, crusher, lift mechanism and surface discharge
3. Sub-system losses – chains, cutting tools

4. Oil spills, leakages – mining/transport vessels
5. Ballast water discharge
6. At -sea processing waste – chemicals, debris, water
7. Human waste – garbage (plastic, metal, etc)

The likely geographic areas that would be affected due to different mining activities range from locations on land to the deepest parts of the oceans (Table 7).

TABLE 7: LIKELY GEOGRAPHIC AREAS THAT MAY BE AFFECTED FROM MINING ACTIVITIES

	Likely areas to be affected			
Activity	Seafloor	Water column	Surface	Land
1. Cutting	#			
2. Collection	#			
3. Crushing	#			
4. Separation	#			
5. Lifting	#	#		
6. Washing	#	#	#	
7. Transport	?	#	#	#
8. Processing	?	?	?	#
9. Tailing discharge	?	?	?	?

Creation of a Multi-Disciplinary Database and its Applications:

The first step would be to draw up an exhaustive list of parameters (e.g., see Table 8) for evaluation for:

1. Impact assessment
2. Mine site identification
3. Mining design and operation

As a second step, categorize all the parameters as follows:

1. Critical – those most critical for data collection
2. Essential - those not critical, but necessary
3. Routine – those which may complement the above parameters.

The third step would be to store all data in standard formats that can be retrieved easily through queries given in an interactive program. Data on different parameters could be stored in distinct tables linked to the program for easy retrieval. The user must be able to retrieve this data in various combinations of locations, phases of the program, parameters, and so on, and these should be stored in specially created files that could be used for further data processing.

TABLE 8 ENVIRONMENTAL PARAMETERS FOR CRUSTS MINING

A. Geology

- Seafloor features
- Sediment /crust thickness
- Topography
- Crust abundance
- Sediment sizes
- Porewater / sediment chemistry
- Geotechnical props.
- Stratigraphy

B. Biology

- Surface productivity
- Microbiology
- Biochemistry
- Meiofauna
- Macrofauna
- Megafauna

C. Physics

- Currents
- Temperature
- Conductivity
- Meteorology

D. Chemistry

- Metals
- Nutrients
- DOC
- POC

A few screens of such an interactive database comprising > 100,000 data for environmental impact assessment of deep-sea nodule mining in the Central Indian Ocean Basin, are shown in Figures 1 to 3 (Sharma and Sankar, 2004).

The applications of such a database would be:

1. To create ecological models for impact assessment and prediction
2. To use the data in mining device design and operation.

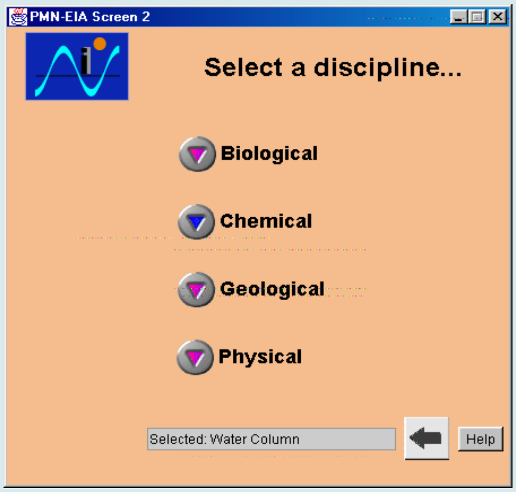

Figure 1 Sample screens for creation of environmental database.

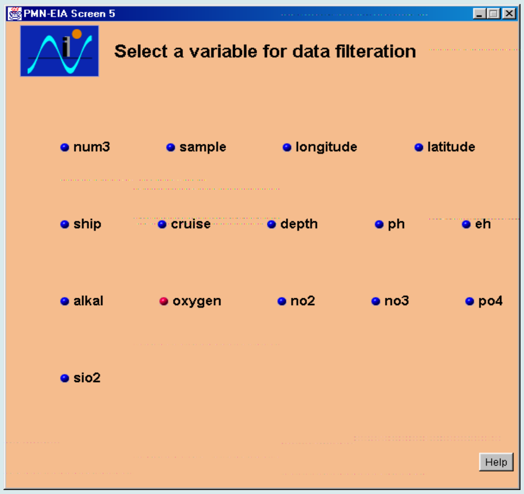

Figure 2 Sample screens for creation of environmental database.

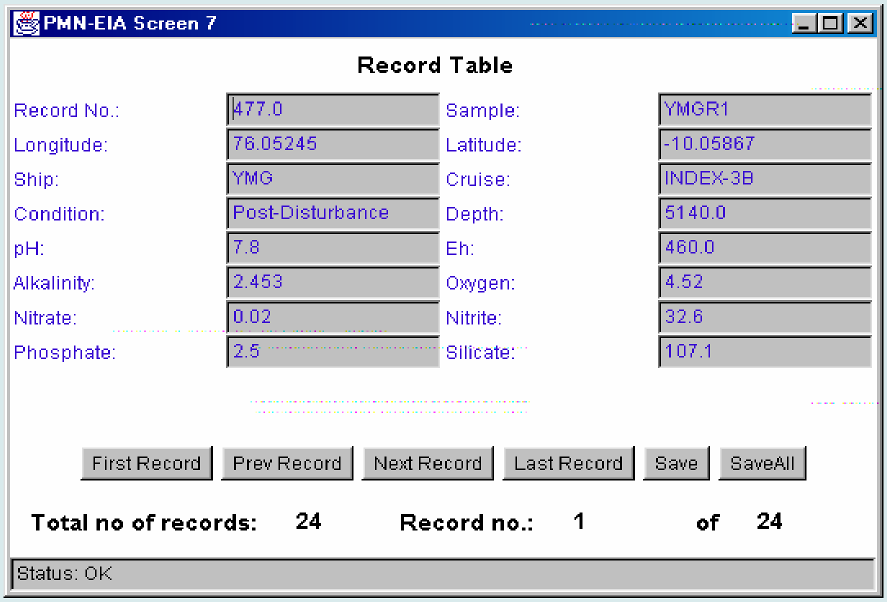

Figure 3 Sample screen for output of environmental database.

Opportunities for Cooperation

The lack of sufficient knowledge of the potential environmental impacts due to crusts mining offers several opportunities for cooperation among interested parties in the following ways:

- Initiating a comprehensive study of all oceans
- Sharing expertise in exploration
- Cooperation in exploring by sharing resources
- Sharing expertise through training manpower
- Preparing policies and guidelines for:

  - Collection, analysis and resource evaluation
  - Environmental impact assessment of offshore mining

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SUMMARY OF PRESENTATION

Dr. Sharma stated that, as was already known, cobalt-rich ferromanganese crusts were mineral deposits that occurred on seamount slopes and were rich in cobalt and other metals. He said that these deposits are potential sources for those metals. He also said that ferromanganese cobalt-rich crusts deposits occur in the exclusive economic zones of some countries and were therefore closer to the coast and at shallower depths than ferromanganese nodule deposits. Dr .Sharma said that interest in ferromanganese nodules reached its peak about 30 years ago. Currently, he said that ferromanganese cobalt-rich crusts deposits appear to be enjoying a similar interest. Of the two types of resources, Dr. Sharma predicted that ferromanganese cobalt-rich crusts would be mined before ferromanganese nodules because of the shallower depth and distance that mining systems would have to cover to exploit the former deposits.

According to Dr. Sharma, when contemplating crusts mining, the initial evaluation is with the geology and economics of profitably mining the deposits, followed by environmental considerations. Dr. Sharma informed participants that ferromanganese cobalt-rich crusts deposits covered areas ranging from a few square metres to a few square kilometres, and this varied according to location. He also informed participants that these deposits occurred at depths between 500 and 5,000 metres but that cobalt-rich crusts were normally shallower than 2,500 metres. He further noted that crusts enriched with other metals did occur even at 5,000 metres depths. He described the thickness of the oxide layers, which was known to vary between a millimetre and about ten centimetres, as most interesting

Dr. Sharma said that crusts did not necessarily cover 100% of the seafloor in the area in which they were found. They were associated with sediments and could be associated with nodules. He noted that associated nodules may or may not be interesting from a mining perspective. Dr. Sharma thought that for a crust deposit to be of any economic importance, it should have a total composition of metal between 30-40%. Cobalt was of interest because it was needed. Manganese and iron found in the crusts were not currently of interest, although they may become relevant if reserves of these metals were completely exhausted.

According to Dr. Sharma, an important consideration was the location of crusts on a seamount or geological structure. He said that ferromanganese crusts deposits occurred on the slopes and summits of seamounts, and not in flat areas such as the abyssal plains where ferromanganese nodules occurred. He said that it would be comparatively easier to mine nodules because the topography of these deposits was smooth. He also said that nodules tended to lie loose on the seafloor and were recoverable using a device similar to a vacuum cleaner. With crusts mining, Dr. Sharma stated that it was not just the slope of the seafloor that was important, but also the microtopography. He also said that density and metal composition would be important in resource estimation.

In Dr. Sharma's opinion, the report by the Hawaii Department of Planning and Economic Development Marine (1987) was the most detailed study on a possible mining scenario for cobalt-rich ferromanganese crusts deposits. He said that the report contained chapters covering all relevant activities ranging from the search for deposits, to the extraction and processing of recovered ore. Dr. Sharma said that the study estimates that, in the Hawaiian Archipelago and Johnston Island's exclusive economic zones, there were suitable crusts deposits with a mean coverage of 40%, resulting in a resource of about 350 million tons with varying compositions and quantities of different metals.

Dr. Sharma noted that in the report, the location of crusts deposits was of interest since their metal values varied depending on where they were located He pointed out that a major concern in the report was metal grade and crust thickness for calculating ore. He also pointed out that cobalt concentrations decreased with depth, so since it was of interest, mining would occur at comparatively low depths. He said that once a deposit had been located the microtopography, that is, the very fine-scale undulations on the crusts, became a consideration. Dr. Sharma informed participants that undulations in the crusts could be as great as 1 metre, at which point, the mining device would encounter crusts associated with nodules and sediments. Dr. Sharma said that in his opinion, the mining device should also be capable of picking up loose materials, such as nodules, if there was an interest in mining them, as this would add to the efficiency of the mining system.

Dr. Sharma said that investigations on the relationship between seamount slopes and resources reveal that nodules are dominant in gentler slopes. Areas with steeper slopes are sediment-dominated and there is a transition zone with a gradient of approximately 7-15^0 where the general distribution of material is about 20-50% nodules, 10-60% crusts and 10-90 % sediment in different combinations. He said that crusts generally occurred on gradients greater than 15 degrees. Dr. Sharma said that designing a mining device that could traverse the varying slopes of a seamount would be a challenge. He stated that the factors that needed to be considered for the mining device were how to scrape the surface of the seamount, how to move on its slope and how to collect the ore. He noted that the three subsystems needed to be efficient.

Dr. Sharma said that the search for cobalt-rich ferromanganese crusts deposits would utilize standard exploration techniques. He said that a typical mining system would have two components: one that was subsurface and the other, on the surface. He said that the system would consist of a device to dislodge the oxide layer containing the crusts from the substrate, another device that would collect the crusts, and a third device to transport crusts from the seafloor to the mining platform.

Dr. Sharma noted that this was once again a problem for engineers and the technology would evolve over the next few decades until crusts mining occurred. He stated the need for the cutting/collector device to avoid obstacles and pointed out the value of detailed sounding records for this purpose. He noted the importance of navigation and propulsion devices to the system, and suggested that a rescue or recovery device would provide a means to recover components of the system that were lost at sea. He said that the surface platform would have to be able to support the mining operation that was taking place at the seafloor.

With regard to the parameters for mining, Dr. Sharma estimated a mining rate of one million tonnes per year based on a deposit or deposits that could support mining for 15 or 20 years. He therefore noted that the operation suggested the need for 15-20 million tonnes of ore. Dr. Sharma said that the mining system would operate 215 days per year, with five days in a month set aside for adverse weather conditions and another five days for routine maintenance. Based on crusts thickness of 2.5 centimetres and average coverage of 40%, Dr. Sharma said that annually, mining of 600 square kilometres of a seamount would occur. In his opinion, this was not a very large area. Dr. Sharma assumed that 70% of the material collected would be crusts. With regard to the remaining 30% gangue material, Dr. Sharma said it should be returned to the ocean. He noted that 36% of the material transported by the mining vessel to land for processing would be the metals, including manganese and iron. He further noted that 64% of the material transported to land would be waste and would need to be disposed of.

Dr. Sharma stated that most of the proposed mining techniques would affect the seafloor. The effects of transportation, processing and tailings discharge would depend on whether processing was on land or at sea. With regard to mining, Dr. Sharma said that cutting and washing might have an impact because of the debris discharged at sea. He said that the water column would be affected during lifting, washing on the platform, transportation, processing and finally by tailings discharge. He also said that the sea surface would be an affected area during mining. Dr. Sharma felt that scientists and technologists needed to find ways of reducing these impacts. He also said that processing and tailings discharges would cause onshore impacts. The amount of substrate collected depended on the thickness of the substrate and its cohesion to the crusts. He said that suspended solids due to the miner's movement, the crusher activity, the lift mechanism and the surface discharge, would result in increased turbidity in the water column. He also said that oil could spill or leak from the mining and transport vessels. Dr. Sharma said that ballast water contamination was becoming a major problem all over the world, and at-sea processing wastes could contain chemicals or some debris and water. He further said that water brought from the seafloor could create a new environment for the organisms living on the surface. Discharge on the surface of debris or unwanted material would have different impacts, such as creating turbidity, affecting the biogeo-chemical process, the bacterial numbers, the plankton, production and so on.

Since mining would affect the environment, Dr. Sharma thought that it would be important to investigate how particles settled through the water column. He said that other parameters that needed measuring included how currents change at different times of the year and at different depths in the water column. He said that seafloor bathymetry would determine where mining was practical. With regard to biological impacts, Dr. Sharma said that if species were found in all parts of the oceans, they could easily recolonize the impacted areas, so there was probably no cause for concern. However, if there were rare species or species, which should be preserved for biotechnological applications, then they must be examined more closely.

Dr. Sharma said that baseline studies were critical and informed participants that Indian scientists had undertaken such studies during tests of a mining device in the Indian Ocean as part of its polymetallic ferromanganese nodule development programme. He said that as a result, the scientists had published many papers in journals such as Marine Resources and Deep-Sea Research.

Dr. Sharma said that since he did not expect crusts mining to occur during the lifetimes of those currently developing the technology, all relevant data collected needed to be put into a very well defined database. He said that for the nodule-mining programme of India, such a database now exists. In this regard, Dr. Sharma demonstrated the software developed for the purpose that contained an interactive data-retrieval system in different formats for water column and benthic data, as well as video and photo data. He said that the ultimate aims of the database were for modelling the environment and designing a mining system.

Dr. Sharma told participants that India's ferromanganese cobalt- rich crusts investigations in the Indian Ocean were an offshoot of its ferromanganese nodule project.

According to Dr. Sharma, with regard to the crusts project and environmental impact assessment, outstanding work included the design of the mining system (without which it was impossible to determine the impacts of mining) and experiments to monitor the impacts of cobalt crust mining were required at the scale of commercial scale mining.

SUMMARY OF DISCUSSIONS

One participant pointed out that there were many similarities between cobalt-rich ferromanganese crusts mining and polymetallic sulphides mining, even though there were differences in, among other things, the animals and temperature regimes.

Dr. Sharma was asked how information was going to be archived, taking into account the fact that technology was always changing and formats that were widely common a few years ago could not now be used. Dr. Sharma responded that data was now stored on CDs or DVDs and constantly updated with the latest technology.

Participants wanted to know about crusts formation and the microbiology that was associated with them. Dr. Sharma stated that he was not the right person to answer that question, upon which another participant pointed out that there was a report written by Dr. James Hein, published by the Authority, that answered those questions and that it was a good review document for those wishing to obtain more information. In response to the question, it was stated that crusts formed very slowly (millimetres per million years) by chemical processes with associated microbes in much the same way that microbes were associated with manganese nodules. It was also pointed out that crusts tended to be associated with the oxygen minimum zone in areas of low sedimentation rates because, as a result of their slow growth, they would be covered up if sedimentation was high. It was stated that crusts were basically oxides of different metals that usually grew on rock outcrops. They also occurred on sediments but only when those sediments were consolidated. The participant concluded by stating that crusts needed hard substrate to start growing and that this was how they differed from manganese nodules.

It was noted that one of the exciting results of research into hydrothermal systems was that it helped scientists to appreciate the chemical budget of the oceans. A participant asked whether cobalt-rich ferromanganese crusts deposits played such a role, and whether removing them could alter this budget. The response by another participant was that removal of crusts would not result in any change to the ocean chemistry budget.

Dr. Sharma was asked whether blasting would be a technique for mining the two types of resources, as it would obviously have impacts on the physical and biological environment. Dr. Sharma responded that blasting was a potential method for mining crusts, but that techniques needed to be developed further. One participant added that, for polymetallic sulphides, blasting was not required as the deposits were soft enough for mechanical removal.

Another technique mentioned in the discussion involved covering the deposit with a "blanket" and then selectively dissolving the cobalt and nickel, leaving the iron and manganese behind. According to one of the participants, the University of Hawaii investigated this process a few years ago, but had since stopped any work in this regard. According to the participant, the main limitation of the hydrometallurgical method is its cost because on land, it is five times more expensive than conventional methods. In addition, the participant pointed out that the problem with the method is to ensure that there is no leakage of the chemical used to dissolve the cobalt and nickel.

Part II

POLYMETALLIC SULPHIDES DEPOSITS IN THE AREA

Chapter 5 Introduction to hydrothermal vents and associated polymetallic sulphides deposits in the Area, with a special emphasis on the chemical environment

Professor Peter Herzig, Leubniz-Institut für Meereswissenschaften, IFM-GEOMAR, Germany

Chapter 6 The physical environment of polymetallic sulphides deposits, the potential impact of exploration and mining on this environment and data required to establish environmental baselines in exploration areas

Dr. Andreas Thurnherr, Doherty Associate Research Scientist, Columbia University, LDEO, Oceanography, New York, United States of America

Chapter 7 The biological environment of polymetallic sulphides deposits, the potential impact of exploration and mining on this environment, and data required to establish environmental baselines in exploration areas

Professor Cindy-Lee Van Dover, Biology Department, College of William & Mary, Williamsburg, Virginia, United States of America

Chapter 8 The work of InterRidge and its potential relevance to the establishment of environmental baselines, including the voluntary code of conduct for scientific research at hydrothermal vents and potential collaboration with the Authority

Professor Colin Devey, InterRidge / Leubniz-Institut für Meereswissenschaften, IFM-GEOMAR, Germany

Chapter 9 ChEss and the biogeography of chemosynthetic ecosystems: the work of the Census of Marine Life and potential collaborations with the Authority

Dr. Lúcia de Siqueira Campos, Census of Marine Life / Departamento de Zoologia, Instituto de Biología, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. (Additional authors: Eva Ramirez Llodra, Christopher R. German and Paul A. Tyler, Southampton Oceanography Centre, United Kingdom)

CHAPTER 5 INTRODUCTION TO HYDROTHERMAL VENTS AND ASSOCIATED POLYMETALLIC SULPHIDES DEPOSITS IN THE AREA, WITH A SPECIAL EMPHASIS ON THE CHEMICAL ENVIRONMENT

Professor Peter Herzig, Leubniz-Institut für Meereswissenschaften, IFM-GEOMAR, Germany

Since the discovery of hot vents and associated polymetallic sulphides deposits in 1979, more than 250 new sites have been located in all oceans. About 50 of these sites are currently hydrothermally active, venting hot and metal-rich fluids at temperatures up to 400°C. Polymetallic sulphides occur at various water depths in a variety of tectonic settings including mid-ocean ridges, back-arc rifts, and island-arc volcanoes.

It has been widely established that circulating seawater that is modified in a reaction zone close to a subaxial magma chamber is the principal carrier of metals and sulphur. Polymetallic sulphides deposits can reach a considerable size and often carry high concentrations of copper, zinc, and lead in addition to gold and silver. It is important to note that the majority of the currently known deposits are located in national, rather than international, waters (i.e., the Area). However, only 5-10% of the 60,000 kilometres of oceanic spreading centres have been explored in any detail to date, indicating that major discoveries in the Area are to be expected. Depending on world metal prices, it is likely that test mining operations will start within waters of national jurisdiction. At a later stage, however, seafloor mining may move to deposits within the Area. It is obvious that baseline studies are needed to assess the impact of sulphides mining on the marine environment, although mining may primarily focus on inactive sites rather than venting hydrothermal systems that are host to unique biological communities.

Introduction

The discovery of high-temperature black smokers, massive sulphides, and vent biota at the crest of the East Pacific Rise at 21°N in 1979 [1,2] confirmed that the formation of new oceanic crust through seafloor spreading is intimately associated with the generation of metallic mineral deposits at the seafloor. It was documented that the 350°C hydrothermal fluids discharging from the black smoker chimneys at this site at a water depth of about 2,600 metres continuously precipitate metal sulphides in response to mixing of the high-temperature hydrothermal fluids with ambient seawater. The metal sulphides including pyrite (FeS_2), sphalerite (ZnS), and chalcopyrite ($CuFeS_2$) eventually accumulate at and just below the seafloor and have the potential to form a massive sulphides deposit. The circulation of seawater through oceanic crust as the principal process responsible for the formation of massive sulphides deposits in this environment is also established. Seawater, which deeply penetrates the oceanic crust at seafloor spreading centres, modifys into a hydrothermal fluid with low pH (acidity or alkalinity of aqueous solutions), low Eh (oxidation-reduction potential), and high temperature during water-rock interaction above a high-level magma chamber. This fluid is then capable of leaching and transporting metals such as iron (Fe), zinc (Zn), copper (Cu), lead (Pb) , arsenic (As), antimony (Sb) and other elements (e.g., sulphur (S), calcium (Ca), potassium (K), barium (Ba), silicon Si, lithium (Li),and rubidium (Rb) from seawater. The leached metals eventually precipitate as massive sulphides at the seafloor or as stockwork and replacement sulphides in the sub seafloor. The resulting massive sulphides deposits can reach considerable size ranging from several thousand tonnes to about 100 million tonnes. High concentrations of base metals (Cu, Zn, and Pb) and precious metals (Au, Ag) in some of these deposits have recently attracted the interest of the international mining industry.

In the more than two decades since the discovery of hydrothermal vents at the mid-ocean ridges, significant mineral deposits have been documented in more than a dozen different volcanic and tectonic settings around the world. These deposits occur at water depths up to 3,700 m. Polymetallic sulphides deposits are found on fast-, intermediate-, and slow-spreading mid-ocean ridges, on axial and off-axis volcanoes and seamounts, in sedimented rifts adjacent to continental margins, and in subduction-related arc and back-arc environments (Figures 1 and 2).

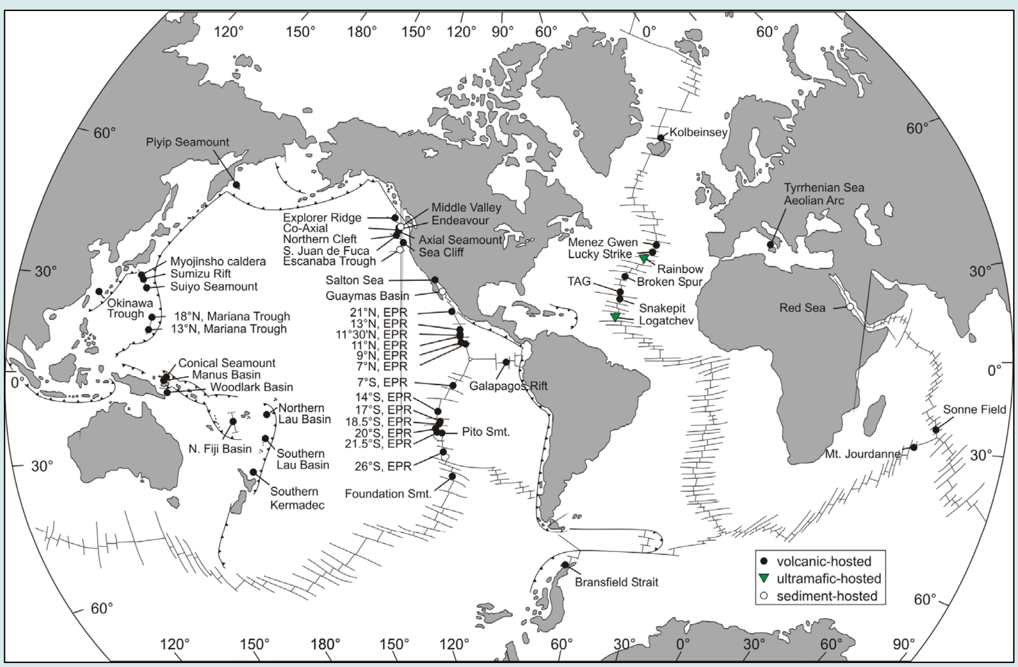

Figure 1: Location of hydrothermal systems and polymetallic massive sulphide deposits at the modern seafloor.

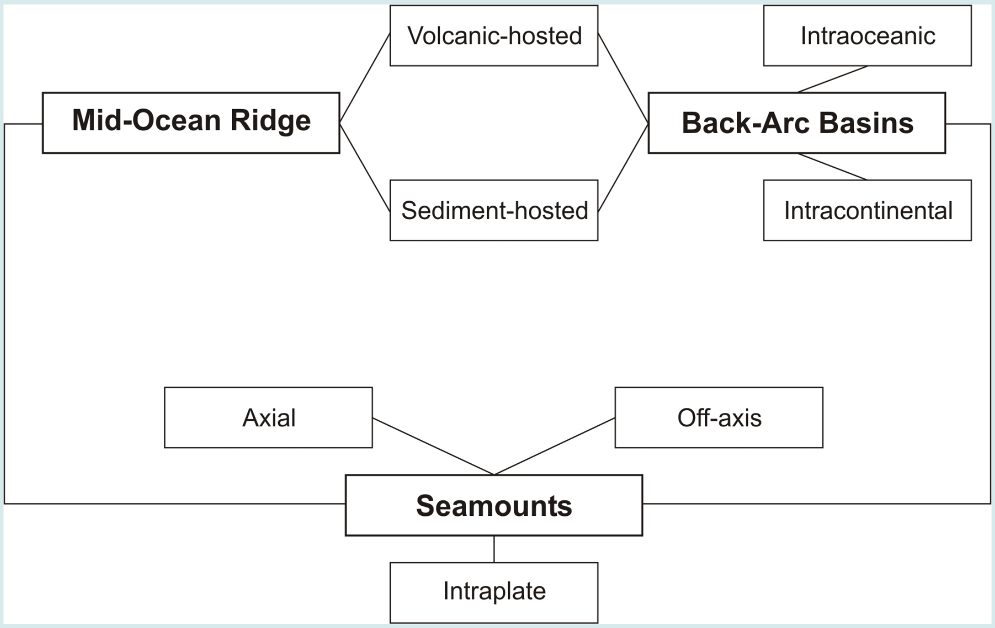

Figure 2: Simplified diagram showing the diverse geological environments for the occurrence of seafloor hydrothermal systems. Polymetallic massive sulphide deposits have been found in all settings except for intraplate seamounts.

Land-based massive sulphides deposits and polymetallic sulphides at the seafloor are products of the same geological and geochemical processes and many analogies are evident between modern examples and base metal deposits presently in production on land [3, 4,5,6,7]. Detailed geological, mineralogical, and geochemical analyses of massive sulphides from back-arc spreading centres of the western and Southwestern Pacific have indicated that these subduction-related sites represent the closest modern analogues of the majority of the economically important land-based deposits. The land-based deposits occur in felsic volcanic rocks instead of mid-ocean ridge basalts.[8] Modern seafloor hydrothermal systems are thus excellent natural laboratories for understanding the genesis of volcanic-hosted massive sulphides (VMS) deposits. This knowledge is applicable to the ancient geological record on land, where evidence of the origin and nature of mineral deposits can often be obscured by millions of years of geological history.

Geologic Setting

Following the discovery of black smokers at the East Pacific Rise, there was a rapid growth in the number of hydrothermal deposits found on fast-spreading mid-ocean ridges. So many deposits were found along fast-spreading segments of the East Pacific Rise, and virtually nowhere else, that it became widely accepted that slower-spreading ridges could not support productive hydrothermal activity. However, in 1985, the discovery of black smokers in the large TAG hydrothermal field at the Mid-Atlantic Ridge[9] offered compelling evidence that slow-spreading ridges may also be important settings for sulphides deposits. Confirmation of this idea occurred with the discovery of a number of large sulphides occurrences along the Mid-Atlantic Ridge (Logatchev, Snakepit, Broken Spur, Lucky Strike and Menez Gwen [10, 11, 12, 13]) and the Central Indian Ridge (Sonne Field[14, 15, 16]).

Shortly after the discovery at 21°N, large sulphides deposits were also discovered in sediment-filled basins in the Gulf of California (Guaymas Basin[17]). The idea that sedimented ridges might also be important sites for sulphides accumulation was confirmed in 1991 and 1996, when the Ocean Drilling Program intersected about 100 metres of massive sulphides in the large Middle Valley deposit on the Juan de Fuca Ridge off-shore Canada.[18,19]

The first sulphides deposits reported in back-arc spreading centres were found in the Central Manus Basin[20] and the Mariana Trough.[21,22] These discoveries led to extensive exploration of the marginal basins and the arc and back-arc systems of the Western and Southwestern Pacific in the late 1980s. The complex volcanic and tectonic settings of convergent margins in the Pacific Ocean suggested that a number of different deposit types might be present in this region. A wide range of mineral deposits have since been found in back-arc rifts at different stages of opening (immature versus mature), on volcanoes along the active volcanic fronts of the arcs, as well as in rifted fore-arc environments. Well-known examples of polymetallic massive sulphides deposits have been described, from mature back-arc spreading centres, such as the North Fiji Basin,[23] along propagating back-arc rifts such as the Valu Fa Ridge in the southern Lau Basin,[24] and in nascent back-arc rifts such as the Okinawa Trough[25]. In 1991, extensive sulphides deposits were determined to be associated with felsic volcanism in the Eastern Manus Basin.[26] Hydrothermal deposits have also been located in the western Woodlark Basin, where seafloor spreading propagates into the continental crust of Papua New Guinea[27]. Today, more than 250 sites of hydrothermal mineralization at the modern seafloor [28, 29, 30] including at least 50 sites with high-temperature (350-400°C) black smoker venting are known.

The majority of the discovered sites are located at the East Pacific Rise, the Southeast Pacific Rise, and the Northeast Pacific Rise. This is because the first discovery of an active high-temperature hydrothermal system was at 21°N at the East Pacific Rise off shore Baja California. To date, three of the discovered sites are located at the ridge system of the Indian Ocean, close to the Rodriguez Triple Junction.[14, 15, 16.] The lack of discovered sites on the Mid-Atlantic Ridge and in the Indian Ocean is, at least largely, a function of restricted prospecting activity in these areas. Of the 60,000 kilometres of oceanic ridges worldwide, only 5 to 10% have been the subject of systematic surveys. On this basis, significant discoveries are expected, in particular in the Area that is thus far largely under- explored.

Hydrothermal Convection

At oceanic spreading centres, seawater penetrates deeply into the newly-formed oceanic crust along cracks and fissures, which are a response to thermal contraction and seismic events typical for zones of active seafloor spreading. The seawater circulating through the oceanic crust at seafloor spreading centres transforms into an ore-forming hydrothermal fluid in a reaction zone situated close to the top of a subaxial magma chamber (Figure 3). Major physical and chemical changes in the circulating seawater include (a) increasing temperature, (b) decreasing pH, and (c) decreasing Eh.

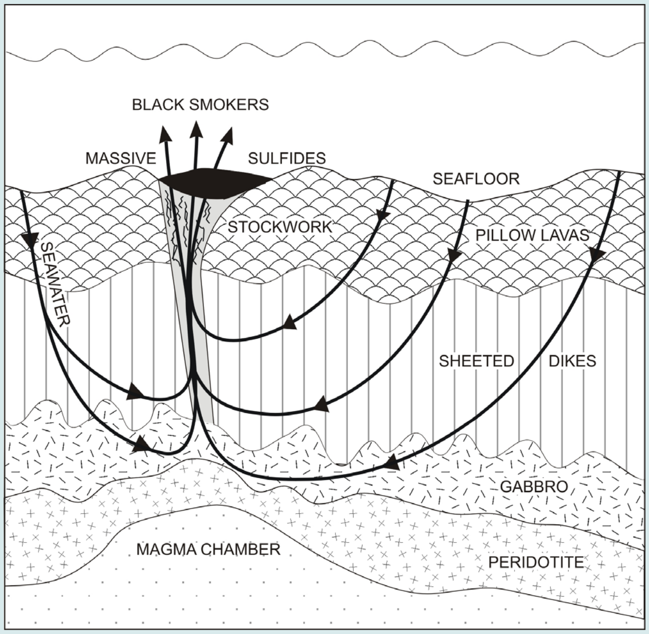

Figure 3: Model showing a seawater hydrothermal convection system above a subaxial magma chamber at an oceanic spreading centre. Radius of a typical convection cell is about 3-5 km. Depth of the magma chamber usually varies between 1.5 and 3.5 km.

The increase in temperature from about 2°C to values greater than 400°C[31, 32] is a result of the conductive heating of a small percentage of the seawater close to the solidified top of a high-level magma chamber.[33.] This drives the hydrothermal convection system and gives rise to black smokers at the seafloor. High-resolution seismic reflection studies have indicated that some of these magma reservoirs may occur 1.5 to 3.5 kilometres below the seafloor[34, 35]. The crustal residence time of seawater in the convection system has been determined to be three years or less.[36.] Data from water/rock interaction experiments indicate that, with increasing temperatures, the Mg^{2+} (magnesium ions) dissolved in seawater (about 1,280 ppm) combines with the OH-groups (hydroxide group ions which originate from the dissociation of seawater at higher temperatures) to form $Mg\ (OH)_2$. The magnesium hydroxide or hydrate is incorporated in secondary minerals such as smectite (<200°C) and chlorite (>200°C).[37, 38, 39, 40.] The removal of the OH-groups creates an excess of H^+ (hydrogen ions), which is the principal acid-generating reaction responsible for the drop in pH from seawater values (pH 7.8 at 2°C) to values as low as pH 2.[41.] The exchange of H^+ for Ca^{2+} (calcium ions) and K^+ (potassium ions) in the rock releases these elements into the hydrothermal fluid. The leaching of Ca^{2+} balances the continuous removal of Mg^{2+} from seawater. End member hydrothermal fluids are defined as presumed deep-seated high-temperature fluids computed by extrapolating compositions and physical parameters back to Mg=0 on the assumption of the quantitative removal of Mg. At high temperatures, however, the formation of epidote (Ca fixation) also results in an excess of $H^{+,}$ which further contributes to the acidity of the hydrothermal fluid. These reactions take place at water/rock ratios of less than five and commonly close to one.[42.] The oxygen that is present in the circulating seawater in the form of sulphate is removed partly by precipitation of anhydrite and partly through conversion of igneous pyrrhotite to secondary pyrite and the oxidation of Fe^{2+} to Fe^{3+} forming Fe-oxyhydroxides and secondary magnetite in the basalt.[40.] Partial reduction of seawater SO_4^{2-} contributes to the formation of H_2S (hydrogen sulphide), but most of the reduced S (sulphur) in the fluid is derived from the rock itself.

This highly corrosive fluid is now capable of leaching elements, such as lithium (Li), potassium (K), rubidium (Rb), calcium (Ca), barium (Ba), the transition metals iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), together with gold (Au), silver (Ag) and some silicon (Si) from the oceanic basement.[43.] Sulphide droplets in the basalt are considered the major source for metals and S.[44.] The metals are mainly transported as chloride complexes at high temperatures and, in some cases, as bisulphide complexes (in particular Au) at lower temperatures.

Due to its increased buoyancy at high temperatures, the hydrothermal fluid rises rapidly from the deep-seated reaction zone to the surface along major faults and fractures within the rift valley or close to the flanks of the rift. In particular, the intersections of faults running parallel and perpendicular to the ridge axis are the loci of high-velocity discharge black smokers and massive sulphides mounds. The sulphide precipitation within the upflow zone (stockwork) and at the seafloor (massive sulphides) is a consequence of changing physical and chemical conditions during the mixing of high-temperature (250-400°C), metal-rich hydrothermal fluids with cold (about 2°C), oxygen-bearing seawater (Figure 4).

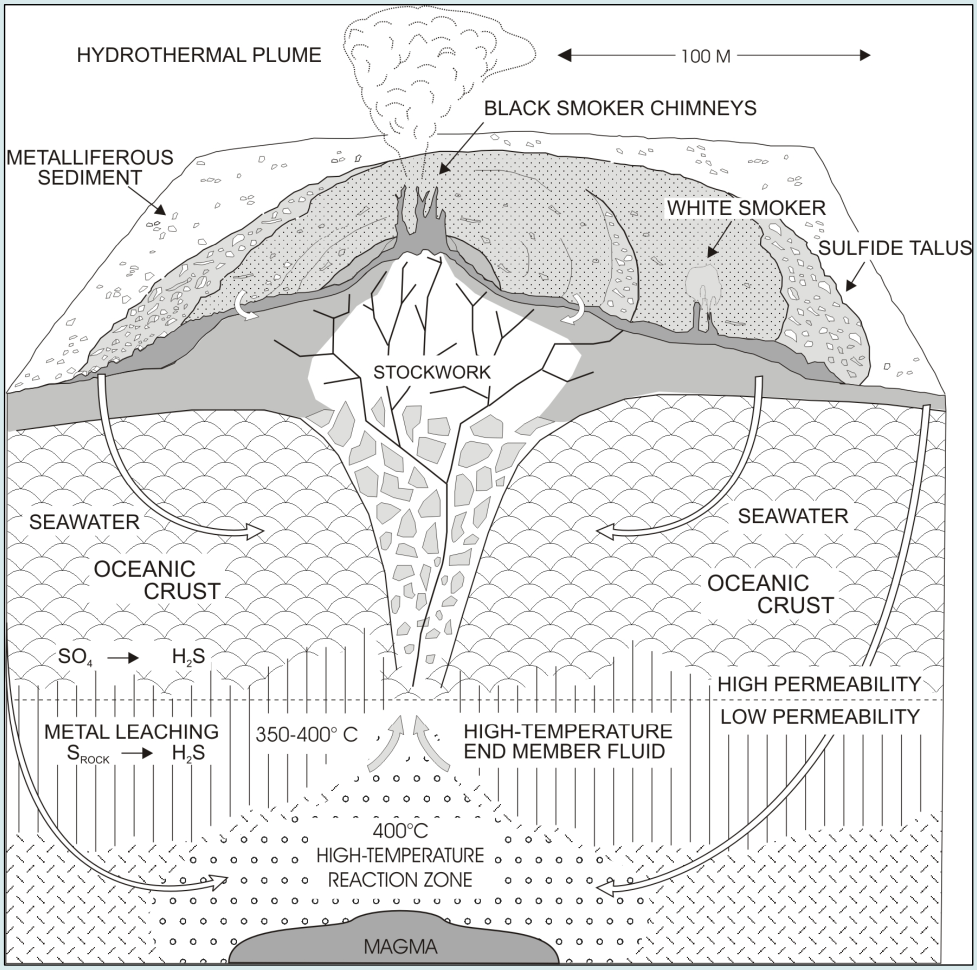

Figure 4: Cross-section showing the principal components of a seafloor hydrothermal system.

Mineralogy

The mineralogy of seafloor sulphides deposits (Table 1) has been documented in a number of detailed studies of samples from various sites.[22,45,46,47,48,49,50,51,52] The mineral paragenesis of sulphides deposits at volcanic-dominated mid-ocean ridges usually includes assemblages that formed at temperatures ranging from about 300-400°C to less than 150°C. High-temperature fluid channels of black smokers and the interiors of sulphides mounds commonly consist of pyrite and chalcopyrite together with pyrrhotite, isocubanite, and locally bornite. The outer portions of chimneys and mounds are commonly composed of lower temperature precipitates such as sphalerite/wurtzite, marcasite, and pyrite, which are also the principal sulphide minerals of low-temperature white smoker chimneys. Anhydrite is important in the high-temperature assemblages, but is typically replaced later by sulphides, amorphous silica, or barite at lower temperatures.

TABLE 1: MINERALOGICAL COMPOSITION OF SEAFLOOR POLYMETALLIC SULPHIDES DEPOSITS

	Back-arc deposits	Mid-ocean ridge deposits
Fe-sulphides	Pyrite, marcasite, pyrrhotite	Pyrite, marcasite, pyrrhotite
Zn-sulphides	Sphalerite, wurtzite	Sphalerite, wurtzite
Cu-sulphides	Chalcopyrite, isocubanite	Chalcopyrite, isocubanite
Silicates	Amorphous silica	Amorphous silica
Sulphates	Anhydrite, barite	Anhydrite, barite
Pb-sulphides	Galena, sulphosalts	
As-sulphides	Orpiment, realgar	
Cu-As-Sb-sulphides	Tennantite, tetrahedrite	
Native metals	Gold	

Sulphide mineralization at back-arc spreading centres has some mineralogical characteristics that are similar to hydrothermal precipitates at volcanic-dominated mid-ocean ridges. Commonly, pyrite and sphalerite are the dominant sulphides. Chalcopyrite is common in the higher temperature assemblages, but pyrrhotite is rare. Barite and amorphous silica are the most abundant non-sulphides. Many of the deposits forming in back-arc rifts are characterized by a variety of minor and trace minerals, such as galena, tennantite, tetrahedrite, cinnabar, realgar, orpiment, and complex, non-stoichiometric Pb-As-Sb sulphosalts. The first examples of visible primary gold in seafloor sulphides were documented in samples of lower temperature (>300°C) white smoker chimneys from the southern Lau Basin[53, 54] and occur as coarse-grained (18 microns) co-depositional inclusions in massive, Fe-poor sphalerite.

It is important to note that the various elements mentioned above are locked into mineral lattices and are, in fact, part of specific minerals. Mining activities would therefore not result in a direct release of (toxic) minerals into the water column, as the mineral structures are not affected by breaking or crushing. Sulphide debris and sulphide sand that may form as a consequence of mining would, however, become subject to oxidation by ambient seawater. This is clearly a natural process currently taking place, for example, at the active TAG hydrothermal mound at the Mid-Atlantic Ridge that is surrounded by large amounts of sulphide debris. The TAG mound is an excellent natural laboratory to study the effects of seafloor sulphide oxidation that is likely to have only a very limited impact onto the marine environment.

Metal Contents

Despite moderate tonnages in several seafloor deposits, recovered samples from about 200 deposits worldwide represent no more than a few hundred tonnes of material. Based on existing data and in the absence of information on the third dimension, it is premature to comment on the economic significance of seafloor massive sulphides. Published analyses of sulphide samples, however, indicate that these deposits may contain important concentrations of metals that are comparable to those found in ores from massive sulphides mines on land. Estimated concentrations of base metals in seafloor massive sulphides tend to be higher, which in part may be due to a strong bias in sampling.

A large number of seafloor sulphides are recovered during submersible operations. A bias in the analytical data arises, because sulphide chimneys which are relatively easy to sample are often the focus of study. However, they are unlikely to be representative of the bulk composition of the deposits as a whole (e.g., 11 analysed samples from the Southern Juan de Fuca site have an average Zn content of greater than 34 wt.%) and little is known about the interiors of larger sulphide mounds and the underlying stockwork zones. Systematic sampling of both high and low-temperature assemblages across the surfaces of some large active areas (e.g., TAG hydrothermal field, Explorer Ridge, Galapagos Rift) are more representative of the range of sulphide precipitates, which comprise large deposits. Sufficient sampling, which has lead to potentially realistic estimates of metal concentrations, has been achieved at only a few sites (e.g., Middle Valley, Explorer Ridge, Galapagos Rift), while quantitative assessment of contained metals has been possible only for the Atlantis II Deep in the Red Sea. Adequate information about the continuity of base and precious metal concentrations in the interiors of the deposits can only be provided by drilling, as successfully demonstrated at the TAG mound (Ocean Drilling Program Leg 158[55]) and the Middle Valley site (Ocean Drilling Program Leg 139,[18] Ocean Drilling Program Leg 169[56]). Shallow drilling operations with a penetration of 5 to 10 metres into the sub-seafloor have been carried out at some deposits in recent years (Conical Seamount, Papua New Guinea; Suju Seamount, Izu-Bonin Arc; North Fiji Basin) and are an effective means to sample the interior of the deposits.

Comparisons of close to 1,300 chemical analyses of seafloor sulphides reveal systematic trends in bulk composition between deposits in different volcanic and tectonic settings (Table 2). The sediment-hosted massive sulphides (e.g., Escanaba

Trough, Guaymas Basin), while being somewhat larger than deposits at the bare-rock mid-ocean ridges, appear to have lower concentrations and different proportions of base metals. Massive sulphides from these deposits average 4.7 wt. percentage Zn, 1.3 wt. percentage Cu, and 1.1 wt. % Pb (n=57). This reflects the influence of thick sequences of turbidite sediments on hydrothermal fluids ascending to the seafloor and the tendency for widespread precipitation of metals beneath the sediment-seawater interface. Calcite, anhydrite, barite, and silica are major components of the hydrothermal precipitates and may significantly dilute the base metals in sediment-hosted deposits. On basaltic, sediment-free mid-ocean ridges, sulphides are precipitated largely around the vent site, resulting in smaller deposits, but higher concentrations of metals. The largest deposits for which there are representative suites of samples (e.g., Explorer Ridge, Endeavour Ridge, Axial Seamount, Cleft Segment, East Pacific Rise, Galapagos Rift, TAG, Snakepit) have a narrow range of metal concentrations, and average 8.5 wt.% Zn and 4.8 wt.% Cu, but have only low concentrations (0.1 wt. %) of Pb (n=1,259, Table 2). Anhydrite, barite, and silica are important constituents of some chimneys, but on average they account for <20% of the samples analysed.

TABLE 2: BULK CHEMICAL COMPOSITION OF SEAFLOOR POLYMETALLIC SULPHIDES

Element back-arc ridges	Intraoceanic back-arc ridges	Intracontinental ridges	Mid-ocean
Pb (wt. %)	0.4	11.8	0.1
Fe	13.0	6.2	26.4
Zn	16.5	20.2	8.5
Cu	4.0	3.3	4.8
Ba	12.6	7.2	1.8
As (ppm)	845	17,500	235
Sb	106	6,710	46
Ag	217	2,304	113
Au	4.5	3.1	1.2
(N)	573	40	1,259

Vent fluid compositions at all of the bare-rock mid-ocean ridge sites are remarkably similar, reflecting the high-temperature reaction of seawater with a uniform basaltic crust at greenschist facies conditions.[57,58,59] Therefore, large variations in base metal concentrations between deposits on the mid-ocean ridges likely reflect a sampling bias or differences in the conditions of formation of the deposits. For example, zinc-rich deposits at Axial Seamount and the Southern Juan de Fuca site appear to have formed at lower average temperatures (<300°C) than Cu-rich deposits (>300°C) elsewhere at the mid-ocean ridges.

Relative to samples from sediment-starved mid-ocean ridges, massive sulphides forming in basaltic to andesitic environments of intraoceanic back-arc spreading centres (e.g., Mariana Trough, Manus Basin, North Fiji Basin, Lau Basin) are characterized by elevated average concentrations of Zn (16.5 wt.%), Pb (0.4 wt.%), and Ba (12.6 wt.%), but low contents of Fe (13.0 wt.%, n=573, Table 2). Polymetallic sulphides in the Okinawa Trough, where rhyolites and dacites are a product of back-arc rifting in continental crust, have low Fe contents (6.2 wt. %), but are enriched in Zn (20.2 wt. %) and Pb (11.8 wt. %), and have high concentrations of Ag (2,304 ppm, maximum 1.1 wt. %), As (1.8 wt. %), and Sb (0.7 wt. %, n=40, Table 2). The high Sb and As contents are accounted for by the presence of tetrahedrite, stibnite, and As-sulphides (i.e., realgar and orpiment) in these assemblages.

The bulk composition of seafloor sulphide deposits in various tectonic settings is a consequence of the nature of the volcanic source rocks from which the metals are leached. Potential source rocks identified in the different tectonic environments range from MORB and clastic sediments at the mid-ocean ridges, to lavas of bimodal composition (andesite, basalt) in intraoceanic back-arcs and felsic volcanics (dacite, rhyolite), which are typical for young intracontinental back-arc rifts. These compositional variations are reflected by differences in the composition of the respective vent fluids. For example, chemical analyses of end member fluids from the Vai Lili hydrothermal field which occurs in andesites of the Valu Fa Ridge in the southern Lau Basin indicate much higher concentrations of Zn, Pb, As and other elements, compared to typical mid-ocean ridge fluids. Massive sulphides from the Okinawa Trough[25] are even more enriched in Pb than massive sulphides from the Lau Basin, which is likely a consequence of the high Pb contents of rhyolites and andesites in the source region and the characteristics of the hydrothermal fluids generated in this environment. High Pb and Ba contents of sediment-hosted seafloor sulphides simply reflect the elevated Pb and Ba contents of individual components in the sediment (e.g., feldspar). Similar trends in the bulk composition of massive sulphide deposits are widely recognized in ancient terrains.[3, 52, 60.]

Size and Tonnage

Considering that estimates of the continuity of sulphides outcrop are difficult, and that the thickness of the deposits is commonly poorly constrained, estimates for several deposits on the mid-ocean ridges suggest a size of 1 to 100 million tonnes, although the depth extent of mineralization is difficult to assess. The largest deposits by far are found on failed and heavily sedimented but still hydrothermally active oceanic ridges. Drilling carried out by the Ocean Drilling Program during legs 139 and 169 at the sediment-covered Middle Valley deposit on the northern Juan de Fuca Ridge has indicated about eight to nine million tonnes of sulphides ore.[56] During both legs, about 100 metres of massive sulphides and 100 metres of stockwork were drilled at the Bent Hill site. The sub-seafloor stockwork zone is underlain by a stratiform Cu-rich horizon ("deep copper zone") with copper grades ranging up to 17 wt. % Cu[56]. This significant discovery now represents an important new exploration target for the land-based mineral industry. The TAG hydrothermal mound located in 3,650 metres water depth at the Mid-Atlantic Ridge 26°N was drilled during Ocean Drilling Program leg 158 in 1994, to a total depth of 125 metres.[55,61] It was estimated that the active TAG mound contains about 2.7 million tonnes of sulphide ore above the seafloor and approximately 1.2 million tonnes of sulphides in the sub-seafloor stockwork.[62] A comparison of the size of the modern deposits with some of the ancient ore bodies and ore districts indicates that extremely large deposits, such as Kidd Creek in Canada (135 million tonnes) or Neves Corvo in Portugal (262 million tonnes) have not yet been discovered on the modern seafloor.

The largest known marine sulphides deposit is still the Atlantis II Deep in the Red Sea, which was discovered more than ten years before the first black smoker at the East Pacific Rise.[63.] The Atlantis II Deep mineralization consists largely of metalliferous muds, instead of massive sulphides, which is a consequence of the high salinity which the hydrothermal fluids acquire by circulation through thick Miocene evaporites at the flanks of the Red Sea rift. A detailed evaluation of the 40-km2 deposit has indicated 94 million tonnes of dry ore, with 2.0 wt. % Zn, 0.5 wt. % Cu, 39 ppm Ag, and 0.5 ppm Au, [64, 65, 66] which results in a total precious metal content of roughly 4,000 tonnes of Ag and 50 tonnes of Au. A pilot mining test at 2,000 metres depth has shown that this deposit can be successfully mined.

Estimates of sizes between 1 and 100 million tonnes for individual massive sulphides deposits on the seafloor are thus well within the range of typical volcanic-associated massive sulphides deposits on land. However, most occurrences of seafloor sulphides amount to less than a few thousand tonnes, and consist largely of scattered hydrothermal vents and mounds, usually topped by a number of chimneys with one or more large accumulations of massive sulphides. More than 60 individual occurrences have been mapped along an 8-kilometre segment of the Southern Explorer Ridge, but most of the observed mineralization occurs in two large deposits with dimensions of 250 metres by 200 metres.[67] Thicknesses of the deposits are difficult to determine unless their interiors have been exposed by local faulting. Typical black smokers are estimated to produce about 250 tonnes of massive sulphides per year. Thus, a local vent field with a few black smokers can easily account for a small-sized sulphides deposit, depending on the duration of activity. Reports of explored dimensions of deposits based on visual estimates from submersibles may be accurate to only +/-50 % of the distances given and commonly include weakly mineralized areas between larger, discrete sulphide mounds (thereby over-estimating the continuity of sulphide outcrop). Reports based on transponder navigated camera tracks are probably accurate to +/-20 %, but the extent of coverage is limited, due to the slow tow-speeds and the narrow image. No geophysical tools currently provide a good basis for estimating the area of sulphide outcrop. High-resolution, deep-towed side-scan sonar may be refined to provide more accurate information over larger areas.

Occurrence and Distribution of Gold

Gold grades are locally high in samples from a number of seafloor deposits at the mid-ocean ridges,[50,68,69,70] and in particular, in samples from the back-arc spreading centres.[54] Average gold contents for deposits at the mid-ocean ridges range from <0.2 ppm Au up to 2.6 ppm Au, with an overall average of 1.2 ppm Au (n=1,259, Table 3). In volcanic-dominated, sediment-free deposits, high-temperature (350°C) black smoker chimneys composed of Cu-Fe-sulphides typically contain <0.2 ppm Au. Here, much of the gold is lost to a diffuse hydrothermal plume. The gold content of massive sulphides from the interior of hydrothermal mounds is supposed to be similar to the gold content of the high-temperature chimney assemblages. Higher concentrations of primary gold occur in lower-temperature (<300°C), sphalerite-dominated assemblages with sulphosalts and late-stage barite and amorphous silica at Axial Seamount (6.7 ppm Au[68, 70]) and the Snakepit site (10.7 ppm Au). Comprehensive sampling of a few large, mature deposits at sediment-free ridges in the Northeast Pacific and Mid-Atlantic indicates typical average gold contents in the range of 1 to 2 ppm Au. Local enrichment of more than 40 ppm Au (TAG hydrothermal field[71]) is a consequence of remobilization and reconcentration (hydrothermal reworking) of gold during sustained venting of hydrothermal fluids through the sulphide mounds (i.e., zone refining).

TABLE 3: GOLD GRADES IN POLYMETALLIC MASSIVE SULPHIDES FROM THE MODERN SEAFLOOR

	Au (ppm)		
	Range	Average	(N)
Conical Seamount (PNG)	0.01-230.0	26.0	40
magmatic-epithermal system.			
Immature back-arc ridges			
intermediate to felsic volcanics			
Lau Basin	0.01-28.7	2.8	103
Okinawa Trough	0.01-14.4	3.1	40
Central Manus Basin	0.01-52.5	30.0	10
Eastern Manus Basin	1.30-54.9	15.0	26
Woodlark Basin	3.80-21.1	13.1	6
Mature back-arc ridges			
MOR-type volcanics			
Mariana Trough	0.14- 1.7	0.8	11
North Fiji Basin	0.01-15.0	2.9	42
Mid-ocean ridges	0.01-10.7	1.2	1,259
MORB			

The gold contents of sulphides from deposits in sedimented rifts (e.g., Guaymas Basin) are typically <0.2 ppm Au. Here, the interaction of hydrothermal fluids with organic-rich sediments causes strongly reducing conditions which limit the amount of gold that can be transported in hydrothermal solutions. However, Cu-rich sulphides from the Escanaba Trough are an exception, as they contain up to 10 ppm Au, with an average of 1.5 ppm Au. This is probably because of an enriched source in the underlying sediments.[72,73] The metalliferous muds in the Atlantis II Deep have bulk gold contents of about 0.5 ppm Au,[64] but sulphide-rich horizons have gold contents from <0.5 up to 4.6 ppm Au and average close to 2 ppm Au.[66]

Polymetallic sulphides from a number of back-arc spreading centres have revealed particular high concentrations of gold averaging between 3 and 30 ppm Au.[54] Gold appears to be most abundant in sulphides associated with immature seafloor rifts in continental or island-arc crusts. These settings are dominated by calc-alkaline volcanics including andesites, dacites, and rhyolites (e.g., Okinawa Trough, Lau Basin, and Manus Basin). Polymetallic sulphides from the Valu Fa Ridge in the Lau back-arc have gold contents of up to 29 ppm Au, with an average of 2.8 ppm Au (n=103, Table 3). These samples represent the first known examples of visible primary gold in polymetallic sulphides at active vents.[53,54] In the Okinawa Trough, gold-rich sulphide deposits with up to 14 ppm Au (average 3.1 ppm, n=40) occur in a back-arc rift within continental crust and resemble Kuroko-type massive sulphides.[25,74,75] Preliminary analyses of sulphides reported from the Central Manus Basin (Vienna Woods) indicate average gold contents of up to 30 ppm Au (n=10) and maximum concentrations of more than 50 ppm Au. The average gold content of massive sulphides in the Eastern Manus Basin (Pacmanus) is 15 ppm with a maximum of 54.9 ppm Au (n=26[76]). High gold contents up to 21 ppm Au have been found in barite chimneys in the Western Woodlark Basin, where seafloor spreading propagates into continental crust off Papua New Guinea.[77, 78]

The most gold-rich seafloor deposit found to date is located at Conical Seamount in the territorial waters of Papua New Guinea, close to Lihir Island. Maximum gold concentrations in samples collected from the summit plateau of this seamount (2.8 km basal diameter at 1,600 m water depth, top at 1,050 m) range up to 230 ppm, with an average of 26 ppm for 40 samples analyzed.[79, 80]

Resource Potential of Seafloor Sulphides Deposits

Out of the more than 250 sites of hydrothermal mineralization currently known at the modern seafloor, only about 20 deposits may have sufficient size and grade to be considered for future mining, although information on the thickness of most of those sulphide deposits is not yet available (Table 4). These potential mine sites include the Atlantis II Deep in the Red Sea, Middle Valley, Explorer Ridge, Galapagos Rift, and the East Pacific Rise 13°N in the Pacific Ocean, the TAG hydrothermal field in the Atlantic Ocean, as well as the Manus Basin, the Lau Basin, the Okinawa Trough, and the North Fiji Basin in the western and Southwestern Pacific. All but two of these sites (East Pacific Rise 13°N and TAG hydrothermal field) are located in the exclusive economic zones of coastal States, including Saudi Arabia, Sudan, Canada, Ecuador, Papua New Guinea, Tonga, Japan, and Fiji. However, the fact that most oceanic ridges in the Area are under-explored and that only 3,000 to 6,000 kilometres of the 60,000 kilometres of mid-ocean and back-arc ridges worldwide are known in some detail, indicates that it is reasonable to assume significant new discoveries in the Area in the coming decades.

TABLE 4: POSSIBLE SITES FOR MINING OF SEAFLOOR MASSIVE SULPHIDES DEPOSITS

Deposit	Ocean Area	Water depth	Jurisdiction	Country
Atlantis II Deep	Red Sea	2 000-2 200 m	EEZ	Saudi Arabia, Sudan
Middle Valley	NE Pacific	2 400-2 500 m	EEZ	Canada
Explorer Ridge	NE Pacific	1 750-2 600 m	EEZ	Canada
Lau Basin	SW Pacific	1 700-2 000 m	EEZ	Tonga
North Fiji Basin	SW Pacific	1 900-2 000 m	EEZ	Fiji
Eastern Manus B.	SW Pacific	1 450-1 650 m	EEZ	PNG
Central Manus B.	SW Pacific	2 450-2 500 m	EEZ	PNG
Conical Seamount	SW Pacific	1 050-1 650 m	EEZ	PNG
Okinawa Trough	W Pacific	1 250-1 610 m	EEZ	Japan
Galapagos Rift	E Pacific	2 600-2,850 m	EEZ	Ecuador
EPR 13°N	E Pacific	2,500-2 600 m	International	
TAG	Central Atlantic	3 650-3 700 m	International	

Scientific drilling has to date been carried out by the Ocean Drilling Program to a depth of 125 metres at the TAG hydrothermal field, and to about 200 metres at Middle Valley. Leg 193 of the Ocean Drilling Program is scheduled for December/January 2000/2001 to explore the third dimension of the Eastern Manus Basin (Pacmanus site). The Atlantis II Deep is still the only deposit that has been evaluated by a commercial company (Preussag, Germany) in the late 1970s, based on standards usually applied by the minerals industry to land-based ore deposits. A pilot mining test has successfully demonstrated that the metalliferous muds occurring below the surface of a 60°C brine, not only in the Atlantis II Deep, can be continuously mined.[81, 82]

Preussag has also performed active exploration for massive sulphides deposits in the Galapagos Spreading Centre 86°W in the mid-1980s during the GARIMAS project (Galapagos Rift Massive Sulphides), which consisted of three cruises with the German vessel, *Sonne*. At that time, it was concluded, that the Galapagos deposits are not sufficiently large and continuous to be economically mined.

It is also unlikely that deposits, such as the TAG hydrothermal field, which is located in international waters at the Mid-Atlantic Ridge, the 13°N seamount at the East Pacific Rise or the *Sonne* hydrothermal field at the remote Rodriguez Triple Junction in the Southern Indian Ocean, will become mining targets in the near future. This is also true for many of the sulphide deposits along the East, Northeast and Southeast Pacific Rises.

However, in this decade, marine mining appears to be feasible under specific conditions ideally including (a) high gold and base metal grades, (b) site location close to land, that is, commonly within the territorial waters (200 nm exclusive economic zone or even 12 nm zone) of a coastal State, (c) shallow water depth not significantly exceeding 2,000 metres (although the technology exists for mining in deeper water). Under those circumstances, massive sulphide mining can be economically attractive, considering that the entire mining system is portable and can be moved from mine site to mine site. An investment into mining systems and ships is thus not tied to a certain location, as is the case on land, where a typical mine development in a remote area, including all infrastructure, requires an initial investment of US$ 400 to 600 million.

Seafloor massive sulphides mining will likely focus on relatively small areas of the seafloor and largely be restricted to the surface (strip mining) and shallow subsurface (open cast mining) to recover sulphide mounds and chimney fields and replacement ore bodies just below the seafloor. Environmental impact studies are yet to be carried out and will likely indicate that mining of seafloor massive sulphide deposits has only a relatively small environmental impact. For example, the high density of the sulphide particles (about 4 g/cm^3) will cause immediate redeposition of any sulphide debris produced by mining equipment, such as large TV-controlled hydraulic grabs or continuous mining systems with cutter heads and airlift. Due to the large surface exposed to seawater, some of the liberated sulphide debris will oxidize in a way that is no different from the oxidation of inactive massive sulphides in many of the seafloor deposits described. Acid mine drainage, which usually causes significant environmental problems in land-based sulphide mines, will not have to be considered at the seafloor, due to the diluting effect of the surrounding seawater.

Sediment which could be disturbed by mining and possibly be transported by bottom currents would potentially create a major hazard to the marine ecosystem.[83] Amos et al.[84] have pointed out that the greatest unknown and the greatest potential hazard with respect to manganese nodule mining is the behaviour and effect of sediment plumes at the seafloor, within the water column, and at the surface. While the bottom water will be directly affected by sediment disturbance due to mining equipment, the impact on the water column and the surface will be due to discharge of sediments which have been lifted along with the manganese nodules. However, a significant sediment cover is commonly not present at most seafloor sulphide deposits (except for Middle Valley and the Guaymas Basin) and thus is not to be taken into account. Consequently, mining of selected seafloor sulphide deposits, in particular, those that are inactive and not inhabited by any kind of vent fauna, is feasible and does not create a larger environmental impact than the construction of a large harbour facility.

In December 1997, the Government of Papua New Guinea granted the first two marine exploration licences for seafloor sulphides deposits to an Australia-based mining company.[85] The licences cover an area of about 5,000 square kilometres in the Manus back-arc basin and include the Vienna Woods (Central Manus Basin) and the Pacmanus (Eastern Manus Basin) sites, which are located on the west side of New

Ireland. Mineralization occurs at a water depth of 2,500 metres (Vienna Woods) and 1,450 to 1,650 metres (Pacmanus). Preliminary analyses of sulphides from both deposits indicate high average gold contents (see above) along with high concentrations of base metals. However, only a limited number of samples has been analysed thus far and information about the depth extent of the mineralization is still lacking.

A recent discovery of gold mineralization at a seamount in a modern fore-arc environment of the Southwest Pacific suggests that a number of previously unexplored settings at the seafloor may be prospective for gold-rich hydrothermal systems. Mapping of largely uncharted waters in the Tabar-Feni island chain off Papua New Guinea revealed the position of several previously unknown volcanic cones about 10 km south of Lihir Island.[86,87] Conical Seamount, the largest of the seamounts south of Lihir (Figures 5 and 6), is host to a new type of marine mineral deposit, characterized by extremely high concentrations of gold and a style of mineralization that indicates the participation of gold-rich magmatic fluids (as opposed to circulating seawater) in the formation of this deposit.[71,87,88] Samples of trachybasalt (1,200 kg) collected from the crater of Conical Seamount at a depth of 1,050 metres contain up to 230 ppm Au (avg. 26 ppm, n=40), with several dozen grains of native gold (up to 30 micron) identified as inclusions in sphalerite, galena, and amorphous silica. High concentrations of gold are uniformly associated with high concentrations of elements such as As, Sb, and Hg, known as the "epithermal suite" and typical for the so-called epithermal (i.e., magmatic) gold deposits on land. The style of mineralization is similar to that of the giant Ladolam gold deposit (1,300 tonnes Au content, daily production 60 kg Au) located on the neighbouring island of Lihir and it may be assumed that Conical Seamount represents a submarine analogue of this world-class terrestrial gold mine.

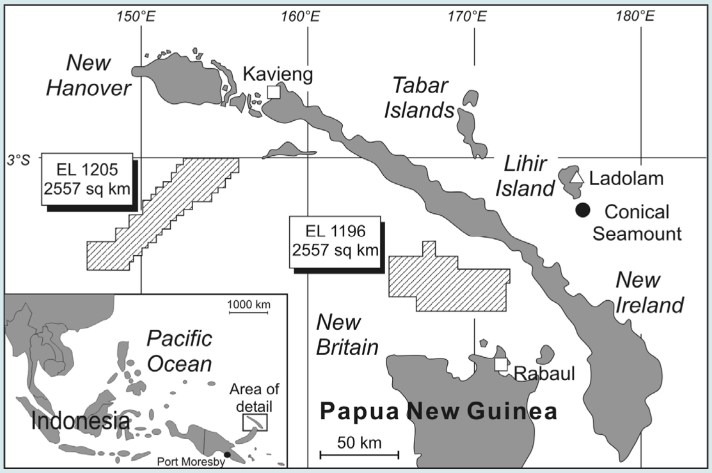

Figure 5: Map of the Manus Basin west of New Ireland showing the location of areas covered by an exploration licence granted to an Australia-based mining company by the Government of Papua New Guinea (after[85]). Notice the location of Conical Seamount south of Lihir Island and the Ladolam gold deposit on Lihir Island.

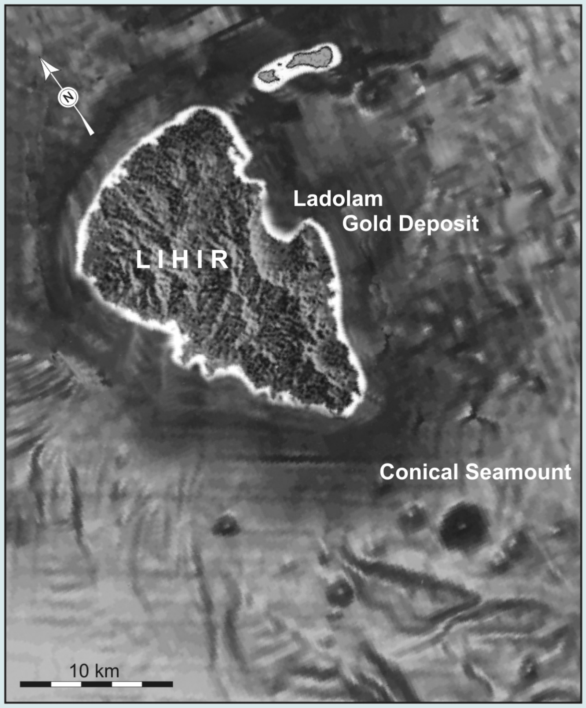

Figure 6: Bathymetry-based shaded relief of the Lihir Island group with the location of volcanic cones south of Lihir including Conical Seamount, which is host to a new type of submarine gold mineralization.

Perspective

If further exploration through drilling proves that high-grade gold mineralization is widespread and abundant, Conical Seamount may become the first marine gold deposit to be mined. In addition to high concentrations of gold, the advantages of this site include shallow water depth (1,050 m) and the location within the 12 nm zone of Papua New Guinea. Furthermore, the deposit is inactive (no disturbance of fauna) and almost sediment-free (no plume development due to mining activities). Processing of the gold ore could take place 25 kilometres away at the Ladolam gold processing plant on Lihir. If this scenario becomes reality, it will have a very significant impact on the future development of seafloor mining for base and precious metals. Given the known distribution of potentially minable sulphide deposits on the seafloor, it is very likely that most, if not all, future development of sulphide mining will take place in national rather than international waters.

Considering all circumstances, mining of seafloor polymetallic massive sulphides deposits is likely to take place in the current decade. In this context it should be remembered that, only about 35 years ago, the oil industry went offshore and there is no doubt that this was a very successful endeavour. Today, the international mining industry is about to follow.

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SUMMARY OF PRESENTATION

Professor Herzig reminded his audience that black smokers and massive sulphides had been discovered about 25 years prior to the workshop at the East Pacific Rise by scientists on board the research submersible, *Alvin*. Those scientists, for the first time, witnessed a black smoker, meaning a hot vent, with hydrothermal plumes at a temperature of 350^0C. The scientists on board *Alvin* realized that the water was black, due to the fact that it contained fine particles of metal sulphides, particularly iron sulphides, copper sulphides and zinc sulphides. This was basically the start of research on hydrothermal systems and massive sulphides.

According to Professor Herzig, this discovery had initiated a number of large-scale exploration programmes led by the United States for many years. Later on, a couple of other countries had joined in and had contributed state-of-the-art research and exploration equipment to the study of hot vents and the seafloor. These efforts very quickly indicated that the majority of hydrothermal systems and seafloor massive sulphides deposits occurred at divergent volcanic plain boundaries, so-called oceanic ridges in the world oceans. These ridges were, in particular, the Mid-Atlantic Ridge, the ridge system in the Indian Ocean (consisting of the Red Sea, the Central Indian Ridge, the Rodriguez Triple Junction, the Southwest and the Southeast Indian Ridge) the Pacific and Arctic Ridges and the East Pacific Rise (the Southeast Pacific Rise, the East Pacific Rise and the Northeast Pacific Rise). In addition to the major mid-ocean ridges, scientists also talked of ridges with respect to the Western and Southwestern Pacific in the back-arc areas. They are smaller ridges but were extremely important with respect to the formation of metal sulphides and hydrothermal systems. Together, the ridges had a length of 60,000 kilometres worldwide. The majority of those ridges - and Professor Herzig thought this was important - were located in the Area. More importantly, only about 5-10% of those ridges had been explored in any detail. That had some consequences. The first consequence was that there was a significant potential for further discoveries of hydrothermal systems and massive sulphides in the

Area; the second was that there was a clear mandate for the International Seabed Authority to deal with those resources.

Professor Herzig pointed out that, in areas of oceanic spreading, new oceanic crust was created by the divergent plate boundaries because the plates were drifting away from each other. This would have been triggered by a magma chamber, containing hot melt at temperatures of about 1,200^{0}C periodically rising up to the seafloor to form new ocean crust. The hot lava cooled in response to the cold seawater at about 2^{0}C, producing pillow lava at the seafloor. Spreading rates varied between 1 and 10 centimetres per year; this meant that, at a particular place in the Pacific Ocean, about 20 centimetres of new oceanic crust was being formed every year. This was a significant and global process.

Professor Herzig stated that he preferred the term “oceanic ridges” to “mid-ocean ridges,” because oceanic ridges also included the back-arc ridges.

Professor Herzig noted that the magma chamber not only drove the seafloor spreading process, but also seawater hydrothermal convection systems. This was basically a large circulation system responsible for the formation of massive sulphide deposits and hydrothermal systems at and beneath the seafloor. Seafloor spreading and the cooling of hot oceanic crust on the seafloor created fractures and this was how seawater could be pushed into the seafloor at 1,000 metre water depths. The water would be forced into the seafloor and flow to the magma chamber in an area called the reaction zone, being modified in a number of ways to become a hydrothermal fluid. First of all, the seawater would be heated to temperatures of up to between 400 and 450ºC. Due to a number of chemical reactions that involved the fixation of magnesium from seawater and hydroxide from seawater, excess hydrogen would be produced, reducing the pH of the water from 7.8 to values as low as 2. The third process involved the oxygen in the seawater in the sulphate being removed. This would occur as the iron in the rock was oxidized from Fe2+ to Fe3+, causing the removal of oxygen and the creation of hydrogen sulphide, which would be a hot, extremely acidic fluid without oxygen. The fluid would be forced up to the seafloor because heating would reduce its density and the surrounding rocks would be leached by the aggressive fluid. It would no longer be seawater, but, rather, a hydrothermal fluid, with a number of metals being transferred from the rock into it because of the disintegration of certain minerals that liberate such metals as copper, zinc, iron, gold, silver, and sulphur. A lot of sulphur in the massive sulphides would be leached from the rock. Sulphur and other metals would be transported in solution up to the seafloor, together with hydrogen sulphide. Here they would form iron sulphides, copper sulphides, zinc sulphides and lead sulphides, in response to the mixing of this high temperature hydrothermal fluid with ambient seawater, creating sulphide mineralization below the seafloor. This was called stockwork remineralization and mixing also created massive sulphides at the seafloor.

Professor Herzig informed the participants that, as a result of the process he had just discussed, black smokers were typically characterized by fluid temperatures in the order of 350^{0}C, but temperatures of 400^{0}C had been recorded. Another characteristic was that black smokers consisted of dispersed metal sulphides and small sulphide particles.

According to Professor Herzig, there were also white smokers. White smokers usually had fluid temperatures that were much lower; in the order of 200 to 270^{0}C. They contained less sulphide particles, because the fluid had already mixed with seawater underneath the seafloor, so most of the metal precipitation had already taken place subsurface and the white colour of the fluid was due to finely-dispersed silica; in some cases, it was barium sulphate or anhydrite calcium sulphate. White smokers always indicated subsurface precipitation of sulphide minerals.

Professor Herzig said that the scientists who had discovered black smokers at the East Pacific Rise had realized immediately that they were associated with unique, biological communities. Those biological communities were based on the hydrogen sulphide. In areas where the fluid being discharged at the seafloor did not contain hydrogen sulphide, vent biota bacteria and vent specific communities were not seen. The bacteria were the first part of the food chain and used hydrogen sulphide to gain energy. They oxidized the reduced sulphur, and were followed in the food chain by shrimp, vent fish and other creatures. The development of unique biological communities at hot vents depended on the availability of hydrogen sulphide.

A question that had been raised was "should mining generally be restricted to inactive deposits, or is recolonization possible as long as the vents remain active after mining?" Professor Herzig believed that this was something that needed to be discussed. He said that it was indeed possible that, after mining of an active deposit had finished, the area may be recolonized, but there was no data to prove this. However, he assumed that many countries would adopt the legislation that was being produced by the Authority and, if it was too restrictive, then the possibilities of mining active deposits would be ruled out.

Another issue noted by Professor Herzig was that the black smokers and the chimneys usually seen on the seafloor were very attractive, in particular to people in submersibles. Those black smokers and chimneys were only the top of the system and ore production took place underneath them in mound-like features that contained the massive sulphides that miners were interested in.

Professor Herzig stated that the mineralogical composition of seafloor massive sulphide deposits was relatively simple, with base metals occurring as sulphides, zinc sulphides, copper sulphides and lead sulphides, in addition to iron sulphides. The minerals of interest were pyrite, marcasite and pyrrhotite, the most common being pyrite. The dominating zinc sulphide was sphalerite and the copper sulphides were dominated by chalcopyrite. In some places, in particular the Western and Southwestern Pacific, there was galena and in those places they also found arsenic sulphides; orpiment and realgar and copper-arsenic-antimony sulphides; tennantine and tetrahedrite. The arsenic sulphides would be a problem for processing and were unwanted elements in lead-based mining. This was a problem on land, but in the marine environment, those elements were locked into minerals, so would not be liberated by mining. Sulphide debris would be produced, so it would just change the grain size; arsenic and other metals would not be liberated from the ore by mining it. In addition, crust mining would not really liberate harmful elements and they would not be released to the surrounding seawater. In addition to the sulphide minerals, there was abundant silica - amorphous silica – a quartz-like mineralogy. There was calcium sulphate, anhydrite, and this dissolved back to seawater as soon as the hydrothermal system became inactive. In some places, some exotic elements and minerals, such as native mercury, were found. It was not unusual for volcanoes to produce mercury. This was not very typical for conventional seafloor massive sulphide deposits at back-arc ridges or mid-ocean ridges, but it could be typical for volcanic features. In some deposits, native gold had been found and that would be good news for miners. The revenue would have to come from the base metals; the gold would be a valuable by-product. In other places, there would be cinnabar, a mineral that contained mercury.

It was noted by Professor Herzig that sulphide deposits occurred along rift valleys of submarine ridges which had a total length of about 60,000 kilometres, but only 5-10% of those had been explored in any detail. Polymetallic sulphides were a three-dimensional resource, in contrast to manganese nodules and manganese crust, as they could have significant extension below the seafloor called sub-seafloor extension stockwork. A great deal of information about this was coming from land-based deposits, where the root zones of those systems could be seen. Professor Herzig believed that it was important to note that the sulphide deposits tended to occur in clusters. They were irregularly shaped in spacing of metres to kilometres and the size of the deposits varied between large mounds up to 200 metres in diameter, such as the TAG mound, and small patches that were only metres across. Tonnage varied between 100 million tons and only a few hundred kilograms of ore. Another example of a large deposit was the Atlantis II Deep in the Red Sea. This was an unusual deposit that had been discovered in the 1960s. It did not have black smokers in the strict sense, but had metalliferous muds. At the time, the assessment had been done by Preussag Marine Technology, on behalf of the Sudanese Red Sea Commission. The assessment had been done by land-based standards and had revealed 100 million tons of dry ore in the Atlantis II Deep, composed of 2% zinc, ½% copper, 40 g of silver per ton and ½ g of gold per ton. That had totalled 2 million tons of zinc metal, 500,000 tons of copper metal, 4,000 tons of silver and 50 tons of gold, and was thus a real ore deposit that had been suitable for mining. Owing to political considerations, mining had not been allowed, but everything was ready and the technology and processing had been tested. This was a large seafloor deposit.

Professor Herzig then spoke about the chemical composition of seafloor massive sulphide deposits. He had listed copper, zinc and lead, because those were the elements in addition to sulphur, but the numbers did not add up to 100%, because there were other elements. Zinc, copper and lead were the important metals and their values combined ranged between 7% and up to more than 35% by weight. While 7% by weight was a small deposit using land-based standards, 35% would be something that was worthwhile to mine and recover.

In some places, there was gold mineralization in the massive sulphides and Professor Herzig wished to draw attention to the average amount in grams per ton (ppm). Mid-ocean ridges, back-arc ridges and island-arc volcanoes had an average of up to 26 ppm. In many cases, this information was based on a relatively small number of samples. For the mid-ocean ridges, the average of close to 1 ppm had been pretty much established. This was the result of about 25 years of research and exploration.

Professor Herzig noted that the deposits in the Southwest and Western Pacific had been shown to be extremely interesting with regard to the metal content. Both had occurrences that contained relatively high amounts of lead sulphides, zinc and, in places, a relatively high amount of gold. Those deposits were the ones that were closest to the land-based deposits that were currently being mined at the time of the workshop.

Professor Herzig focused on a number of critical steps for mining seafloor polymetallic sulphides. First of all, a company would need reliable size and tonnage calculations, based on systematic drilling and coring. Surface sampling would not be good enough; drilling and coring would be required. Second, chemical analyses of representative bulk core samples would be required to establish average metal grades. This information was needed for economic feasibility studies and was also necessary to develop and test suitable mining technology.

According to Professor Herzig, a contractor would need to carry out an economic feasibility study. At a meeting that he had attended, he had been told that Nautilus Mineral Corporation had conducted a study and had discovered that the capital cost for mining would be 40% of the capital cost to open a land-based mine in Saskatchewan, Canada, and he thought that this was something to keep in mind. That company was looking at the moving mine concept, meaning that the same mine could be used at different deposits. Therefore, the economic feasibility study needed to be done based on the average metal grades and the size and tonnage calculation, but the equipment would probably be only 40% of what would be needed for a land-based investment. Last, but not least, on the issue of the workshop, Professor Herzig said that an environmental impact study would have to be conducted.

Professor Herzig informed the participants that most of the known deposits were located in exclusive economic zones. Of these, only two - the large seamount in the East Pacific Rise and the TAG deposits - were located in the Area. However, there was significant potential for further discoveries, particularly in the Area, which highlighted a clear role for the Authority to play. There were large areas of oceanic ridges that had not yet been examined, in particular, in the Southeast Pacific Rise, the South Atlantic and the Indian Ocean outside the 200-nautical-mile zone that would be under the regulation of the International Seabed Authority.

Professor Herzig rhetorically asked what the environmental considerations for mining of seafloor sulphides were. Again, there was the question of mining of inactive sites, if only to avoid destruction of hydrothermal vent fauna. Professor Herzig realized that there had been some discussion with respect to the fact that, on the one hand, inactive deposits could also contain specific fauna that would be worthwhile to protect. On the other hand, the bacteria that were settling on oxidizing sulphides in inactive areas were not special in any way. Mining deposits that were sediment-free or had only a thin sediment cover was important. Mining of a sediment-covered deposit would definitely have a larger impact on the environment than mining deposits that were not covered by sediments. Sediment plumes should be avoided. According to Professor Herzig, this would always be a big issue when mining manganese nodules. It would be easier to avoid the problem by going to sediment-free deposits. However, when the activities of DeBeers offshore of Namibia were considered, there were a lot of sediments being disturbed and for many years now, DeBeers had been mining up to 30 miles offshore and claimed that there was no impact on the environment.

According to Professor Herzig, the next part that was important was the sulphide debris that would be formed as a consequence of mining. This debris would have a relatively high density and would settle close to the mine site and it would be impossible to liberate harmful elements from the sulphide debris as a consequence of mining. Finally, sulphide mining would impact only very small areas. The areas being discussed were about the size of several football fields. Professor Herzig believed that there would be an impact on the environment, but that it would be in a very limited area.

In order to collect reliable data on the environmental impact of seafloor sulphide mining, a pilot mining site would need to be established. Professor Herzig said that he had suggested this many times before. It could be coordinated either by the International Seabed Authority or other authorities, but it was required in order to get reliable data for the impact of sulphide mining on the marine environment. Test-mining operations would be needed and then economics could be considered. First of all, environmental data needed to be collected, so that it could be decided whether mining should be allowed in certain areas.

Professor Herzig stated that there would always be three steps to be followed: the first step would be surface sampling and, for this to be done, a proper mine site would need to be selected. This step had been taken for 250 deposits worldwide. The second step was shallow drilling and resource assessment. This had been done in only a few places, such as the TAG mound and the Manus area. The final step, which had never been done before, would be mining and monitoring. Again, a location in which massive sulphides could be test-mined would need to be selected. A coordinated monitoring programme to get reliable data would be needed and legislation for mining of seafloor massive sulphide deposits would need to be drafted. In Professor Herzig's view, it was not a matter of whether it would happen, but rather, when. Oil companies had been in the same situation about 35 years prior to the workshop with regard to oil deposits. Since then, there was no doubt that this had been a very successful development. In Brazil, there was deep water production from 1,600 metres of water depth and even deeper. Professor Herzig concluded by stating that this was the next step and that the international mining and exploration companies were in the same position that the oil companies were in 35 years ago and reiterated that it was not a matter of whether it would occur, but when.

SUMMARY OF DISCUSSION

A participant raised the question of the potential toxicity created by mining polymetallic sulphides because some very fine sulphides material would drift away from the site and could settle on the gills of filter-feeding animals, thereby creating more of an impact than the toxicity. A biologist replied that, if the filter-feeding apparatus of an organism were clogged, there would be a problem. It may be a short-term (non-permanent) effect, where other animals could come in and recolonize the area. It was stated that fishermen had been trawling shallow waters for a long time, so it depended on what was accepted as the level of impact on the environment. It was felt that this was one of the issues to be considered at the workshop. The biologist had also wondered about the bio-availability problem, because she believed that if the metals were bound to the sulphide, it would not be an issue.

Professor Herzig was questioned about the cut-off of 100 million tons of metallic-rich sediments in the Atlantis II Deep, which he had said had been a political decision. The participant who posed the question thought that the Saudi-Sudanese Commission worked effectively and that the main issue was economics, relating to the market for those metals after all the expenses of extracting and refining them. Professor Herzig responded that he had gotten the information from Harold Becker, the Chief Scientist at Marine Technology for many years, who had said that the Commission could not decide which sector should be mined and where the mining should start. He said that the Commission had not mentioned economic considerations but that he did not want to exclude them.

CHAPTER 6 THE PHYSICAL ENVIRONMENT OF POLYMETALLIC SULPHIDES DEPOSITS, THE POTENTIAL IMPACT OF EXPLORATION AND MINING ON THIS ENVIRONMENT, AND DATA REQUIRED TO ESTABLISH ENVIRONMENTAL BASELINES IN EXPLORATION AREAS

Dr. Andreas Thurnherr, Doherty Associate Research Scientist, Columbia University, LDEO, Oceanography, New York, United States of America

Introduction

Polymetallic sulphides are deposited on the deep seafloor in active high-temperature hydrothermal vent fields. High-temperature hydrothermal circulation is known to occur along the crest of the global mid-ocean ridge system, in back-arc basins and on island-arc volcanoes. (In this report, no consideration is given to the observation that many of the non-mid-ocean ridge sites may lie within the exclusive economic zones of particular countries and, thus, outside the area governed by the International Seabed Authority). Because of seafloor spreading, polymetallic sulphides deposits can also occur away from the sites of active hydrothermal circulation, for example, on the flanks of mid-ocean ridges. In principle, the mining of polymetallic sulphides is possible both in active and extinct hydrothermal vent fields.

The anticipated primary effect of polymetallic sulphides mining on the physical environment consists of the release into the water column of dissolved and suspended mining products. The main focus of this report is, therefore, an assessment of dispersal from potential mining sites. The direct influence of mining on the oceanic circulation is most likely limited to spatial scales up to the order of the size of the sulphides deposits (hundreds of metres). Larger-scale indirect effects are possible in principle because of the weak stratification in the deep ocean, which implies that even small-density anomalies cause convective plumes. In conjunction with the Earth's rotation, the density anomalies introduced into the water column by convective plumes can drive basin-scale circulations (beta plumes; Stommel, 1982). In this report, it is assumed that mining techniques will not introduce any large-scale density anomalies into the water column; as a result, only effects up to scales of a few tens of kilometres are discussed.

It is possible that future mining operations will employ blasting techniques, which greatly influence the physical environment on very short temporal, but large, spatial scales and can have severe ecological impacts. Investigating the physical effects of underwater explosions is a separate topic of study, in particular with engineering and military applications (e.g. Cole, 1948); it is not covered in this report.

The present report is structured as follows: first, important characteristics of the physical environment particular to active and extinct hydrothermal vent fields are described; followed by a discussion of considerations that are important in the context of dispersal assessments. Data from five different deep-ocean sites, near known vent fields or potential sulphides deposits, are then presented to illustrate important characteristics of dispersal in the deep ocean near topography, and also the different techniques commonly used to assess such dispersal followed by the conclusion with a short discussion.

Physical environment

(a) The deep ocean

Most known hydrothermal vent fields are located in the deep ocean below 1,000 metres, where ambient light is negligible and typical temperatures are a few degrees above freezing. The background water column is normally stably stratified in temperature and density, but it can be both stably (e.g. in the deep Pacific) and unstably (e.g. in the deep Atlantic) stratified in salinity. Away from boundary currents and choke points, most of the kinetic energy is usually found in the tidal and near-inertial frequency bands, with velocities reaching a few $cm \cdot s^{-1}$. Mesoscale eddies are associated with similar velocities. Hydrothermal vent fields are not entirely restricted to the deep ocean, however. There are known shallow sites on the mid-ocean ridge crest (German et al., 1994) and on the flanks of island-arc volcanoes (de Ronde et al., 2001).

(b) Topographic effects

Being associated with spreading tectonic plates and underwater volcanism, hydrothermal vent fields are commonly located in regions of complex topography. Topographic effects influence the physical environment in many ways. The following incomplete list and the sketch in Figure 1 briefly introduce some of the topographic effects that are important in the context of dispersal from potential mining sites:

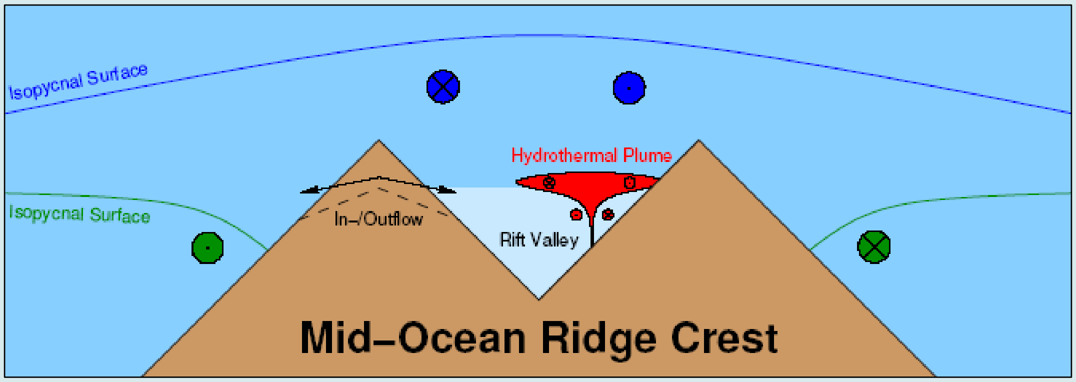

Figure 1: Sketch illustrating some of the effects of important physical processes acting near the crest of a slow-spreading ridge in the northern hemisphere.

Diapycnal mixing. Microstructure observations between the continental slope of South America and the crest of the Mid-Atlantic Ridge in the South Atlantic indicate high levels of diapycnal mixing over the rough Mid-Atlantic Ridge flank (Polzin et al., 1997; Ledwell et al., 2000). Mixing reduces the stratification of the water column and spreads tracers across isopycnals. Spatially varying mixing causes density gradients, which drive secondary circulations. The commonly observed sloping of isopycnal surfaces over the flanks of mid-ocean ridges is usually assumed to be caused by mixing on the slopes, although available theoretical models are not consistent with the thickness of the observed layers (Thurnherr and Speer, 2003). On the rotating Earth, sloping isopycnals on planar slopes imply along-slope flows. Numerical models have been used to predict mixing-driven flows along the flanks of mid-ocean ridges (e.g. Thompson and Johnson, 1996; Huang and Jin, 2002), although in at least one case, the available data indicate dispersal in the opposite direction from that predicted by the model (Thurnherr and Speer, 2003).

Hydraulics and blocking. Topographic obstacles in the path of a current force it to flow either over or around. Blocking takes place when there is no way around the obstacle and when the impinging flow is not sufficiently energetic to pass over it. If the upstream velocities are large enough, the resulting overflow is often associated with signatures characteristic of hydraulic control and elevated mixing (e.g. Thurnherr and Richards, 2001). Hydraulics and blocking are particularly important in sloping submarine valleys, both on the axes of slow-spreading mid-ocean ridges (Thurnherr et al., 2002) and on ridge flanks (Thurnherr and Speer, 2003).

Flow amplification. The quasi-steady circulation in the deep ocean away from topography is associated with characteristic velocities of a few mm·s–1. (The velocities associated with mesoscale eddies are of order $cm \cdot s^{-1}$.) In the vicinity of topography, mean velocities of several $cm \cdot s^{-1}$ are not uncommon, again, particularly in sloping submarine valleys (e.g. Keller et al., 1975; Thurnherr et al., 2002). Temporally varying flows can also be amplified near topography. For example, deep tidal velocities exceeding 20 $cm \cdot s^{-1}$ have been observed at one site in the rift valley of the MAR (Jean-Baptiste et al., 1998).

Wave trapping and flow rectification**.** Topography can trap large-amplitude waves and generate significant residual currents. It has been inferred that this effect is responsible for the anticyclonic residual flow observed on both sides of the crest of the Juan de Fuca Ridge (Cannon and Pashinski, 1997), as well as for the amplification in the three-to-seven-day band observed in the same region (Lavelle and Cannon, 2001). (Additional information regarding wave trapping and flow rectification can be found in the report by Beckmann.)

Vorticity effects. The conservation of angular momentum introduces a tendency for anticyclonic flow over topographic highs (and cyclonic flow over topographic depressions). This effect commonly manifests itself by a doming of isopycnal surfaces over mid-ocean ridges. (Additional information regarding vorticity effects can be found in the report by Beckmann.)

(c) Hydrothermal plumes

Hydrothermal effluents that enter the water column in active vent fields are associated with physical and chemical anomalies compared to the background water at the source (e.g. Von Damm, 1995). The geothermally heated effluents rise as buoyant plumes through the water column if their density deficits are sufficiently large. The high ambient pressure at depth prevents even high-temperature hydrothermal effluents (300°–400°C) from boiling. On entering the ocean, the hydrothermal effluents mix with background water and rapidly decrease in temperature. As a consequence, metal sulphides and oxides precipitate and the buoyant plumes take on the characteristics of more-or-less dark “smoke” (e.g. Feely et al., 1987). Continuous mixing with background water, called entrainment, gradually increases the density of the buoyant fluid, which eventually reaches its equilibrium height of neutral density in the stratified background water column (Morton et al., 1956). Neutrally buoyant hydrothermal plumes are typically found between the seabed and several hundreds of metres above the sources. Because of differences in background salinity stratifications and source-fluid properties, the neutrally buoyant plumes can be associated with temperature/salinity anomalies of either sign (McDougall, 1990). Because of strong non-linearities at high temperatures in the equation of state of brines there is potential for buoyancy reversal in rising plumes, which can cause brine pools on the seafloor (Turner and Campbell, 1987). The double-diffusive nature of the interface of such brine pools significantly reduces further mixing with overlying background water (e.g. Kelley et al., 2003).

While typical effluent temperatures of black-smoker fluids are high (300°–400°C), temperature excesses of more than one degree are restricted to the first few metres inside the buoyant smoker plumes immediately above the vents (e.g. Kim et al., 1994). In spite of exit velocities of order $1 m \cdot s^{-1}$ (Converse et al., 1984), typical effluent volume fluxes of hydrothermal sources are small, implying that the entrained volume fluxes are small as well: using values given by Converse et al., (1984), the model of Morton et al., (1956) predicts radial entrainment velocities at 1m horizontal distance from the source of order 10^{-3} $m \cdot s^{-1}$. With the exception of particle-related optical anomalies, strong physical effects of hydrothermal circulation are therefore restricted to the immediate vicinity of the effluent sources. Theoretical considerations suggest that larger horizontal plume-related velocities may be possible because of the effects of the Earth's rotation. In the simple model of Speer (1989) the convergence caused by entrainment into a buoyant plume causes a coherent cyclonic vortex with velocities reaching several $cm \cdot s^{-1}$; an anticyclonic vortex of similar magnitude is predicted in the neutrally-buoyant spreading plume. The predicted coherent vortices have been observed in laboratory experiments, but they are unstable and propagate away from the sources (Helfrich and Battisti, 1991). Apart from large neutrally-buoyant event plumes (caused by volcanic eruptions on the seabed), which have been observed to rotate anticyclonically (e.g. D'Asaro et al., 1994), there is currently no observational evidence for coherent plume-driven vortices in the ocean. In particular, the predicted strong coherent cyclonic vortices around buoyant plumes appear to be missing (e.g. Joyce et al., 1998). On even larger scales, the density anomalies caused by the integrated effects of many hydrothermal sources can potentially drive basin-scale circulations (Stommel, 1982). The inferred flow velocities are small, however, and the observational evidence is ambiguous at best (Talley and Johnson, 1994).

Dispersal in the ocean

(a) Time and space scales

In order to assess dispersal of mining products, the relevant time and space scales, related by the velocity field, must be determined. In case of dissolved dispersants, an upper limit for the timescale depends on the reactivity of the substance and/or on the level at which it is considered to be sufficiently diluted so as not to be significant any more. In case of dispersing particles the upper limit of the timescale is determined by the height above the seabed at which particles are released and the settling velocity v. Small, near-spherical particles settle with the Stokes' velocity (e.g. Acheson, 1990)

$$v = g \Delta\rho D^2 / (18 \eta)$$

where g ~ 10m^2·s^{-1} is the acceleration due to gravity, $\Delta\rho$ is the density excess of the particles with respect to the water, D is the particle diameter, and η ~ 0.01 kg·m^{-1}·s^{-1} is the (dynamic) viscosity of water.

In addition to the upper time limit relevant for dispersal, there are two more time and associated space scales that merit special consideration:

Tidal and inertial scales. Even in regions of complex topography, the kinetic energy spectra are often dominated by peaks at tidal and/or near-inertial frequencies. This implies that on small temporal scales, dispersal is usually not significantly constrained by low frequency flows, that is, on timescales of hours, dispersal against the mean flow is often nearly as probable as dispersal with the mean flow. Tidal dispersal distances are typically a few hundreds of metres.

Lagrangian integral timescale. The temporally varying flow field in the ocean causes dispersal along isopycnal surfaces (see below). On scales longer than the Lagrangian integral timescale (typically of order 10 days in the deep ocean; e.g. LaCasce and Speer, 1999) the dispersal is diffusive, that is, particle separation increases with the square root of elapsed time. On shorter scales, dispersal is linear in time (e.g. Speer et al., 2003).

(b) Eulerian vs. Lagrangian viewpoints

Moored current meters yield time series of velocities at a fixed point in space, called Eulerian velocities. Flow-following tracers, such as hydrothermal particle plumes and neutrally buoyant floats, are called Lagrangian. Lagrangian measurements can be differentiated in time to calculate velocities following the flow, although there are numerous issues related to real, finite sampling by a limited number of drifters that need to be taken into account when estimating Lagrangian statistics (Davis, 1991). In unsteady flows, Eulerian and Lagrangian means at the same point are often different, as illustrated in Figure 2 by the example of Stokes drift associated with a train of idealized surface-gravity waves. The solid circle shows the integrated Eulerian velocities, which have a zero mean value. The dashed line shows the corresponding integrated Lagrangian velocities, illustrating a horizontal mean velocity in the direction of wave propagation. This Stokes drift is caused by the exponential dropoff of the velocities with depth, that is to say, the positive horizontal velocities associated with the wave crests are always greater than the negative velocities in the deeper troughs. Stokes drift is not restricted to surface gravity waves, but is a common feature of unsteady spatially varying flows.

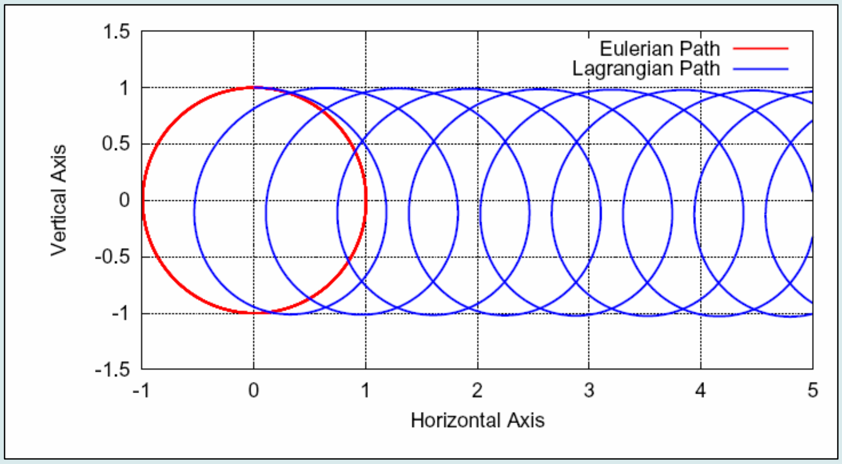

Figure 2: *Hodographs (integrated velocity measurements) of Eulerian and Lagrangian velocities under a train of idealized surface gravity waves propagating to the right; Speer et al. (2003).*

(c) Advection vs. eddy diffusion

In practice, dispersal is often assessed on the basis of Eulerian measurements (current-meter records), which are averaged in time in order to yield record-mean advection velocities. This ignores that in addition to advection, the stochastic nature of the oceanic flow field causes a cloud of Lagrangian tracers to spread horizontally. At times greater than the Lagrangian integral timescale (see above) this spreading follows a square-root law and can, therefore, be described by defining an eddy diffusion with units of $m^2 \cdot s^{-1}$. Figure 3 compares the relative effects of advection and diffusion for typical oceanic parameter values. Only in regions of strong, low-frequency flows can eddy-diffusive dispersal be safely ignored on timescales of months to years. Elsewhere, dispersion takes place both with and against the mean flow!

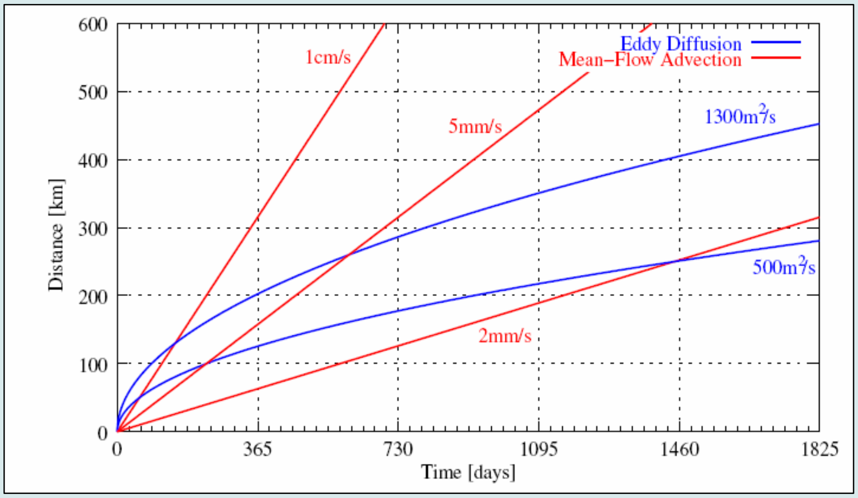

Figure 3: Advective vs. diffusive dispersion for typical deep oceanic mean flow velocities and eddy diffusivities; from Speer et al. (2003).

Dispersal observations

(a) Dispersal in the rift valley of a slow-spreading ridge

The particle plumes released into the water column on active, high-temperature hydrothermal vent fields can sometimes be used to assess dispersal some distance above the vent field. The left panel of Figure 4 shows the topography of the Mid-Atlantic Ridge crest in the vicinity of the Rainbow hydrothermal vent field, located at 2,300 metres on the western flank of a topographic high partially blocking the rift valley near 36^0N. Active vent fields on slow spreading ridges are usually found in the deep axial rift valleys. In the case of the Rainbow site, the ridge axis runs roughly southwest to northeast and the rift-valley walls block direct exchange with the deep ocean basins on either side of the ridge up to ¼1,800 metres. The time-averaged neutrally-buoyant Rainbow particle plume extends from the source depth to 2,300 metres, that is, it is confined within the rift valley (Thurnherr and Richards, 2001). The right panel of Figure 4 shows a perspective view of an extensive plume survey carried out in 1997. Hydrothermal particles are only observed northeast of the vent field, implying that the flow during the three-week survey was essentially unidirectional and strong enough for eddy diffusion to be ignored. This inference agrees with at least three additional plume surveys that were carried out in different years, suggesting that the northeastward flow in the rift valley near 36^0N is persistent on long timescales (see Thurnherr (2000) for details).

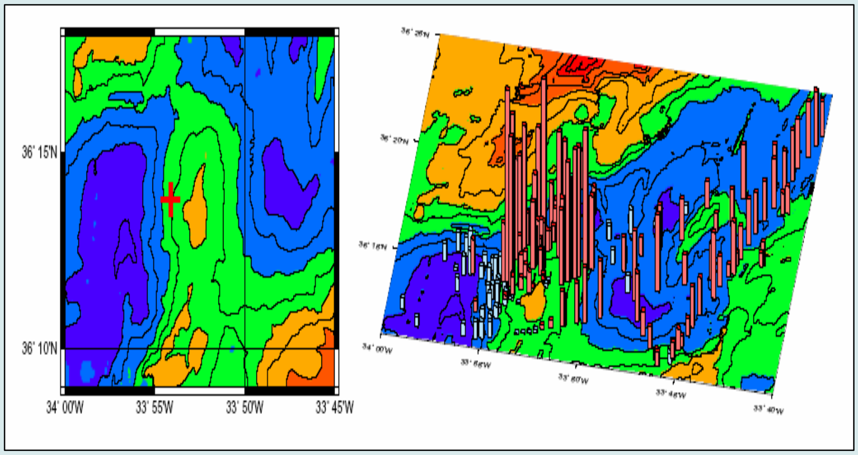

Figure 4: Hydrothermal plume in the rift valley of the Mid-Atlantic Ridge near 36±N. Left panel: topography and vent-field location; blue regions are deeper than 2500 m, green regions are between 2,000 m and 2,500 m, and orange regions are less than 2,000 m deep; bathymetric contour interval is 250 m. Right panel: depth-integrated hydrothermal plume particles; profiles with (without) plume signals are shown in red (blue). See Thurnherr and Richards (2001) for details.

While the dispersal information inferred from the Rainbow hydrothermal plume is useful, it is entirely qualitative. Furthermore, it does not answer important questions regarding temporal and spatial (in particular, vertical) variability of the flow field. Without additional surveys, the representativeness of the data shown in figure 4 would not be clear. The variability of hydrothermal plume observations is another problem, as large numbers of profiles are generally required in order to determine some sort of a "mean" plume (Thurnherr and Richards, 2001). Because of these considerations, the rift-valley near the Rainbow site was instrumented with moored current meters, which measured the rift-valley flow at several levels during an entire year. The available data reveal that the flow near the vent field was unidirectional below 2,000 metres, but that it changed direction at 1,800 metres (Figure 5). The inference that eddy diffusion can be ignored at this site is consistent with the magnitude of the low-frequency advective velocities near the vent field; Figure 3 implies that unusually large eddy diffusivity would be required for this process to become important here.

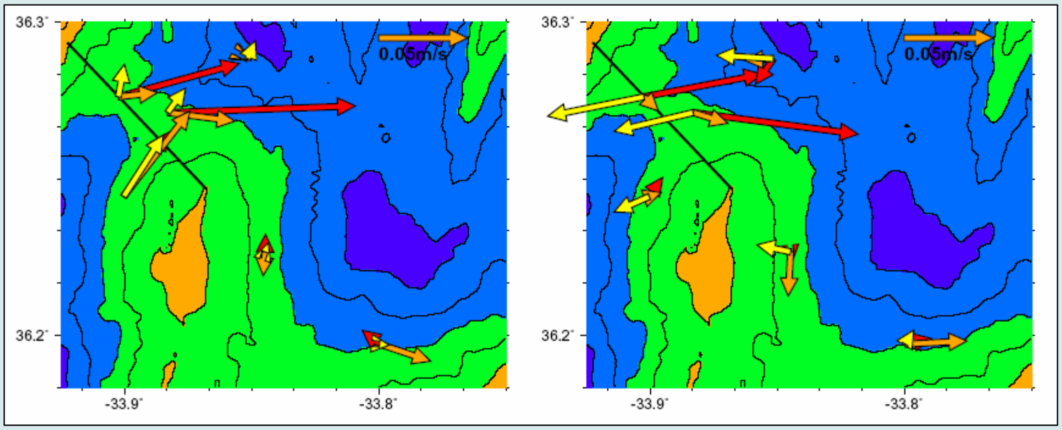

Figure 5: Two examples of weekly averaged current-meter velocities at 1,800, 2,100 and 2,300 m (yellow, orange and red arrows) near the Rainbow vent field. Topographic shading and contours are the same as in Figure 4. See Thurnherr et al. (2002) for details.

Persistent unidirectional flows, such as the one near the Rainbow hydrothermal site are fairly atypical in the deep ocean. At one site in the North Atlantic, the mean flow direction could not be determined after nine years of uninterrupted current-meter measurements (Müller and Siedler, 1992)! A segment-scale hydrographic survey near the Rainbow hydrothermal site reveals an interesting picture (Figure 6): the density inside the rift valley decreases in the along-stream direction. Apart from inflow across sill "I" the water below the white contour in the figure is blocked within the rift valley. It must therefore gain buoyancy before it can flow out at the northern end of the segment. A detailed analysis reveals that the along-stream buoyancy gain is dominated by diapycnal mixing, whereas geothermal heating plays an insignificant role (Thurnherr et al., 2002). (Elsewhere, there is at least one site where an along-valley flow is driven by entrainment into hydrothermal plumes; Thomson et al., 2003.) An earlier review of temperature data reveals that along-segment hydrographic gradients are common in the rift valley of the Mid-Atlantic Ridge (Saunders and Francis, 1985), suggesting that the situation near the Rainbow hydrothermal vent field may be common. However, there are current-meter records from other rift-valley sites on the Mid-Atlantic Ridge that contain frequent reversals of the direction of the low-frequency flow (e.g. Jean-Baptiste et al., 1998; Murton et al., 1999).

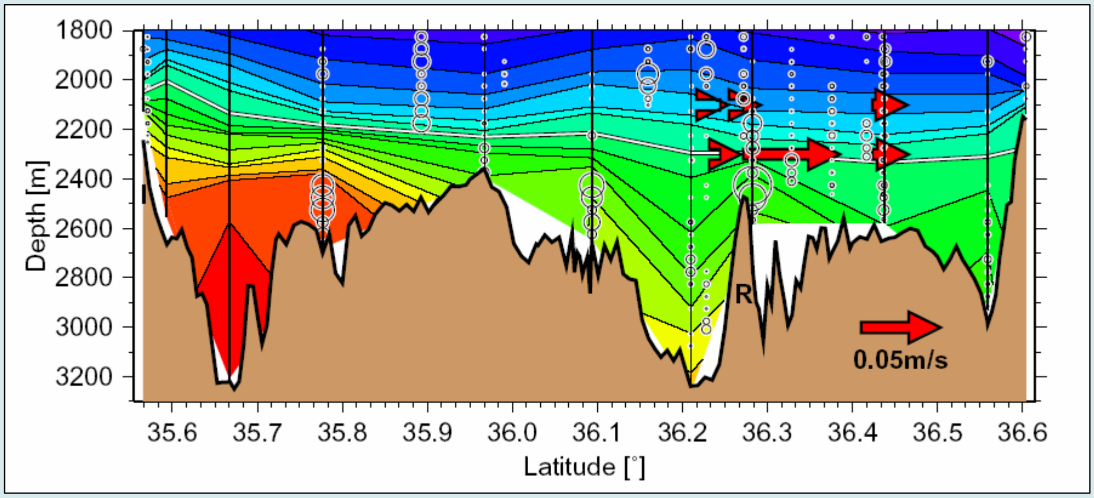

Figure 6: Rift-valley density section (contours), flow speeds (arrows), and diffusivity estimates from overturning scales ("bubbles"); the area below the white contour is blocked within the rift valley. See Thurnherr et al. (2002) for details.

(b) Dispersal on a ridge flank

Valley flows, such as the one near the Rainbow hydrothermal site (section 4a.), are not restricted to the rift valleys of slow-spreading ridges. The inversion of hydrographic and mixing data from a ridge-flank canyon in the South Atlantic carried out by St. Laurent et al., (2001) yields a solution that is similar in many respects, with strong mixing balancing a mean along-valley advection of dense water toward the ridge crest. Recently obtained current-meter records from the same canyon confirm the existence of the inferred mean along-valley flow (left panel of Figure 7). A detailed analysis of available hydrographic data from the South Atlantic reveals that the canyon analysed by St. Laurent et al., (2001) is in no way special: similar along-canyon density gradients (and, by inference, mean crestward valley flows) occur on the ridge flanks across the entire tropical and subtropical South Atlantic Thurnherr and Speer (2003). Since cross-flank canyons are characteristic of slow-spreading ridges (which make up more than half of the global mid-ocean ridge system), valley flows are potentially very common (Speer and Thurnherr, 2003).

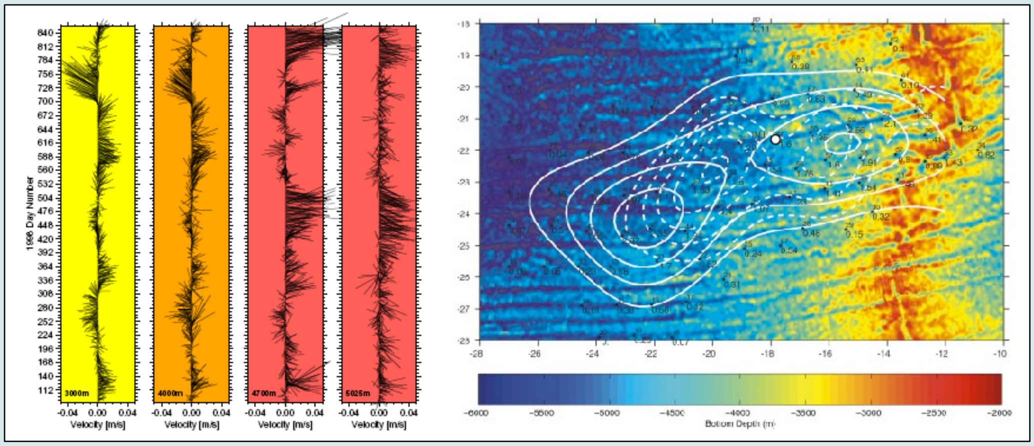

Figure 7: Flow and dispersal over the western flank of the Mid-Atlantic Ridge in the South Atlantic. Left panel: daily averaged current-meter velocities at (orange) and above (yellow) the topography and inside a ridge-flank canyon (red). Right panel: tracer isopleths in 1998 (dashed) and 2000 (solid) and current-meter location (bullet); western tracer patch lies above topography; eastern tracer patch is confined within the ridge-flank canyons; see (Ledwell et al., 2000) for details.

Lagrangian data from the flank of the Mid-Atlantic Ridge in the South Atlantic (Figure 7) nicely illustrate the combined effects of advection and diffusion in controlling dispersal. In 1997, a cloud of tracer was injected into the water column above the western flank of the Mid-Atlantic Ridge near 22°S (Ledwell et al., 2000). During the two years of current-meter measurements the centre of a tracer patch above the ridge flank moved southwestward with a mean speed of approximately 0.4 $cm·s^{-1}$. The western tracer patch is in the right panel of Figure 7; the eastern patch is within the canyons on the Mid-Atlantic Ridge flank and moved crestward, consistent with the previously discussed valley flows. At the same time, the patch spread laterally under the influence of eddy diffusion. While the bulk of the tracer moved with the mean flow, some of the tracer dispersed in the opposite direction. Available float and tracer data from this region indicate that the meridional component of the eddy diffusivity is ¼103 $m^2·s^{-1}$ (Thurnherr and Speer, 2004). The expected advective and diffusive contributions to dispersion are therefore approximately equal (200–300 km; Figure 3), consistent with the tracer observations.

The two-year current-meter records taken during the same time in this region above the ridge-flank canyon (at 3,000 and 4,000m in the left panel of Figure 7) are not useful for assessing dispersal in this case. In fact, both record-mean velocities indicate mean flow of ¼0.5 $cm·s^{-1}$ to the north. Nevertheless, the current-meter data are consistent with the tracer observations because the observed variability indicates a velocity standard error >1 cm·s^{-1} (Thurnherr et al., 2004).

In the context of the South Atlantic data sets, it is also interesting to note that a recent numerical model, which was specifically designed to investigate the flow on the flank of the Mid-Atlantic Ridge in the South Atlantic, predicts northward flow in the region of the tracer (Huang and Jin, 2002). The reason for the discrepancy is that the model resolution does not resolve the ridge-flank canyons, which block northward flow that would otherwise be the result of bottom-intensified mixing there (Thurnherr and Speer, 2003). Devising numerical models that can adequately resolve the topography at the scales relevant for dispersal remains a formidable task.

(c) Flow on the crest of a fast-spreading ridge

Not all ridge-crest hydrothermal vent fields are located on slow-spreading ridges; in fact, it has been suggested that there is a linear relationship between ridge spreading rate and hydrothermal heat flux (Baker and Hammond, 1992). Fast-spreading ridges are not associated with deep rift valleys, implying that dispersion from ridge-crest sites is much less directly constrained by topography. This is illustrated in the left panel of Figure 8, which shows five-month current-meter data collected 1 and 172 metres above the seabed at 9°N on the East Pacific Rise. During the 20 weeks of data collection, weekly averaged velocities in any direction were observed at both levels. There appears to be little coherence between the observed flows at the two levels.

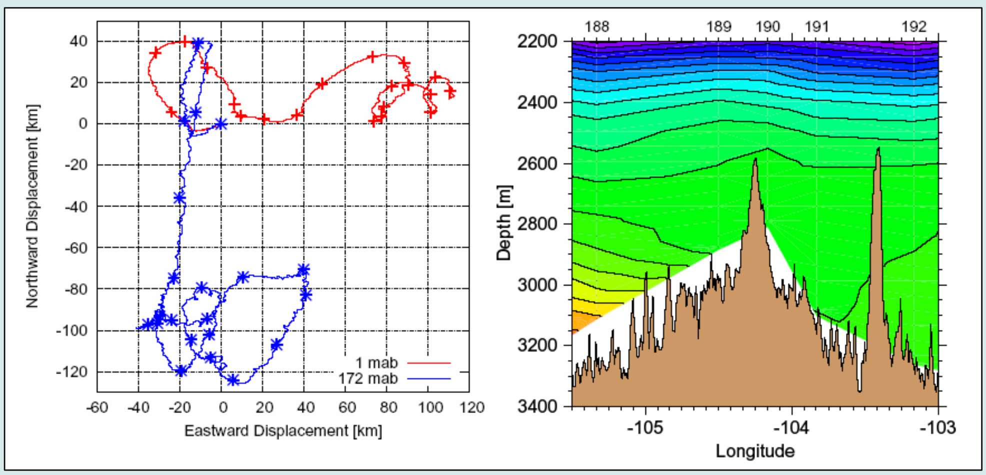

Figure 8: Data from the East Pacific Rise crest at 9±N. Left panel: progressive vector diagram from 20-week current-meter records collected 1m and 172m above the seabed; symbols are plotted every week. Right panel: cross-ridge section of neutral density from WOCE P04 section.

The current-meter data from the Eastern Pacific Rise are presented as progressive vector diagrams, which show Eulerian data in a quasi-Lagrangian fashion. This view seems to suggest that a tracer released into the near-bottom water column at the beginning of the measurements would end up 110 kilometres to the east five months later. This is an invalid inference, however. Progressive vector diagrams can be misleading, in particular near topography, because they implicitly assume that the flow field is horizontally homogeneous over the scales involved. In order for the progressive vector diagrams to approximate (Lagrangian) particle trajectories, the velocity 20 kilometres west and 40 kilometres north of the lower current meter three weeks after the beginning of the experiment, for example, would have to be to the east. While the true velocity there is not known, the density section across the ridge shown in the right panel of figure 8 suggests that it is unlikely that the velocities on either flank are the same as the velocity on the crest, as the vertical shears east and west of the ridge crest are of different sign. Of course, this argument assumes that the cross-ridge density structure during the current-meter experiment was similar to the one shown, which was observed in a different year. However, isopycnals sloping downward into ridge flanks and doming above ridge crests are commonly observed in hydrographic sections crossing mid-ocean ridges and the assumption is, therefore, more reasonable than the assumption of horizontally homogeneous flow.

The record-mean velocities recorded by both current meters are approximately 1 $cm \cdot s^{-1}$. Here too, the standard error is ~1 $cm \cdot s^{-1}$, indicating that the means are only marginally significant. If it is assumed (for lack of data-based estimates) that the horizontal eddy diffusivity is also of the order 10^3 $m^2 \cdot s^{-1,}$ Figure 3 implies that the dispersive effects of eddy diffusion are similar to those of advection by the mean flow. In this case, some portion of a hypothetical tracer released into the water column at the beginning of the current-meter measurement could end up in any direction. If the record-mean flows were representative on longer timescales, mean-flow advection would eventually dominate over eddy diffusion. However, hydrothermal particle plume observations from the same region in another year suggest predominantly westward off-ridge flow (Baker et al., 1994).

(d) Flow in back-arc basins

A further disadvantage of moored current meters is that the instruments have to be recovered in order to gain access to the data. (There are currently efforts underway to solve that problem. In one prototype solution, Ultramoor, data capsules are periodically released from the mooring sending the data back by satellite without requiring a ship to visit the mooring site; see http://www.whoi.edu/science/AOPE/prototype/projects/ultramoor for details). An alternative measurement technique, consisting of neutrally-buoyant floats, is currently being employed in order to determine the regional circulation in the Lau Back-arc Basin (left panel of Figure 9). The floats used in this particular project have an expected lifetime of about five years and periodically return to the surface, where they are tracked by a network of satellites. The mean velocities at depth are calculated from the float displacements; they are contaminated by the displacements taking place during descent to and ascent from the target depths, as well as on the surface. It is therefore important that the time between surfacings is long enough for the deep velocities to dominate the displacements, which requires a priori estimates of the expected velocities at depth. The floats are usually equipped with sensors, the data of which are transmitted back to shore by satellites. Currently, pressure, temperature and salinity sensors are available off-the-shelf. It is also possible to track floats acoustically while they are drifting at depth. This allows much better temporal resolution of the velocity measurements but it requires the deployment and maintenance of acoustic mooring arrays. In particular, in regions of rough topography, such tracking can be problematic because of shading effects.

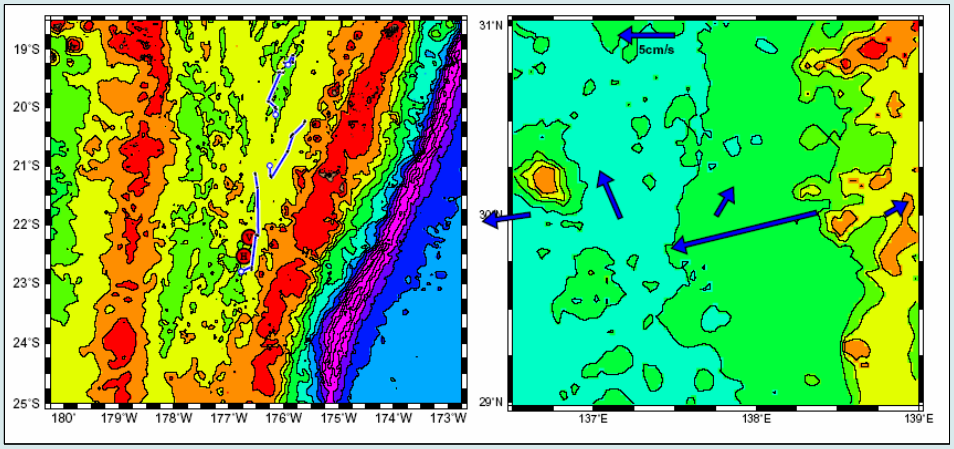

Figure 9: Velocity data from two back-arc basins. Left panel: 12-week-long float trajectories near 1700m in the Lau Basin between Fiji and Tonga; topographic contour interval is 850 m; "H" and "V" mark the locations of hydrothermal sites known at the time of float deployment. Right panel: bottom-100m velocities from LADCP data in the eastern part of the Shikoku Basin near Japan; topographic contour interval is 850 m.

The currently available float data from the Lau Basin (four 28-day cycles from four floats) suggest a remarkably consistent northward flow of order 1–2 $cm \cdot s^{-1}$ in the eastern part of the basin. This is approximately two to four times stronger than expected, based on a hydrographic analysis carried out during the project proposal. If the flow pattern is confirmed by future data, it implies that dispersal over timescales of months to years is likely dominated by advection (Figure 3), unless the Lau Basin is associated with extraordinarily strong horizontal eddy diffusion. Eventually, it may be possible to estimate the eddy diffusivity from the float data (e.g. Speer et al., 2003). However, many more data than currently available will be required for a meaningful estimate.

Recently obtained Lowered Acoustic Doppler Current Profiler (LADCP) profiles from the Shikoku Basin southeast of Japan suggest that much stronger deep flows are possible in back-arc basins (right panel of Figure 9). It is of course dangerous to draw inferences from a single profile, but it should be noted that the directions of flow along the eastern boundaries of both back-arc basins are consistent with anticyclonic (clockwise in northern hemisphere and anticlockwise south of the equator) circulations in the basins. There are reasons to expect either cyclonic or anticyclonic circulations in stratified (partially) enclosed basins. On the one hand, Johnson (1998) analysed current-meter records from a number of deep oceanic trenches and found primarily cyclonic circulations, consistent with upwelling-related vortex stretching. Boundary mixing on slopes, on the other hand, are known to cause horizontal density gradients consistent with anticyclonic along-slope flows (Thompson and Johnson, 1996) but Thurnherr and Speer (2003) show that the anticyclonic along-slope flows can be (partially or fully) topographically blocked and that diapycnal mixing can also cause gradients consistent with cyclonic along-slope flows. Hypsometric effects associated with upwelling in basins with sloping sidewalls can also lead to anticyclonic circulations (Rines and MacCready, 1989; Speer and Tziperman, 1990).

DISCUSSIONS

The physical environment of polymetallic sulphides deposits is highly complex, because hydrothermal vent fields are usually situated in regions of rough topography. Topographic effects on the dynamics include the imposition of small scales by blocking and channelling, strengthening of externally forced flows, for example, in boundary currents and overflows, driving of secondary circulations by bottom-enhanced diapycnal mixing in valleys and on slopes, as well as circulations driven by the conservation of angular momentum (potential vorticity). In active hydrothermal vent fields, additional highly localized strong vertical circulations are driven by convection.

Because of the range of scales involved, numerical modelling of dispersion near polymetallic sulphides deposits presents a formidable task. On the other hand, the technology required to assess dispersal is readily available. For a comprehensive assessment, both Eulerian (current meters) and Lagrangian (floats and/or tracers) measurements are required in general because both advection and eddy diffusion are important for dispersal.

ACKNOWLEDGMENTS

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SUMMARY OF PRESENTATION

Dr. Thurnherr began his presentation stating that deposits of polymetallic sulphides form on the seafloor by high temperature hydrothermal circulation and that hydrothermal sites are globally distributed. He said that hydrothermal vent fields occurred in three different settings, namely, along the axis of the global mid-ocean ridge system; in back-arc basins (mainly in the western Pacific, but also in the Mediterranean and Antarctica); and on island-arc volcanoes.

Dr. Thurnherr noted that these settings had similarities. Along the mid-ocean ridge, he said that the crest was predominantly deep - below 1,000 metres - and the region showed complex topography. He also said that the back-arc basin ridge zones were usually deep, characterized by complex topography and their environment was very different to that of manganese nodules, which were in the deep-ocean basins. He described the third setting, the island-arc volcanoes, as one where hydrothermal vents were possible at any depth, with varied topography. He informed participants that at all these settings active hydrothermal vent fields were always in a region of complex or significant topography.

Dr. Thurnherr said that he would give a brief overview of the physical environment of hydrothermal vent fields. He said that his talk would include both active and inactive hydrothermal vent fields. With regard to the latter, he said that as sulphides deposits could move off the axes of ocean ridges, he would also cover the physical environment on ridge flanks. He also said that the location of deposits, whether in the Area or in exclusive economic zones was irrelevant since it did not affect the physical environment. He said that in the second part of his presentation, he would talk about dispersal near complex topography. In relation to the impact of polymetallic sulphides mining on the physical environment, he linked this to dispersal processes, that is, the dispersal of pollutants and particles released at mine sites.

According to Dr. Thurnherr, the physical environment near a polymetallic sulphides deposit was the typical deep-ocean environment: it was dark, cold (a few degrees above freezing) and generally high pressure. He said that the instantaneous velocity of water in the deep-ocean environment was generally in the order of a few centimetres per second, and that mean flow velocities over weeks and months were a few millimetres per second. Dr. Thurnherr said the expectation is that mining operations will directly affect the environment in any significant way beyond the scales of mining. In this regard, he also said that mining a deposit of the size of the TAG mound astrodome would change the currents over that scale, but would not have a significant effect on a larger scale. He pointed out that blasting the deposit would be the exception, although he suggested that this was unlikely. He said that with blasting, the scales would depend entirely on the amount and the size of the blast.

It was noted by Dr. Thurnherr that there were other indirect large-scale effects possible if density anomalies were introduced into the water column. For example, if large amounts of fresh water were pumped down to the seabed, some kind of connected plumes would be formed and these would have the potential to drive large-scale circulations. Dr. Thurnherr considered it very important to consider scales larger than the physical scale of mining, because of the possibility of dispersal of material released into the water column during mining or during transport to the surface by physical processes. He said that should this occur, the impact would be on a larger scale - much larger, in some cases - than that of mining.

Dr. Thurnherr showed a slide of a schematic part of a ridge crest on a slow-spreading mid-ocean ridge to illustrate the influence of topographic effects on the physical environment near polymetallic sulphides deposits. The processes were the same everywhere and he believed that the most important one was diapycnal mixing. He said that anywhere near rough topography there would be a lot of mixing and this distributed dissolved and suspended materials in the water column. He said that mixing also caused isopycnal surfaces of constant density in the ocean and the flow in the ocean tended to be along these surfaces. He also said that if there was mixing on the rough ridge flanks, it would cause the isopycnal surfaces to lower into the flanks. He pointed out that the rotation of the earth would create along-flank flows. He said that the velocity of these flows would usually be about a few millimetres per second, and thus not particularly strong.

Dr. Thurnherr said that other items of importance were blocking and hydraulics. He described the rift valley of the Mid-Atlantic Ridge as an example of a feature usually blocked from the environment on either side of the ridges. He said that in back-arc basins, the water was usually blocked, with only one entry and exit point, and that usually caused lower stratification. According to Dr. Thurnherr, there was background flow amplification, meaning that, whenever flow measurements were taken near topography, much higher mean flows were recorded than away from the feature. Instead of having mean flows with millimetres per second, flows of up to tens of centimetres per second were recorded. There was wave trapping and flow rectification. There was also a vorticity effect, resulting in hydroactive sections across a ridge where a dome could be seen, and this dome implied a circulation; flow tended to be in one direction on one side of the ridge and the other direction on the other side. These flows were also a few millimetres per second, so they were fairly weak. There were also hydrothermal plumes, which had been mentioned in other presentations.

The source temperatures of high temperature hydrothermal circulations were very high (300-400^{0}C) and the virtual velocities at the source had been determined at 41 metres per second. As these fluids came out of the seabed, there was mixing with seawater and sulphides, and oxides precipitated. Dr. Thurnherr stated that he was only concerned with the physics and that these fluids produced clouds of particles in the water column that were very easy to observe with transmissometres. The plumes usually rose to an equilibrium height of somewhere between 50 and 400 metres above the seabed.

It was noted by Dr. Thurnherr that, as the fluid mixed with background water, it could suddenly become heavier than the background water column and could sink into depressions on the seafloor, producing brine pools. This happened, for example, in the Red Sea. These brine pools were very interesting because they were hot, salty water underneath cold, less salty water. Because the diffusion provisions for heat and salt were different this led to a very curious effect, which totally suppressed mixing at the interface, so the brine pool interfaces did not mix any more. These may be important for sulphides deposits. Dr. Thurnherr said that he was not a geologist and did not know what the deposits looked like, but he had seen references to the brine pool situation.

Dr. Thurnherr said that hydrothermal plumes were very high in temperature, but observations 5 metres above the plume showed temperatures similar to surrounding waters. In addition, particles floating past these plumes as they shoot out of the chimneys were not entrained into the plume as would be expected as a result of mixing. The entraining velocities were much smaller than the background velocities, which were usually tidal. The physical effects of the hydrothermal vent fields, apart from the plume, were actually very small, because the volume fluxes of these hydrothermal sources were very small. A virtual source, which was basically one medium-sized chimney stack or several orifices, had a typical volume flux of less than 0.01 cubic metres per second. There would be an immense amount of dilution as these plumes rose so, whilst the vertical volume flux was virtually zero at its source, at height, it was less than 200 cubic metres per second with a huge plume. Entrainment velocities were a few millimetres per second one or two metres from the plume, which was simply not strong enough to cause entrainment.

According to Dr. Thurnherr, far field plumes had been hypothesized to have a significant effect. Theory suggested that there were coherent vortices around hydrothermal plumes with velocities of several centimetres per second. The idea was that the entrained volume flux flowed in because of the effects of the earth's rotation; it heated up and theory suggested that a coherent vortex of several centimetres per second - which was similar to tidal velocities - would be found around the plume. These vortices should be cyclonic around both buoyant and equilibrium spreading plumes. However, the only instance where vortices were observed, was in eruption plumes in detached eddies. On even larger scales, there was a theory that suggested that circulation could be set up that would span the entire ocean basins, but Dr.

Thurnherr stated that the velocity of these circulations was small, if they existed at all. The observations at the time of the workshop were very unclear.

Dr. Thurnherr informed participants that active hydrothermal circulation was largely insignificant in the context of dispersal of mining products, although there were other considerations (e.g., not wanting to put mining equipment in an active mound).

Dr. Thurnherr noted that, in order to assess the dispersal of mining products, it is important to know the relevant time and space scales. He said that the determination of the lower limit is by how long something stayed in the water. For dissolved substances, he said that the upper time limit is the dilution of the substance to levels that were not important. Dr. Thurnherr said that the settling velocity that was important for suspended particles. He said that the height of the release of the particles into the water column determines the settling velocity.

Dr. Thurnherr stated that near topography, the tidal oscillations were dominant and tended to be on a six-hour period, but could be anything from a few hours to 30 hours. On most sites, the direction of mean flow did not really matter, as tides were stronger. If dispersal on a timescale of two hours was important, it could usually be assumed that it could be in any direction, but the distances were typically fairly small. Because the flow field in the ocean was temporally and spatially varying, dispersal was not just by the mean flow. On timescales that were longer than about ten days, ocean particle clouds would spread, and that was called eddy diffusion.

According to Dr. Thurnherr, there were two viewpoints when investigating dispersal in the ocean. One was called Eulerian and the other Lagrangian. Lagrangian was any particle or any dissolved constituent in the ocean fields and Lagrangian flow was measured by following a particle through the ocean. The Eulerian view was from a point fixed in space, such as measuring velocity at a given point, using a current meter. Eulerian measurements were easier to carry out. The problem was that very often people took current meter measurements over a period of time at given point and interpreted these as dispersal pathways. Dr. Thurnherr wished to note that the two things were not the same. An example of why this was incorrect was that, if a current meter was placed below a wave and the currents integrated over time, there would be no net movement. However, if a particle were placed in the water, it would move. That effect was called stokesdrift and the reason for it was that there was spatial variability of the flow field. Moving down the water column, the wave velocities got smaller, so as a particle moved, it would be exposed to different forces and so may not return to its start position. This was drift, but it could not be measured with current meters. Therefore, care needed to be taken when interpreting Eulerian measurements.

Dr. Thurnherr told participants that dispersal in the ocean was the combined effect of two processes. The first was advection by low frequency or mean flows (the information provided by current meter measurements). It was based on the theory that multiplying mean flow by time defined where a particle ends up. Dispersal by advection was proportional to time, so doubling the time would double the distance travelled by the particle. However, there was a totally different effect, which was eddy diffusion. Eddy diffusion was the effect of the temporally flow field, which meant that if a substance was injected into the ocean at a given point, after two months it would have spread in all directions. The question was which of these effects was more important. In most studies that Dr. Thurnherr had seen, it was usually assumed that diffusion could be ignored but, in his opinion, this was quite often wrong. Eddy diffusion was difficult to measure, but was typically in the order of about 1,000 m^2 per second. Typical mean-flow velocities in the ocean were somewhere between a few millimetres to a couple of centimetres per second. Advection was linear in relation to time, but eddy diffusion was defined by the square root law. There would be a point when the two processes were equally important. For example, over a period of months, almost regardless of what value was used for eddy diffusivity, diffusion dominated. The probability that a particle placed in the water would go against what the current meter results indicated would be almost as high as the probability that it would go with the direction of mean flow as indicated by the current meter. Dr. Thurnherr presented some images from his work at the Mid-Atlantic Ridge illustrating this.

Dr. Thurnherr noted that, sometimes, hydrothermal particulate plumes could be used in active vent fields as an easily observed natural Lagrangian flow monitor. It was Lagrangian because it followed the flow. At the Rainbow sites, the particle plume was dispersed unidirectionally along the rift valley. From this, it could be inferred that the dispersal was atypically advectively dominated, so did not spread against the mean flow. Current meter measurements showed that the reason for this was because there were high mean velocities of five centimetres per second for the entire year. Therefore, at this particular site, dispersal was totally dominated by the mean velocities.

Dr. Thurnherr gave an example of a tracer experiment from the Mid-Atlantic Ridge in the South Atlantic to show how part of the tracer was sucked into the canyons and flowed out of the canyons towards the crest. That was one of the two flow regimes there. Current estimates in the canyons showed that flow was advectively dominated towards the crest. More importantly for the deep ocean was the tracer cloud that had been observed above the topography outside the canyons. The centre of the tracer cloud had moved towards the southwest over the two years of the experiment. The whole cloud had gotten bigger, so while the centre of the cloud had been advected towards the southwest, some particles in the cloud had gone against the mean flow. Two years of current meter data gave velocities of 0.5 centimetres per second to the north, which was opposite of what the tracer indicated. However, the variability was so large that, after two years, scientists still did not know the direction of the mean flow. The most extreme example given by Dr. Thurnherr was that of a German group who had had uninterrupted current meters for nine years, but still could not determine the direction of mean flow.

Dr. Thurnherr believed that another problem was that sometimes the currents were too weak to be detected using current technology. He gave an example where a study on the East Pacific Rise did not record velocities 30 per cent of the time, because they were too weak. The same study had current meters at two depths and there was little coherence in the flow at those two levels. One measurement was very close to the seabed and perhaps was more important in the current context, but the flow higher up in the water column may also be important if a lot of sediment was released into the water column during recovery.

Dr. Thurnherr noted that there was also the problem of how to present data from current meters. Current meters measured a time series at one point, so what was happening away from the current meter would not be known. The only thing that would be known was what the flow was doing exactly where the current meter was. When current meter data had been presented, it had always been assumed that there was no spatial variability in the flow. Single current meters were a serious problem unless the observer was interested in small spatial scales, using the assumption that spatial uniformity was correct, or for experiments over small timescales.

There were methods other than current meters and Dr. Thurnherr described an experiment that he was doing in the Lau Basin. The Lau Basin is a back-arc basin near Fiji and Tonga. Five floats had been dropped into the water, although one float had failed. The other four floats drifted at the depth of the hydrothermal plumes, programmed to come to the surface every four weeks to send data on pressure, temperature, salinity and location to scientists via satellites. Dr. Thurnherr said that the floats showed that there was a coherent northward flow in the eastern side of the basin. At the time of the workshop, he noted that there was another cruise in the area deploying similar floats, but these were programmed to come up to the surface every three weeks. He noted that the problem with such experiments were the assumptions about what the float was doing when it was on the surface, as it would be influenced by near-surface flows. Dr. Thurnherr described an interesting result from these experiments as the flow velocities, which were two to four times higher than originally thought, based on hydrographic data. He also characterized as a significant advantage, the fact that he received data every four weeks, which allowed him to update his website with information, carry out his work and be aware of what was happening. With current meters, he pointed out that they must be deployed, left for a period of time and recovered, in the hope that everything worked.

According to Dr. Thurnherr, the other advantage was that, with more floats, it would be possible to measure dispersal directly. It was possible to estimate eddy diffusivity, but it was entirely unknown in regions of varied topography. The only region where Dr. Thurnherr knew about eddy diffusivity was the South Atlantic on the ridge flank, because there were natural tracers.

Dr. Thurnherr told participants of a cruise he had participated in to the Shikoku Basin. He said that before the cruise, he was of the opinion that instantaneous velocity profiles were useless in most areas of the deep ocean, because they only measured tides. During the cruise, he said that the results obtained at one station where the velocities recorded at depths greater than 3,000 metres were over 15 centimetres per second and over 20 centimetres per second in the rift valley, surprised him. He said that the currents were at an area of an incredibly steep slope, and that large variations in currents over a short distance had implications for mining operations. For a better understanding of the environment, Dr. Thurnherr said that high-resolution surveys would be required in potential mining areas, at scales that were appropriate based on initial results.

In conclusion, Dr. Thurnherr said that it was best to assess dispersal using a combination of Lagrangian techniques, dye-release experiments and floats. These floats cost about $8,000 and their expected lifetime was approximately five years.

SUMMARY OF DISCUSSION

Dr. Thurnherr was questioned on whether it was possible to measure tidal currents at hydrothermal vents and how they compared to eddy diffusion and advection. He responded that tidal currents were measurable. Based on all the records that he had seen, tides were the dominant peak in energy with typical speeds of two to four centimetres per second, although in the rift valley of the Mid-Atlantic Ridge, tidal flows of up to 20 centimetres per second had been seen. In response to a question regarding topography, Dr. Thurnherr said that topography affected the flow of tides and internal waves.

Discussions occurred on the economics of monitoring currents with floats, rather than with current meters. Dr. Thurnherr stated that, in his experience, a series of floats cost as much as a year-long deployment of one or several current meters at different depths. However, he noted that the movement of floats from the areas of interest represented a significant problem. He said that if current measurements were required below the surface, different floats needed to be used which would increase costs, but would yield information of much better resolution.

CHAPTER 7 THE BIOLOGICAL ENVIRONMENT OF POLYMETALLIC SULPHIDES DEPOSITS, THE POTENTIAL IMPACT OF EXPLORATION AND MINING ON THIS ENVIRONMENT, AND DATA REQUIRED TO ESTABLISH ENVIRONMENTAL BASELINES IN EXPLORATION AREAS

Professor Cindy-Lee Van Dover, Biology Department, College of William & Mary, Williamsburg, Virginia, United States of America

The Biological Environment of Polymetallic Sulphides

Polymetallic sulphides deposits may be dichotomously characterized as active and inactive deposits. At active sulphides deposits (also called hydrothermal vents), chemically modified fluids exit from the seabed as either focused high-temperature flows through mineral conduits (Figure 1) or as low-temperature diffuse flows through a variety of geological and mineralogical contexts. These include the surfaces of sulphide edifices, through sediments where deposition of minerals occur, or through cracks in basalt (with concomitant subsurface mineralization and alteration). Inactive polymetallic sulphides deposits, as defined here, were once the site of hydrothermal fluid flux and mineral deposition, but they no longer have a surficial temperature anomaly and lack any contemporary flux of hydrothermal fluids into the overlying water column.

Figure 1: High temperature (35^0C) fluids laden with metal sulphides exit from a metal sulphides chimney on the seafloor. Photo by R. Ballard.

Active hydrothermal systems offer environmental gradients of chemistry and temperature to suit a diverse array of obligate and facultative physiologies and tolerances in free-living microorganisms. Major habitat distinctions within vent fields (Figure 2) are typically made on the basis of: oxygen availability (aerobic vs. anaerobic, with microaerobic gradients in between); temperature (superthermophilic [> 115^{0}C], hyperthermophilic [80-115^{0}C], thermophilic [50-80^{0}C], mesothermophilic [10-50^{0}C], and psychrophilic [<10^{0}C]); (microorganisms suspended in the water column *vs.* microorganisms attached to rocks, sediment, animals, etc). Superimposed on these habitats are complex, biogeochemically influenced, dynamic gradients of chemistry critical in the control of the composition of the microbial assemblage. The surface of inactive hydrothermal deposits lack thermal gradients, but gradients of oxygen availability are present, and mineralogical heterogeneity may result in heterogeneous distributions of microbial metabolic types.

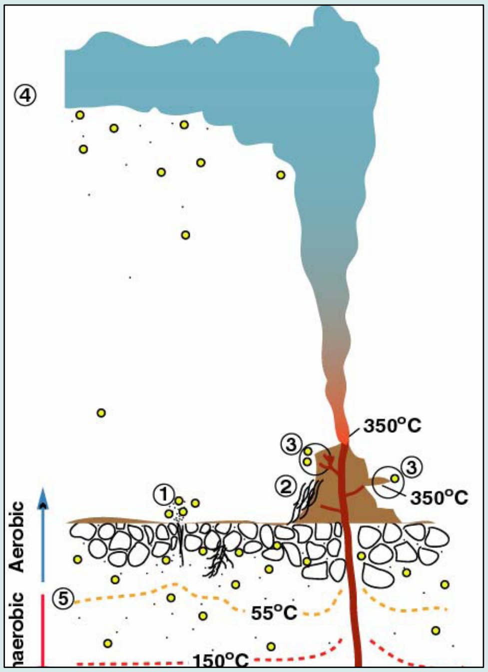

Figure 2: Microbial environments at active polymetallic sulphide deposits

1 = diffuse low temperature flow from cracks in basalt or from sediment;

2 = diffuse low-temperature flow from surfaces of sulphides deposits;

3 = diffuse high-temperature flow (to 12^{0}C or possibly more) associated with sulphide flanges and other structures;

4 = buoyant and neutral plumes;

5 = subsurface biosphere (to 12^{0}C or possibly more). Microbial environments are generally anaerobic where fluid temperatures exceed 15^{0}C.

The base of the ecosystem associated with active polymetallic sulphides deposits is primarily chemosynthetic primary production by aerobic and anaerobic microorganisms (Figure 3). For a review of many aspects of the ecology of these ecosystems, see Van Dover (2000). In chemosynthetic (more precisely called chemoautotrophic) primary production, chemical energy derived from the microbial oxidation of reduced compounds – for example, oxidation of hydrogen sulphide – is used to fix inorganic carbon (dissolved CO_2 in seawater) into organic carbon (i.e., cellular components). This is directly analogous to photosynthesis, where energy is derived from photons captured by biological systems to fix carbon. It was the discovery of chemosynthetically-based ecosystems in the deep sea that fundamentally changed the way we think about the potential for life in extreme environments on our own planet and on other planetary bodies.

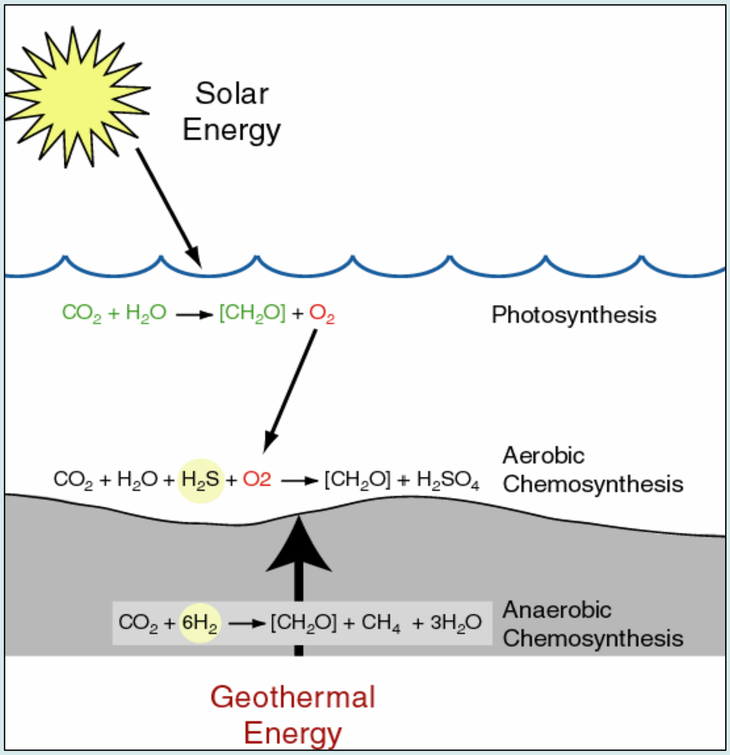

Figure 3: Relationship between photosynthesis (primary production based on energy derived from sunlight) and chemosynthesis (primary production based on oxidation of reduced compounds). From Jannasch, 1995.

The large biomass of invertebrates that is characteristic of most known, active vent sites is represented by species that support aerobic, chemoautotrophic symbiotic bacteria, either within their tissues (endosymbionts) or on the surface of the animals (episymbionts). The host invertebrate species of hydrothermally active polymetallic sulphides deposits display adaptations that allow them to exist in an environment with high dissolved sulphide and dissolved metal concentrations that are toxic to most marine invertebrate species. The biology of the iconoclastic hydrothermal-vent species, the giant tubeworm *Riftia pachyptila*, has been the focus of considerable research, and development of an understanding of the fundamentals of the adaptations of this and other unusual vent species to the active vent environment continue to engage the scientific community. In addition to the large, charismatic invertebrates hosting symbiotic bacteria [such as alvinellid polychaetes, alvinocarid shrimp, giant tubeworms, mussels (Figure 4)], active polymetallic sulphides are also host to large numbers of smaller invertebrate species, including a variety of gastropod, crustacean, and polychaete species. Most of these species are new to science (Figure 5). The invertebrate assemblage at any given site is generally characterized by relatively low species richness (typically on the order of 100 species or less) and dominance by a few species with high abundance and with high biomass. High levels of dominance means that most species (as much as 80%) at a given sulphides deposit are uncommon or rare.

Figure 4: Symbiont-bearing, biomass dominant species of active polymetallic sulphide deposits. Left to right: Alvinellid polychaetes (Alvinella pompejana; episymbionts; East Pacific Rise); shrimp (Rimicaris exoculata; episymbionts; Mid-Atlantic Ridge); vestimentiferan tubeworms (Riftia pachyptila; endosymbionts; Mid-Atlantic Ridge); mussels (Bathymodiolus thermophilus; endosymbionts; East Pacific Rise).

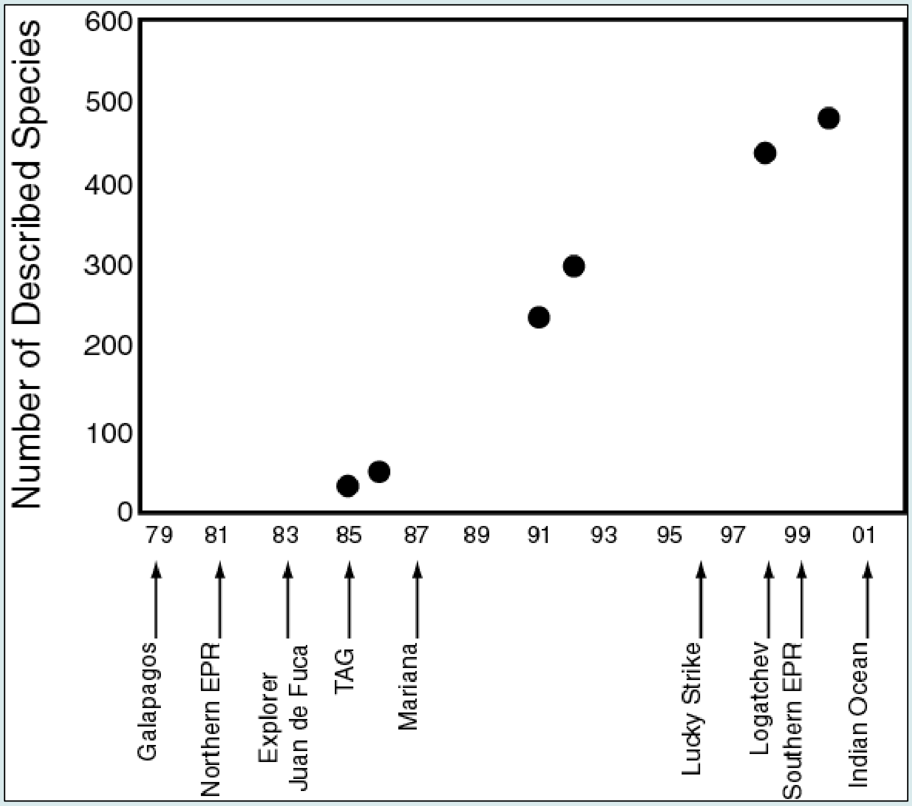

Figure 5: *Rate of discovery and description of new species of hydrothermal vent invertebrates in the global ocean. X-axis indicates year and identified the date of discovery of important hydrothermal vent fields. Red data point is the most recent tally by D. Desbruyères (pers. comm.).*

Maintenance of populations of microorganisms and benthic macro- and megafauna within active sulphides environments is typically through dispersal by pelagic stages, especially larvae. The extent to which a local population depends on local production of gametes is unknown, but is often assumed to be low, although mechanisms for local retention of propagules have been proposed (Figure 6) and may be important in the maintenance of the large biomass of invertebrates once a vent field has become established. It is conceivable that hydrographic regimes favour one population or brood stock above others as the source of recruits within a large region, but this has yet to be demonstrated for any species. Dispersive larval stages are especially important where habitats are ephemeral and/or insular.

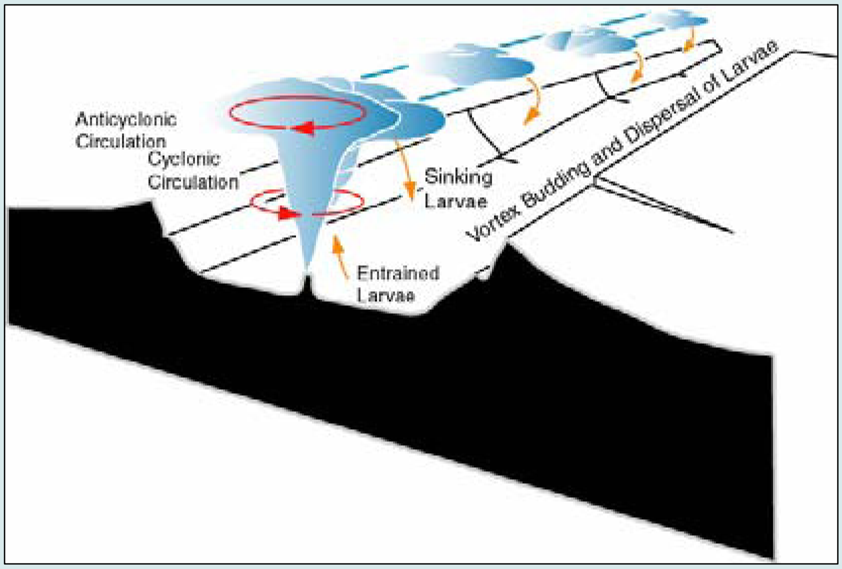

Figure 6: A hypothesised mechanism of larval transport and retention along ridge axes via hydrothermal plumes. Modified from Mullineaux and France, 1995.

The duration of activity of hydrothermal systems varies depending on the geological context, but the activity is everywhere ephemeral, lasting days (pervasive venting following eruptive events), to months and decades (e.g., on the East Pacific Rise), to thousands of years (e.g., TAG, Mid-Atlantic Ridge). Even where venting activity is of long duration, as at TAG, there is currently no evidence for a locally endemic fauna specific to a single sulphides deposit. Based on present know-ledge, the destruction of the TAG habitat would not likely result in the global extinction of any species.

The biogeography of vent and other chemosynthetic faunas (i.e., the pattern of distribution of species) is an important key to understanding the degree to which perturbation of a habitat may result in extinction of species. Where species, or groups of species, are geographically widespread, the impact of habitat perturbation in a relatively local area is likely to be minimal. But where a species or group of species is geographically restricted, loss of critical habitat can have an important impact on the survival of those species. Our current understanding of the distribution of vent species on mid-ocean ridges indicates that geographic ranges of species groups are considerable, perhaps in some cases exceeding those of terrestrial species. Extensive ranges of some vent species (e.g., *Riftia pachyptila*, which occurs along the East Pacific Rise from at least 27ºN to 18ºS) is due in large part to the absence of latitudinal gradients of climate in the deep sea. There is nevertheless a biogeography of vent and other chemosynthetic species; few if any species are cosmopolitan (occurring throughout the world's oceans). At least seven biogeographical provinces have been identified (Van Dover et al., 2002; Figure 7), and more are anticipated as polymetallic sulphides deposits in additional ocean regions are discovered.

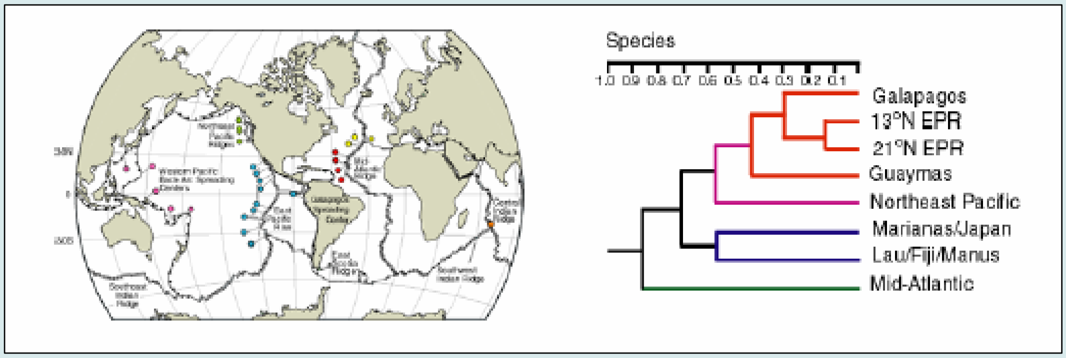

Figure 7: Left: Known deep-sea hydrothermal vent fields (circa 2002); colours indicate different biogeographic provinces (from Van Dover et al., 2002). Right: Summary of dissimilarities among faunas (at the species level) of active hydrothermal systems on various ridge systems; known vents on the Mid-Atlantic Ridge share very few species with vent faunas at other sites (from Tunnicliffe and Fowler, 1996).

The biogeography of fauna associated with active polymetallic sulphides deposits of back-arc ridge systems is poorly understood, but these systems may be more isolated and their faunas thus more susceptible to habitat degradation than their mid-ocean ridge counterparts (Juniper, 2002). The biogeography of active seamount polymetallic sulphides deposits is essentially unknown, but the fauna might be expected to be as endemic as other seamount organisms, given the hydrographic potential for closed circulation cells in association with seamount topography.

In the excitement of studying the biota of active hydrothermal vents, the biology of inactive sulphides anywhere has been all but ignored. Where sampling of biota associated with inactive polymetallic sulphides has taken place, it has generally been as opportunistic, incidental efforts undertaken outside the scope of funded research studies. Several species of invertebrates have been described from inactive sulphides deposits and we understand that there are active microbial communities that depend on resources associated with the sulphides. Inactive polymetallic sulphides deposits should be considered as extreme environments. It is plausible to expect that there are entire assemblages of invertebrates and microbes that are characteristic of and possibly restricted to metal-rich, inactive sulphides environments. It is also plausible to expect that the structure and function of the community may be influenced by the mineralogical and geochemical attributes of the sulphides, and that some inactive sulphides may be of much greater biological interest than others. To date, there has been little incentive for biologists to expend much effort on studies of the biology associated with inactive sulphides, given the large number of compelling issues to study in organisms living at active vents. Microbial, psychrophilic autotrophs and other psychrophilic microbial metabolic types associated with polymetallic sulphides are potentially of tremendous importance to biotechnology, bioremediation, and our understanding of the metabolic menus exploited by life on Earth and potentially elsewhere.

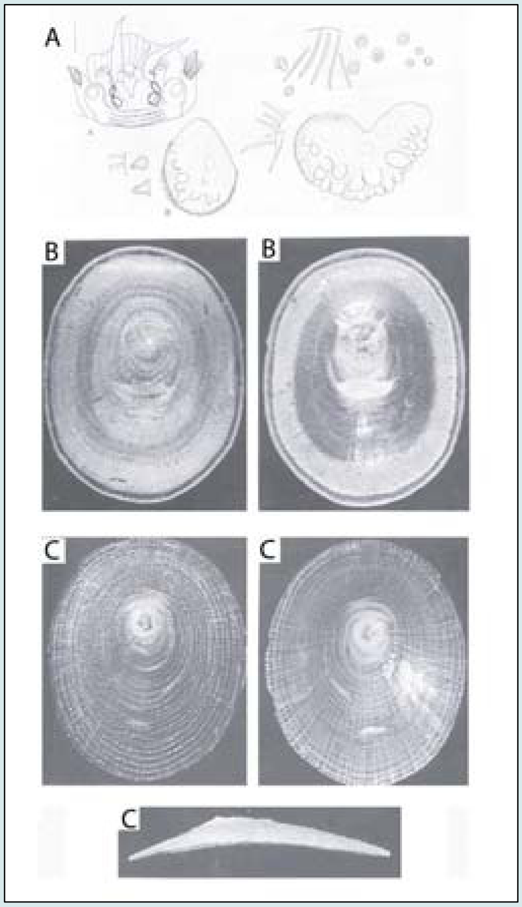

Figure 8: Illustrations from descriptions of new species thus far known only from inactive polymetallic sulphides deposits on the East Pacific Rise:

A.- Polynoid polychaete (Eunoe alvinella; Pettibone 1989);

B. - Archaeogastropod limpet (Neolepetopsis verruca; McLean 1990);

C. -Archaeogastropod limpet (Neoleptopsis dentata; McLean 1990).

Despite evidence that inactive sulphides structures are abundant and that metal sulphide oxidation can support primary production by chemolithotrophic microorganisms (Eberhard et al., 1995; Edwards et al., 2000), microbial populations of inactive sulphides have rarely been studied. Rates of CO2-fixation by four microbial isolates from vent sulphides depended on the type of polymetallic sulphides provided as a substrate (Figure 9; Eberhard et al., 1995). Bacterial isolates provided with vent sulphides rich in chalcopyrite resulted in higher microbial activities than the same bacterial isolates provided with commercially obtained sphalerite, galena, or chalcocite as substrates. Microbial communities associated with inactive sulphides chimneys collected from the mid Okinawa Trough (Iheya North) and from the Central Indian Ridge (Kairei Field) were decidedly different from that of active sulphides (Suzuki et al., 2004). The Iheya sulphides were barite-rich, with only a minor iron sulphide mineral content; the Kairei sulphides were chalcopyrite rich. Microbial diversity in the Iheya sample was less diverse than that of the Kairei sample. Bacteria dominated in both samples, although Archaea were present. One important lineage identified from the samples is a lineage related to that of *Magnetobacterium bavaricum,* a magnetosome-rich lineage previously unknown in the marine environment.

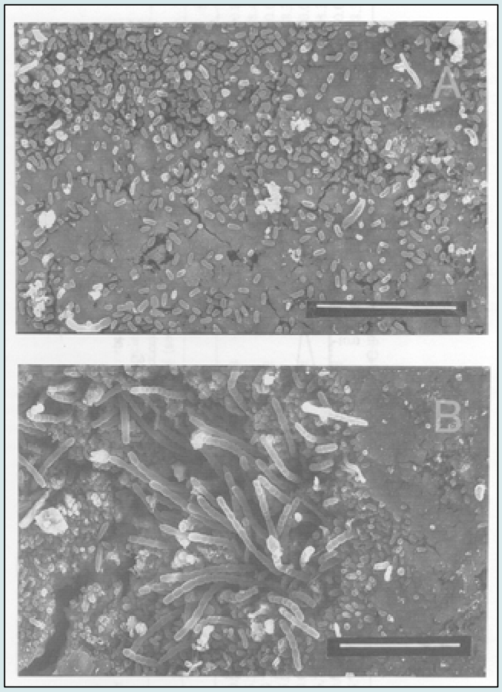

Figure 9: Scanning electron micrographs of microorganisms on surfaces of polymetallic sulphides (from Eberhard et al., 1995).

The substantial biomass at active vents is usually represented by invertebrate taxa that host endosymbiotic, chemoautotrophic bacteria. These invertebrate-symbiont associations are at present unknown from inactive sulphide deposits and may not exist. It is not inconceivable, however, that a host organism might locally regulate the pH of a sulphide-rich mineral to facilitate dissolution of the sulphide and acquisition of that sulphide for the nutrition of its symbiotic bacteria. There is a paucity of quantitative data on the biomass associated with inactive sulphides, but there are anecdotal reports of relatively high biomass, for example, at relict deposits on Gorda Ridge. Macro and megafaunal invertebrates cover at least some of the Gorda Ridge sulphides and include large populations of brachiopods (Van Dover et al., 1988), which are otherwise thus far unknown from modern chemosynthetic environments, but which dominate the fossil record (Little & Vrijenhoek, 2003). The trophic basis for this high biomass at some inactive sulphides is unknown. Elevated biomass of suspension feeders is often associated with local topographic highs, due to hydrographic effects that concentrate food particles (Genin et al., 1986) and is independent of autochthonous, chemoautotrophic production. Topographic relief of large sulphide deposits may result in the same phenomenon. A contribution of chemoautotrophic production cannot be ruled out, however, and need not be exclusive of other mechanisms of trophic enrichment. Fortunately, stable isotope techniques (Conway et al., 1994) can be used to outline the general nature of trophic relationships among organisms occupying inactive sulphide mounds.

Figure 10: Brisingid seastars and sponges on inactive polymetallic sulphides

The Potential Impact of Exploration and Mining on the Polymetallic Sulphides Environment

Exploration of active or inactive polymetallic sulphides deposits, where it is non-intrusive or includes precision and limited test sampling to determine ore contents (i.e., grab samples, coring on a scale comparable to that currently undertaken by scientific endeavours), should not be environmentally detrimental to either inactive or active polymetallic sulphides environments. Towed instrument packages and acoustic techniques are innocuous to benthic organisms; lights associated with imaging devices, while likely to damage eyes of some vertebrates and invertebrates (e.g., Herring et al., 1999), are routinely used in the deep sea without apparent, long-term detriment to metazoan populations. Positive benefits likely to accrue from exploration include discovery of new sites, species, metabolisms, and adaptations, expansion of our understanding of the limits to life in extreme environments, and constraints on models of the importance of biological activity associated with sulphides deposits. The impact of test mining and commercial mining on inactive polymetallic sulphides environments is especially difficult to assess with certainty, given the near absence of any studies of the ecosystem associated with these environments.

Assuming a worst-case scenario, negative impacts of mining on active or inactive polymetallic sulphides deposits include

- Loss of sulphide habitat
- Degradation of sulphide habitat quality
- Modification of fluid flux regimes
- Local, regional, or global extinction of endemic or rare taxa
- Decreased diversity (at all levels: genetic, species, phylogenetic, habitat, etc.)
- Decreased seafloor primary production
- Modification of trophic interactions
- Exposure of surrounding seafloor habitats (non-sulphide) to sediment and heavy metal deposition
- Effects of scaling-up
- Continued ignorance about what is not known

Such a worst-case scenario might be a polymetallic sulphides deposit that supports narrowly endemic species (i.e., species thus far known only from that sulphides deposit), and that includes microbial primary production based on oxidative metabolisms and higher trophic level metazoans adapted to the particular extremes of the polymetallic sulphides environment (e.g., high metal content, potentially low pH). This ecosystem would be hydrographically isolated and long-lived, thereby supporting species with extremely restricted ranges. The impact of mining on this environment would be severe, including loss of critical habitat and extinction of species. Given our understanding of active chemosynthetically-based ecosystems in the deep sea and the rate of inorganic oxidation of sulphide minerals, it seems unlikely that the typical inactive polymetallic sulphides deposit along a mid-ocean ridge is so isolated or long-lived as to support such a locally, rather than regionally, endemic fauna. The situation is not so clear for polymetallic sulphides deposits of non-mid-ocean ridge settings (i.e., on back-arc ridges and seamounts).

Old sulphides deposits (> 1,000 years) are likely to contain fossil records that would provide important information regarding ecological and evolutionary histories of sulphides communities and organisms (Figure 11). Attention to these fossil records should be encouraged during test and commercial mining.

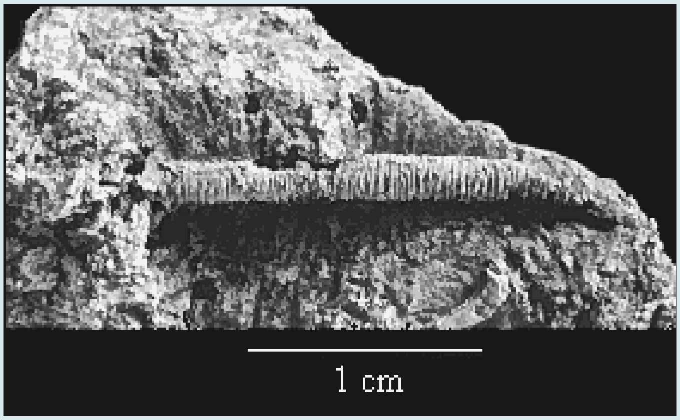

Figure 11: Fossil polychaete worm from an ancient polymetallic sulphide deposit. (C. Little and R. Herrington; http://www.nhm.ac.uk/mineralogy).

Data required for the establishment of environmental baselines in exploration areas

Critical data required for the establishment of environmental baselines centre on the question of the degree to which a fauna is endemic to an exploration area and on the susceptibility of an endemic fauna to mining activities. This includes fauna associated with the sulphides deposits themselves and fauna associated with surrounding or nearby environments such as seamounts that are likely to be indirectly impacted by mining activities (e.g. by degradation of specialized and restricted habitats).

Key data identified by Juniper (2002) and expanded upon here include:

1. Detailed maps of the distribution of inactive sulphides deposits as well as of critical habitats such as active or inactive vents, active seeps, seamounts, whale skeletons, etc., within the zone likely to be influenced by particle deposition.
2. Measurement of the prevailing hydrographic regime and development of particulate fallout models to predict the suspended particulate and depositional gradients generated by mining activity, especially where critical habitats occur in the exploration area. This should include an assessment of the depositional shadow of specific minerals/metals potentially toxic to marine organisms (e.g., copper).

3. Determination of the extent to which the biota is endemic or cosmopolitan.

4. Determination of the extent to which an endemic biomass associated with the inactive sulphides is dependent on chemoautotrophic production.

5. Characterization of community structure (defined below).

6. An estimate of the age of the sulphides deposit and its potential as a fossil record.

7. Modelling to determine the effects of scaling-up of test-mining activities.

Types of baseline data on community structure that will assist in assessment of the impact of mining activities include:

- Characterization of microbial diversity, biomass, primary productivity, biogeochemistry
- Characterization of the metazoan community structure, including taxonomic composition, species richness, diversity, evenness, biomass, and abundance of
  - "Strategic" sulphide-associated mega-, macro-, meiofaunal communities
  - background communities in areas within the depositional shadow
  - reference communities outside the depositional shadow
- Genetic diversity of strategic species of background and sulphides habitats
- Trophic relationships among vertebrates, invertebrates, microbes, and mineral deposits
- Species ranges (can they be found outside the area likely to be impacted by mining) and degree of endemism of microbial, invertebrate taxa in association with sulphides deposits
- Identification of adaptations specialized for polymetallic mineral deposits
- Dose-response parameters, especially for background fauna or fauna of critical habitats within the depositional shadow

The importance of reserves or sanctuaries as required in the draft regulations of the International Seabed Authority cannot be underestimated, especially given our lack of knowledge of the biology of certain types of polymetallic sulphides deposits (e.g., those associated with inactive sulphides, those occurring on isolated seamounts). These may not be easy to identify and require careful consideration and definition as to what is acceptable in a given region.

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SUMMARY OF PRESENTATION

Professor Van Dover said that it was obvious from previous presentations that both active and inactive deposits should be considered; she would therefore talk about both.

She told participants that the excitement about chemosynthetic environments was about the process of chemosynthesis in contrast with photosynthesis. She said that in photosynthesis, carbon dioxide, water and the energy from sunlight yield organic material and some oxygen. In contrast, she said that in chemosynthesis, there are two kinds of conditions, the aerobic and the anaerobic condition. She explained that during photosynthesis and chemosynthesis, the conversion of carbon dioxide, the source of inorganic carbon, into organic material occurs. Professor Van Dover said that in aerobic conditions, oxygen is available. She pointed out that the source of oxygen in aerobic conditions is photosynthesis. She therefore stated that the aerobic parts of the chemosynthetic system did not work independently of sunlight in the long term, because that was where the oxygen originated.

Professor Van Dover noted that people often misunderstood that the sulphides drove the aerobic chemosynthesis by their oxidation. She said that aerobic chemosynthesis supported the large invertebrates found at hydrothermal vents, including the giant tubeworms and shrimps. She also said that the tubeworms and shrimps had a relationship with the bacteria that carried out chemosynthesis. She described the system as microbial, and said that although invertebrates were not chemosynthetic, they hosted chemosynthetic organisms. She said that bacteria or the Archaea Kingdom is responsible for the process.

According to Professor Van Dover, energy from the oxidation of sulphides allows microorganisms to produce organic material, using the same biochemical pathway as plants. Anaerobic chemosynthesis tended to occur subsurface (which could be just centimetres into the sediment). She said that the fluids from the vents had very little oxygen and therefore created the anaerobic environment pointing out that while there was an oxidation-reduction reaction, oxygen was not the oxidant. Professor Van Dover said that although sulphides were typically the oxidants in these systems, there were several hydrothermal systems where methane is important. As examples, she referred to the Endeavour Ridge and the Lost City site in the Atlantic Ocean that had high methane concentrations. She said that the tremendous biomass at active hydrothermal vents derives from a sort of symbiosis between the invertebrates and the microbes. In the case of tubeworms, Professor Van Dover pointed out that the microbes were in them and so are endosymbiotic. In the case of the shrimp, she said that as they were on the outside, and so they are episymbiotic. Irrespective of where the microbes were on the body, Professor Van Dover said they had a solid relationship with invertebrates. She noted that the water for dissolving the sulphides is from the hydrothermal vents. She also said that this water is toxic to most organisms, creating an anomaly in which vent animals are in a sulphides environment, which would normally poison their relatives in shallow water.

Professor Van Dover said that the fluids from black smokers have a temperature of 350º, and that nothing lived in them. She said that she is unaware of any high-temperature microbes. With regard to temperatures suitable for microbes, Professor Van Dover informed participants that these tended to be less than 100^0 C, although there were records of 121^0C. She pointed out that the microbial population included both the Archaea and the Bacteria, two of the major kingdoms on earth.

Professor Van Dover said that microbes lived in all sorts of places and that other organisms feed on them. She said that hydrothermal plumes carry some sulphides and other compounds that microorganisms make use of, such as manganese. As a result, she said that many microbes lived in the plume. Professor Van Dover informed participants that at inactive vents bacteria grew on the sides of the sulphides structures or in the internal part of the structures, temperatures permitting. According to Professor Van Dover, an interesting thing about active vent environments is that they host the extreme temperature gradients known on Earth. In this regard, she pointed out that in the case of a flange pool, the hot water pool had a temperature of 350^0C, on top of which was water at 2^0C. She said that the distance between the two extremes was 7 millimetres.

Professor Van Dover noted that in addition to these structures there were also hot fluids that formed the mineral structures. She said that these flows are visible where seawater mixes in the shallow sub-surface of the structures. She said that the temperature in these areas was much lower, in the range of $2\text{-}10^0$ C, with most of the invertebrate biomass. Professor Van Dover pointed out that the flows may be on the sides of some of the chimneys where there had been a lot of mixing of the ambient seawater with the vent fluid. Sub-surface there was still a mostly anaerobic environment where oxygen could be available, but in lower concentrations than on the surface. Oxygen was coming from the ambient seawater, not anything sub-surface. There were serious anaerobic conditions in the warmer water.

Professor Van Dover informed participants that the highest temperature environment for macro vertebrates were associated with the Alvinellid tubeworms. She said that while tubeworms do not have symbionts in them, they have symbionts on them. In this regard, she pointed out that the feeding relationship was not clear. She said that the best available data suggests that 40^0 C is the maximum temperature for these kinds of metazoan invertebrates. With regard to shrimps on the Mid-Atlantic Ridge, Professor Van Dover said these also had a maximum temperature of 40^0 although some shrimp are found in temperatures as low at 2^0C.

Professor Van Dover informed participants that the giant tubeworms had haemoglobin in their blood that takes up oxygen and sulphides, delivering them to the bacteria that they housed in a tropozone. She described the tubeworm as a kind animal that had adapted to a vent environment, and therefore did not have a digestive system. On the subject of mussels, Professor Van Dover also informed participants that mussels are found at hydrothermal vents in all the world's oceans. She described mussels as habitat engineers, like the tubeworms, and said that both animals created environments suitable for other vertebrates. She said that the pelagic community of zooplankton found at vents is localized, and not well studied. She stated the reason for the lack of studies is probably that the number of individuals available for study, unlike the nearby benthic fauna, is not large.

According to Professor Van Dover, mussels also have symbionts that are a special organism, which the bacteria housed in their gills. However, Professor Van

Dover noted that since the surrounding waters contained anemones, and suspended material that had fallen out of the plume to the seabed; the mussels are also filter feed. She pointed out that there are many new species discovered. She said that each time scientists go to a new site they find new species. Professor Van Dover stated that if it was possible to get to the Cayman Rise and the active hydrothermal vents found there, she could guarantee that there would be animals never seen before and with unknown novel adaptations.

Professor Van Dover indicated that the most significant problem faced by biologists engaged in this field is the lack of taxonomists. She said that in America, there are very few taxonomists, and that she sent almost all of the material she had collected for taxonomic description to people in other countries because of this problem. Before the workshop, she said that these scientists described 550 species, with about two hundred more to be completed. Professor Van Dover said that the species in her collction are macrofauna and megafauna; ranging from animals that can be retained on a 250-micron sieve, and the giant tubeworm, which can be picked up by hand. She also said that the collection does not include meiofauna, such as the nematodes. In addition, Professor Van Dover said that the collection contained charismatic species, and smaller animals that were at least as important in terms of the study of community structure. She said that with respect to biodiversity at a site, the smaller types of animals that live amongst the mussels, tubeworms and shrimp have to be tken into account.

Professor Van Dover said that a problem associated with sampling vents is the hard substrate. In this regard, she said that quantitative sampling of vents is not as easy as it is in the soft sediment seafloor among manganese nodules. She said that normally, box corers are used to obtain very good quantitative data from a known sample size. On hard substrate, however, Professor Van Dover said it is not possible to collect the substrate efficiently and to determine the sampled area. She added that a technique for sampling mussel beds in a rigorous quantitative manner is under development.

Professor Van Dover explained that when scientists talked about these animals they were not only interested in how many species there were and what the species' richness was, but also in the distribution of individuals among those species, which was related to the rank, abundance and dominance.

Professor Van Dover noted that, when considering the impact of mining on the environment it is necessary to identify the seafloor area likely to be impacted and determine the response of animals in that area to plume fallout. She said that it is necessary to know the distribution of the habitat, the species composition, community structure and basic biology of the species. She also said that specific and detailed maps of the target sulphides deposits are required, including whether or not they are at active or inactive vent sites. Professor Van Dover said that the maps should also indicate the critical habitats that might be near those structures and in the impact zone of the dispersal plumes. Pointing out that many attributes of the environment are susceptible to impacts, Professor Van Dover said that it is necessary to know about, inter alia, seeps, non-target sulphides seamounts, and whale skeletons in the area. She said that while it is not necessary to know the full range of all organisms of a species, if the species existed in the area of impact it is necessary to know if it is endemic to the region. In this regard, she gave an illustration by pointing out that if the microbes the species fed on required sulphide as an energy source, it would be endemic to the sulphides deposit. She said that other information required included community structure, the age of the sulphides deposit, and the fossil record because of the insight it could provide into the history of the vent fields. She further pointed out that although scientists could follow active vent fields for 10-15 years, the 100,000-200,000-year fossil record may be in the sulphides deposits and this might be lost during mining.

According to Professor Van Dover, the required baseline data included microbial diversity biomass product, productivity and biogeochemistry. In order to understand inactive sulphides systems, she said it would be necessary to know the basics prior to commercial activity. She pointed out that if the geochemistry was the same in two locations, then the results from one could be extrapolated to another, but if the geochemistry differed, then the microbiology would also differ. Professor Van Dover said that other baseline data required included community structure, taxonomic composition, species richness, diversity, and biomass across multiple size classes, for megafauna, macrofauna and meiofauna. She said it would be necessary to sample within each sub-habitat in an area, including mussel beds and tubeworm clumps, although the processes may be the same at each. She also said that the community to sample should be a strategic decision. In addition to the reference communities, Professor Van Dover said that an assessment of the background communities in the area in the shadow of the deposit, but which was not the same as the active or the inactive sulphides, had to be carried out.

Based on their dispersal type or their relationship to the sulphides deposits, Professor Van Dover believed that information is required on the genetic diversity of specific species affected by exploitation. She said that other data required for assessing the likelihood of extinction because of localized impact, are the trophic relationships between all groups, between groups and the mineral resource they are associated with, and species ranges.

Professor Van Dover emphasized the use of multivariate analyses. Noting that species lists were good, she said that multivariate analysis provides better results, as it showed how communities change.

Professor Van Dover summarized her presentation as follows:

1. Inactive sulphides and seamount sulphides may be likely targets for mining efforts but biologists did not know anything about these two environments. Specifically;

2. Microbiology is important as microbes may be psychrophilic and they may have biotechnological uses or may help understanding the metabolic menus that might be exploited elsewhere both on Earth and outer space;

3. Taxonomists were required for faunal surveys but there is a lack of taxonomists;

4. Baseline assessments must be carried out in the fallout shadow, not just the habitat that was being mined;

5. Large, old sulphides deposits may contain important fossil records, and

6. It is pleasant to see reserves or sanctuaries referred to in the ISA Regulations, but this needs further work, as it would be hard to find suitable sites. She said that each site is different; one example is the TAG site, which, as far as scientists knew, was unique and it would thus be impossible to create a suitable reference site for it.

SUMMARY OF THE DISCUSSIONS

Professor Van Dover was asked about the theory that certain areas acted as "motherload incubators" from which species radiated outwards, such as nursery grounds in shallow water fisheries. Professor Van Dover responded that, when animals released gametes, these did not necessarily settle at the point of release. She said that the gametes move by the currents and those areas that provide brood stocks might be different for different species. She followed up by stating that answers are not currently available. Professor Van Dover suggested that genetics might help to address the question. She also noted the need to choose reserves carefully, so that there were brood stocks available.

A participant asked Professor Van Dover whether the TAG deposits could be mined, with the areas around them identified as brood stock areas left untouched, in order to preserve the species. Professor Van Dover responded that, while in general that could be the case, it is not the case with TAG.

Professor Van Dover had made the point that the fossil record for the past 200,000 years could be lost if mining occurred, but a participant suggested that mining might help to find the fossil record. A participant said that geologists had obtained samples from commercial mines on land and cited the example of the Urals where the fossil record from 400-million-year-old vents with fossil tubeworms and other information became available because of mining. Professor Van Dover acknowledged this and said that although there would be an impact, mining could be positive if it resulted in the collection of fossils. A participant suggested that a possible solution is to include in the regulations a provision that miners undertake scientific sampling.

Some participants, while acknowledging that taxonomists are required for environmental impact assessments, wanted to know how to address the problem of their shortage. Professor Van Dover replied that it differed from country to country, but that there were programmes to try to assess this question and it was a source of potential collaboration that could result from the work of the Authority.

One participant asked whether reproduction in active and inactive vents was seasonal, yearly or continuous. In response, Professor Van Dover explained that it is species, site, and local conditions dependent. She said, however, that time series sampling suggested that growth at active hydrothermal vents was very rapid, so it is assumed that reproduction probably occurrs more than once a year, maybe weekly or monthly, depending on the species. Professor Van Dover said that answers to these time-based questions might be forthcoming with frequent sampling. As an example, she said that sampling on the Juan de Fuca Ridge only takes place in the summer, because it is not possible to get there at any other time of the year.

Since some vents may be active for timescales of years to decades, but then inactive for several thousand years, a participant sought clarification from Professor Van Dover on inactive mounds. The participant noted that if an inactive mound is within range of a heat source, its inactivity might only be part of its normal cycle. In response, another participant said that the episodic nature was critical in building large deposits that could be economically interesting, since more than one venting process is required. This participant further stated that large deposits form through multiple episodes of venting, over thousands of years to create what economic geologists call "zone refinement". The participant described zone refinement as the process whereby economically interesting metals separate from the iron, which constitutes most of the deposit.

It was noted that there needs to be a balance in the recommendations between what scientists would like to know in these areas from a research point of view and what a contractor needed to know to estimate the impact on the environment. It was suggested that it might be useful to have two lists.

Finally, in response to a question whether there are underground pathways between vents, Professor Van Dover said that the sub-surface was the area where there is sulphides-rich, hot sea water and for microbes it was a good way to disperse, especially for organisms that could survive periods of anoxia, or were anaerobic. For larval stages, she said it was more problematic. She concluded by stating that sub-surface pathways were a possibility, but that, as far as she was aware, they had not yet been investigated.

CHAPTER 8 THE WORK OF INTERIDGE AND ITS POTENTIAL RELEVANCE TO THE ESTABLISHMENT OF ENVIRONMENTAL BASELINES, INCLUDING THE VOLUNTARY CODE OF CONDUCT FOR SCIENTIFIC RESEARCH AT HYDROTHERMAL VENTS, AND POTENTIAL COLLABORATION WITH THE AUTHORITY

Professor Colin Devey, InterRidge / Leubniz-Institut für Meereswissenschaften, IFM-GEOMAR, Germany

Background: What is InterRidge?

The InterRidge initiative was created with the main objective of supporting and developing programmes addressing mid-oceanic ridge research. These programmes should be of major scientific interest, interdisciplinary, globally or thematically defined and, most importantly, require or will benefit from international discussion, planning and implementation. InterRidge also aims to strengthen contacts to the less industrialized or non-coastal nations, heightening the appreciation that the world's oceans are relevant to the lives of all the peoples on Earth. The original science plan for InterRidge was written in 1994 to cover a period of 10 years which came to an end in 2003. The InterRidge steering committee adopted the Next Decade science plan in July 2003, paving the way for another 10 years of international spreading axis research.

InterRidge has no budget for funding data collection or analysis. Instead, its contribution to international ridge research is to facilitate and coordinate research. InterRidge achieves its objectives by:

- Bringing the expertise of the international ridge research community together to identify priority issues, define questions and focus interests both geographically and thematically;

- Facilitating the exchange of ideas and planning, for example, by convening international meetings and workshops;

- Providing a unified voice to express the views and priorities of the international ridge community to other scientists, the general community, and most importantly, to government bodies, including national funding agencies and other international programmes;

- Assisting in defining and coordinating field programmes and experiments;

- Providing current information about research activities, especially seagoing operations, by publication of workshop reports and a newsletter;

- Encouraging participation of smaller oceanographic nations and individual scientists from non-seagoing nations, and

- Providing an international electronic directory of InterRidge researchers.

The first decade of InterRidge activity produced a united, coordinated international ridge community consisting of over 2,700 active researchers from 55 countries. A number of countries that joined InterRidge during this first decade (for example, China, India and Japan) were able to boast impressive developments in their ridge research activities within just a short period of time. Ridge research internationally received a huge boost from the establishment of InterRidge, with InterRidge workshops leading to the formulation of project plans to tackle some of the major outstanding scientific problems. Thus, the primary objective of the first decade of InterRidge was achieved. This led to the definition of a slightly different focus in the new decade, reflecting the fact that a mature and active community had been developed and so more emphasis could be placed on major, long-term scientific goals as well as education and outreach initiatives. The next decade science goals include more in-depth studies of the ridges and the use of cutting-edge technology to establish a permanent presence on the spreading axes. InterRidge will also focus on the sharing of resources, expertise and costs of scientific cruises as well as future ocean bottom observatories, all of which will increasingly depend on international and multidisciplinary collaborations to minimize research costs to individual nations while at the same time maximizing research output.

Organizational structure of InterRidge

InterRidge Office and Steering Committee

InterRidge has three levels of membership: the fee-paying principal and associate members, and the free corresponding members. Currently there are 29 InterRidge countries comprising 5 principal members (France, Germany, Japan, the United Kingdom and the United States); 6 associate members (Canada, China, India, Korea, Norway and Portugal) and 18 corresponding members (Australia, Austria, Brazil, China, Denmark, Iceland, Italy, Mauritius, Mexico, Morocco, New Zealand, Philippines, Russia, South Africa, Spain, Sweden, Switzerland and SOPAC[1]).

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[1] SOPAC is the South Pacific Applied Geosciences Commission. Its membership comprises American Samoa, Australia, Cook Islands, the Federated States of Micronesia, Fiji, French Polynesia, Guam, Kiribati, Marshall Islands, Nauru, New Caledonia, New Zealand, Niue, Palau, Papua New Guinea, Samoa, Solomon Islands, Tonga, Tuvalu, and Vanuatu

InterRidge is managed through the InterRidge office, which houses the Chair and the Scientific Coordinator. The office is supported by annual membership fee contributions of the principal member countries (recommended US$ 25,000 per annum, as of 1 January 2005, required as of 1 January 2007) and associate member countries ($5,000 per annum). The location of the office rotates between the principal member nations, usually every three years. At the beginning of 2004, the office moved from Japan to Germany, initially to Bremen and then to Kiel in May 2004, where it is located at the Leibniz Institut für Meereswissenschaften, IFM-GEOMAR. Colin Devey currently chairs interRidge, and Katja Freitag is the Scientific Coordinator (coordinator@interridge.org).

Representatives from the principal and associate member nations form the steering committee. Principal member nations may have two steering committee members and associate member nations may have one steering committee member. Ex-InterRidge chairs may remain on the steering committee for one year after their term of office for purposes of continuity. Working group chairs are invited to the meetings of the steering committee, which meets annually to plan and direct InterRidge activities. At that meeting, in addition to the financial and reporting business, proposals for new working groups, for workshops and science education activities are also considered.

Each member nation also has a national correspondent. This person is a vital component of InterRidge, as the national correspondents represent the main nodes of communication between InterRidge and the member nations.

InterRidge working groups

InterRidge working groups are the principal mechanism for implementing the InterRidge programme. Working groups oversee development and execution of various projects identified by them and the steering committee (usually because of proposals from the active research community). The working groups and the Steering Committee see these projects as requiring, or potentially benefiting from, international and multidisciplinary collaborations. The main function of the working groups is to provide a forum for the international ridge community to define and refine scientific questions and to focus interests, both geographically and thematically. This is achieved in the form of workshops, symposiums and theoretical institutes. The end products are reports representing a synthesis of international and multidisciplinary efforts to pose the scientific questions and propose how best to address them. The reports often form the basis of and partial justification for grant proposals and carry the weight of international support and recognition.

The Next Decade’s Science Plan identifies seven working groups considered by the community to be necessary to focus international research on actual and pressing problems. Details of these groups are in Table 1. The detailed reasons for creating each of these groups are obtainable from the "Next Decade" science plan available on the InterRidge website *(see http://www.interridge.org/irnd.pdf):*

TABLE 1 "NEXT DECADE" InterRidge WORKING GROUPS

Theme	***Background***	***Start***	***Chair***	
Ultraslow-spreading ridges	Non-geographic emphasis, merged Arctic & SWIR Ridge WGs	2004	Jon Snow	Germany
Ridge-hotspot interaction	No change to previous WG	2000	Jian Lin	USA
			Jérôme Dyment	France
Back-arc spreading systems /Back-arc basins	Continuation of Back-arc basins database W/G	1995	Sang-Mook Lee	Korea
Mid-oceanic ridge ecosystems	Continuation of Biological studies at the ridge crest WG, new co-chair	1994	Françoise Gaill	France
			Nicole Dublier	Germany
Monitoring and observatories	No change to previous WG	2002	Javier Escartin	France
			Ricardo Santos	Azores
Deep earth sampling	New WG	2004	Benoit Ilsedefonse	France
Global exploration	New WG		To be announced	
Biogeochemical interactions at deep-sea vents	New WG (proposal accepted May 2004)	2004	Nadine le Bris	France

Building and maintaining an international community

Much of the groundwork involved in building a solid international community of spreading axis researchers was carried out during the initial years of InterRidge. Our goals now are to keep this sense of community alive and to try and identify and contact other possibly interested scientists. This is achieved in several ways:

- Through the maintenance of an up-to-date web site containing information on upcoming meetings and cruises, a membership database, information repositories relevant to the work of the different working groups etc. (see www.interridge.org)

- Through the production and distribution of a yearly newsletter (*InterRidge News*). Currently, over 2.700 people from 55 countries receive *IR News*, which is an important means of providing the most recent and up-to-date research articles to scientists without easy access to the Web. Due to budget constraints, *IR News* is an annual newsletter; however, all its articles are available online as soon as they are accepted and edited.

- Through regular email alerts issued by the InterRidge Office.

- By brokering ship berths on cruises, and
- By presentations at non-InterRidge meetings (opportunistic use of business trips).

Education and outreach

InterRidge has a major role to play in informing the public and policy makers about the global significance of ridges. The science of ridges can serve as an extraordinarily good vehicle for teaching basic concepts of physics, chemistry and biology. The InterRidge outreach goals include a wide variety of initiatives, such as: downloadable presentations on the Web to be used by InterRidge scientists in any member country, a video series highlighting ridge research for school systems and informal education settings (e.g., museums, science centres) worldwide, and education workshops to be held at various InterRidge-related meetings. InterRidge is seeking outside funding to be able to support these outreach initiatives.

Science foresight

InterRidge has, in the past, been extremely successful at fostering ambitious scientific targets. At its inception in 1992, large areas of the global ridge system were unsampled and unknown. During the first decade, this state of affairs was changed radically due to a concerted effort of InterRidge scientists, which led, for example, to large-scale efforts to understand the Southwest Indian Ridge and the first-ever sampling of the ice-covered Gakkel Ridge. This effort is continuing into the next decade, with such ambitious targets as continuous, real-time monitoring of a hydrothermal site (MoMAR, south of the Azores Islands) and with a specific liaison, via the Deep Earth Sampling Working Group, to the Integrated Ocean Drilling Project.

Representing the views of ridge scientists, a code of conduct

Scientists have a fundamental role to play in marine environmental protection; environmental protection without strong and continuous scientific study of the objects to be protected (studies which go far beyond just monitoring of the protected area) will, I am convinced, ultimately fail. To date, InterRidge has not been called upon in any formal way to provide expert advice to guide the discussion on environmental guidelines relevant to the regulation of polymetallic sulphide prospecting, exploration or exploitation, a situation which, in my opinion, both sides should actively try to change. In order to make their position clear as a group of expert stakeholders in the field of marine environmental protection, the InterRidge community, through the mid-ocean ridge ecosystem working group and the InterRidge Steering committee, is presently formulating a voluntary code of conduct for scientific work at hydrothermal vents. This work is still in progress and, as such, documents are not yet available for external distribution. General points which I personally feel should become part of this code are:

- Scientists are best qualified to assess the environmental impact of all activities at hydrothermal vents.

- Environmental protection without ongoing scientific study is inconceivable.

- Scientists have an obligation, both as role models, experts and human beings, to ensure that their work does not impinge significantly on the environment.

- All observations involve some form of impact on the environment being studied. Scientists should ensure that the extent of this impact does not exceed that of naturally-occurring processes (this point bears directly on environmental baselines - what are those processes).

- Study methods should be refined continuously with the aim of reducing their environmental impacts.

- Maximum use must be made of samples collected, only collecting for research and teaching is endorsable.

- Cost/benefit considerations must be taken into account when choosing the study method.

Potential collaborations with the Authority

Regulating the commercial exploitation of polymetallic sulphides deposits on the spreading axis will be an enormous task, requiring inputs from experts in many different fields to ensure minimum environmental impact. Although InterRidge is neither intended to nor is in position to contract experts for this work, it does possess unique extensive contacts to those experts, which could be immensely useful for the Authority when seeking expert advice. One role of InterRidge could therefore be as an "information exchange," helping to place the required experts in touch with the Authority.

Closer ties to the Authority could, however, also be envisaged. InterRidge has several working groups (e.g. Vent ecology, Monitoring and observatories, and Back-arc systems), the members of which possess expertise clearly of relevance to the needs of the ISA, with the added advantage that they represent a wide spread of nations. The Authority may consider engaging specific working groups in a consultative function, tasking them, for example, with the planning, execution and reporting of an international workshop to a theme of specific importance for the regulations. As a purely voluntary organization, InterRidge would neither wish to nor could it impose upon its working groups to take up such a contract. Nevertheless, the working groups may be some of the few groupings internationally that could perform the task in a manner commensurate with the Authority's standards.

SUMMARY OF THE PRESENTATION

Professor Devey outlined the structure of his presentation, as follows:

- The work of InterRidge, including what it did, why it has been established and why its members thought it was useful.

- The relevance of InterRidge.

- The voluntary code of conduct for scientific research at hydrothermal vents. This was something that InterRidge had been trying to develop over a couple of years prior to the workshop, which was near completion. Professor Devey also pointed out that he was the leader of the German Ridge programme and that, in Germany, InterRidge is producing a national code of conduct that is much easier, as the body is dealing with one legislative body and a limited number of funding agencies. He said that in the international arena this became quite complicated.

- Potential collaborations with the International Seabed Authority.

Professor Devey did not know how many of the other speakers would give a basic introduction to ridge research and also realized that there were not that many magmatic petrologists present. He stated that he was someone who studied volcanoes and tried to get into the mantle beneath them. Many of the papers that he wrote were about what was going on 100 kilometres below ground, which he found frustrating because he would never go there.

Professor Devey said that spreading axes form where tectonic plates move away from each other and material from the Earth's interior fill the hole produced. He commented that when the solid Earth interior rises, pressure-release melting occurs. He described this situation as the opposite of ice-skating, which was possible because of pressure-increase melting. He said that ice skating works because melted ice forms a thin film of water. In this regard, he pointed out that ice skating would not work below minus 22^{0} C, as the ice would not melt and the skater would not slide forward.

According to Professor Devey, magma transported heat from the Earth's interior to the surface at a temperature of about 1200^0 C. He said that the tectonic plates were constantly moving, thus producing new magma at the axes. He also said that this phenomenon is visible through the Earth's topography, with for example, a ridge running down the centre of the Atlantic Ocean from Iceland, called the East Pacific Rise. Professor Devey rhetorically asked whether there is a form of biogeography related to tectonics, saying that this is an issue of interest to the scientific community.

Professor Devey pointed out that the location of polymetallic sulphides in the deep seabed is very different from their land-based counterparts. He said that deep seabed polymetallic sulphides occur at earthquake epicentres, which are very dangerous places. To understand these systems, he stated the need for continuous monitoring of the environment, recalling some of the problems alluded to by Professor Van Dover, in this regard. He noted, however, that earthquakes occurred unpredictably on short timescales and said that in the deep seabed continuous monitoring is required to detect their occurrence. Therefore, Professor Devey said that one of the major things that InterRidge is trying to encourage is continuous real time monitoring of the seafloor. He pointed out that data from continuous real time monitoring could provide answers to some of the questions raised at the workshop. He said that continuous real time monitoring is an expensive and complicated option. As an example, Professor Devey described an area on the Juan de Fuca Ridge where lava flows periodically destroyed vents covered with shrimps, clams or tubeworms. He said that in dynamic environments, momentary observations were not sufficient to explain how such systems worked at longer timescales.

Professor Devey said that trying to find hydrothermal vents in the ocean was like trying to find a house in the Himalayas. He further noted that while polymetallic sulphides deposits are relatively small, the regulations concern a very large area. Professor Devey said that the catalyst for the establishment of InterRidge was the realization that the oceans covered such a large area that it would be difficult for a single nation to try to investigate and understand it. He said that InterRidge has 27 countries as members and that there are various categories of membership. He informed participants that financing for InterRidge's activities is through contributions from the individual country members. He said that about 2,700-2,800 individual researchers and institutes from these member countries participated in InterRidge's activities. He also said that some of InterRidge's members are from countries other than Western Europe and North America. Professor Devey emphasized that InterRidge is trying to involve countries that, for example, might not have the resources to do expensive research, but probably needed to do it. He described countries whose Exclusive Economic Zones contain parts of back-arc basins in the Western Pacific Ocean as an example.

Professor Devey said that to get so many people working together, there needed to be community building. He described community building as an active and ongoing process supported by InterRidge through the *InterRidge Newsletter,* which was sent out by mail to anybody who requested it. He said that updates to the newsletter include activities of member countries, articles about recent cruises and alerts about available places on cruises. He said that the newsletter is to provide information about activities taking place among and between the members of InterRidge; it was not a scientific publication containing reviewed papers.

Professor Devey observed that although ship-berth exchange requires a lot of work, InterRidge promotes it because many cruises have spare berths that provide one or two people who might not otherwise have the chance to go on a cruise the opportunity to do so. Professor Devey stated that in an upcoming cruise to the South Atlantic Ocean, he would have PhD students from Beijing and Korea coming along just to gain experience of life at sea. He felt that these types of activities would help the next generation of scientists involved in the Ridge Programme.

According to Professor Devey, many cruises that take place result in discoveries of interest to the scientific community. He said that InterRidge publishes such information using:

- A website it has developed that provides, inter alia, information about InterRidge, its activities, its publications and the work of its working groups. He said that the Coordinator of InterRidge maintains the website that also provides visitors with reference information.

- An international vessels and vehicle database containing information about the ships of the world. He said that the database contains information such as the capability of ships, and information on cruises. With regard to data on sampling, Professor Devey explained that although it is sometimes difficult to obtain data from earlier cruises, the database provides information on samples recovered.
- A hydrothermal vents database,
- A cruise list containing details of planned cruises, including information on the chief scientist, the name of the ship, the basic goals of the cruise, and the dates of the cruise, and
- A list of meetings that is relevant to the work on mid-ocean ridges.

Professor Devey believed that an important component of the work of InterRidge is to instigate research and to identify areas where research is not occurring or where international coordination can better facilitate research. He said that InterRidge's purpose is not to replace national programmes, but to support such programmes and provide international collaboration and involvement if required.

Professor Devey informed participants that InterRidge held workshops and symposiums. Some of these workshops and symposiums included Ridge-Hotspot Interaction and Mid-ocean Ridge Ecosystems, which is at the working group meeting stage. He said that in January 2005, InterRidge would convene a meeting in Goa with Indian InterRidge. He said that the objective of the meeting is to plan to investigate the Indian Ocean; to find out about the research that has taken place there and to plan the additional work to obtain better knowledge of this geographic area. He said that less research has taken place in the Indian Ocean than in the East Pacific Rise.

Professor Devey informed participants of an InterRidge effort that resulted in the first-ever exploration of spreading axes that went through the Arctic Ridge. He said that InterRidge organized three workshops and formulated a programme subsequently funded by German and American agencies. He said that this would never have happened without InterRidge.

Professor Devey said that scientists have not solved the problem of monitoring the Oceans. He said that InterRidge is actively supporting workshops in an effort to obtain implementation of MoMAR (Monitoring of the Mid-Atlantic Ridge). He said that MoMAR is taking place south of the Azores in Portuguese territorial waters and the European economic zone.

Professor Devey stated that coordination of scientific work is important and that apart from the coordination in the InterRidge office, InterRidge's working groups undertook a lot of this work. He said that InterRidge has eight working groups that are concerned with different aspects of what the research community currently thought was important. He also said that the working groups have been set up because the community wanted them. He said that the working groups are:

- Ridge ecosystems
- Monitoring and observatories (these were the people working on the MoMAR initiative)
- Back-arc basins (very important in terms of mineral deposits)
- Ultra-slow ridges
- Deep earth sampling
- Global exploration
- Hotspot-ridge interactions
- Biogeochemical interactions at vents.

Professor Devey said that suggestions for workshops and symposiums came from working group members. InterRidge then contributes to the workshop. He suggested this approach for collaboration with the Authority. He also suggested the work of the first three working groups on the list as appropriate areas for collaborations with the Authority.

Professor Devey informed participants that InterRidge is also involved with science policy and representation. He said that InterRidge tries to be a mouthpiece for all researchers. He described a workshop on "Management and conservation of hydrothermal vent ecosystems" that InterRidge convened in 2000 in Canada, and informed the participants of the lead role played by marine biologists in this effort. He also informed participants that the concerned working group is responsible for finalizing the "Code of conduct for the scientific research of marine hydrothermal vent sites"

Professor Devey noted that there is a lot of discussion about permissible activities in the Area and on the high seas. He said that recently, a non-governmental organization (NGO) had made the statement that "the Logatchev hydrothermal vent area has been visited by several expeditions since its discovery in 1994 and a further one is planned for 2003. Research activities can adversely affect vent systems for example by sampling when not managed and monitored adequately." Professor Devey said that he doubts that research activity could adversely affect vent systems on a global scale taking into account their volatile nature. However, he also said that there could be rare localized situations where it would occur. Professor Devey said that there are groups trying to impose boundaries on what researchers could do. He said that it is therefore important for scientists to make their standpoint clear, and is one of the reasons that InterRidge promotes the code of conduct. He identified as important, the need for scientists to clarify that effective conservation of the deep sea requires research to back it up. In this regard, he said that a danger emanating from the establishment of marine protected areas on the high seas is the ease of curtailing research in these areas. He said that a basic tenet of the code of conduct is proper scientific research to obtain the understanding required to protect the environment. Professor Devey explained that those involved in the code were not adversaries of NGOs, or environmental protectors

According to Professor Devey, the image projected is that scientists are ruining the hydrothermal sites just because they thought it would be fun to knock down some chimneys. He said that scientists needed to explain their research, in particular how it will help to minimize impacts on the environment to non-scientists. He described the code of conduct as the outreach for marine and environmental protection, and said that scientists on a research vessel adhering to and talking about this code influence people who were not necessarily scientists, such as the crew on the ships.

Professor Devey said that although he wanted to provide participants with more information about the code but the code is incomplete. However, he offered his personal view on what he felt belonged in the code of conduct, as follows:

- Clear statements on how scientists choose locations and sampling methods. The aim should be minimum invasion, maximum output for what was being done, being as efficient as possible, changing the environment as little as possible. It is known from basic physics that any activity imposed on the environment results in changes; the aim, when conducting activities should be to minimize changes to the environment and to assess the impact of those changes.

- Minimize contamination by ensuring that scientists conduct their activities according to nature. For example, ensure that equipment did not act as carriers of species from one region to another where they did not naturally occur.

- There should be pre-cruise planning and post-cruise assessment. Many scientists are concerned about these two activities because they sound like a lot of documentation that they have to prepare.

- There should be a component of personal responsibility and this was one of the highest priorities. The individual researcher would be responsible for what he or she did on the seafloor to those systems that he or she was studying. It was important to say that all scientists had that responsibility and that they took it seriously.

- Maximum use should be made of minimum sampling. This would involve sample sharing; telling people what samples were going to be taken, so that perhaps samples could be taken which other people would be able to work on.

- Coordination of site visits and equipment left. There were some sites which had been visited very often which had become intense study sites. They were almost monitoring sites. It was important to coordinate activity around them. There was no point if, after sticking a thermometer into one of the mussel banks and collecting data for a year, somebody came along with their submersible and knocked over the temperature probe and wrecked the whole project. The code could ensure that scientists were not disturbing one another. In most places, it was not a problem, but there were some places where it had the potential to be. This was also being addressed by InterRidge, as it required a lot of organization.

Professor Devey discussed another idea that is under consideration regarding marine protected areas. He stated that scientists were concerned that they may spend a great deal of money setting up a long-term experiment and then may be restricted if the area was then designated a marine protected area. He said that scientists, who had set up long-term experiments, did not want other people coming in, and interfering with them. Some of these scientists have proposed the idea of a science-priority protected area. Professor Devey said that scientists felt this was a reasonable request, because for example, there are laws that prevented them from getting too close to undersea cables.

Similarly, the scientists felt that the same restrictions should apply to cabling companies near important scientific sites.

Professor Devey noted that many of the previous presentations discussed environmental baselines. He offered an InterRidge perspective, including how InterRidge could help the Authority with the establishment of environmental baselines. He further noted that presently, InterRidge does not have a working group dealing with the subject matter. However, he felt there was no reason why they should not and suggested that the ecology-working group could consider this subject.

Professor Devey concluded his presentation saying that another important factor that is not under consideration at InterRidge is hydrothermal precipitates, which included the chimneys, the fallout from hydrothermal plumes, and the subsurface deposition of minerals. He informed participants that a large pool of expertise on these matters is available in Russia. He also said he would ask the community if there was interest in setting up a new working group to work on hydrothermal precipitates. He stated that this working group could interact closely with participants in the workshop.

SUMMARY OF THE DISCUSSIONS

Professor Devey was asked about the major constraints in implementing the code of conduct internationally. He responded that the major problems were, inter alia, that some researchers were bound by their funding agencies, that some funding agencies regarded the code as a legally binding document, and that others objected to references to the Law of the Sea Convention. As an example, he mentioned the National Science Foundation in the United States that could not commit to the code of conduct because it perceived the code as a legally binding document. He said that as a result, many American researchers could not agree to the code of conduct if they wanted funding for their work from this source. Professor Devey's personal view was that the voluntary code of conduct must be a scientific document written by scientists for scientists. He said that the code must be a statement of how scientists should work, without undue references to laws. He believes it is better to have comments, such as "we commit to minimizing the environmental impact of what we are doing, using the best methods we have to get the solutions we want, by coordinating with other scientists to make maximum use of the samples we are taking". Professor Devey thought that every scientist could commit to that, but telling a scientist they must abide by a particular section of a legal regulation would not be practical.

CHAPTER 9 CHESS AND THE BIOGEOGRAPHY OF CHEMOSYNTHETIC ECOSYSTEMS: THE WORK OF THE CENSUS OF MARINE LIFE AND POTENTIAL COLLABORATIONS WITH THE AUTHORITY

Dr. Lúcia de Siqueira Campos, Census of Marine Life / Departamento de Zoologia, Instituto de Biología, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil. (Additional authors: Eva Ramirez Llodra, Christopher R. German and Paul A. Tyler, Southampton Oceanography Centre, United Kingdom)

The Census of Marine Life (CoML) is a 10-year international programme that addresses diversity, abundance and distribution of life in the oceans. ChEss is a pilot project within the CoML initiative. Its main objective is to determine the biogeography and biodiversity of deep-water chemosynthetic ecosystems (hydrothermal vents, cold seeps, whale carcasses, sunken wood, oxygen minimum zones (OMZs), and to understand the processes driving them. Through international collaboration and coordination of efforts, ChEss is developing a field phase for the discovery and exploration of key target areas that would lead to a better understanding of the diversity and functioning of chemosynthetic communities at the global scale. In the last 27 years, nearly 500 new species have been described from vents and over 200 new species from seeps. A sound knowledge of the biodiversity, biogeography patterns of chemosynthetic species, gene flow, the biotic and abiotic processes that control these patterns, is essential to develop management and conservation options. These studies are crucial in chemosynthetic ecosystems as the high degree of endemicity, dynamism and patchy traits of these habitats result in an increased risk of habitat loss or population extinction. The ChEss community involves international collaboration and diverse expertise like in other related CoML projects (i.e. CeDAMar, MAR-ECO, Seamounts and Margins). This provides tools and scientific knowledge essential to develop environmental assessment and advice. In collaboration with the Authority, ChEss would provide the necessary framework from which to develop management and conservation options for the potential exploitation of chemosynthetic regions.

Introduction

The discovery of hydrothermal vents along the Galapagos rift in the 70's (Lonsdale 1977a, b, Corliss & Ballard 1977), and the subsequent discovery of cold seeps at the base of the Florida escarpment (Paul et al., 1984) has stimulated one of the most dynamic periods in the history of deep-sea biology for the past 27 years. This is because hydrothermal vents and cold seeps ecosystems can function independently of sunlight, with chemosynthesis being the primary energy source for the development of complex faunal communities in these environments.

Evidence of hydrothermal venting is now available from every ocean basin and at all spreading rates (Van Dover et al., 2002). Cold seeps occur at both passive and active continental margins, where seepage of cold fluids with high concentrations of methane, and/or sulphide from the underlying sediments, is characteristic (Sibuet & Olu, 1998).

Hydrothermal fluids are formed by the reaction of seawater with hot rock deep within the ocean crust, powered by heat from the Earth's mantle, whilst reducing substances from cold seeps are derived from the degradation of sedimentary organic matter (Van Dover 2000, Herzig & Petersen 2002, Tunnicliffe et al., 2003). Hydrogen sulphide and methane present in hydrothermal and seep fluids provide energy for micro-organisms that chemosynthetize organic matter from carbon dioxide and mineral nutrients (Juniper 2002, Tunnicliffe et al., 2003). This type of primary production may sustain a remarkably high biomass (500-1000 times higher than the surrounding deep-seafloor), and diverse fauna (Juniper 2002) with specific physiological and ecological adaptations to the highly toxic, dynamic and patchy ecosystem. Some of these adaptations may be of interest to the biotechnological and pharmaceutical industries.

The discovery of most hydrothermal vents and seeps has been in relatively low-latitude locations, essentially for logistic reasons. A wide variety of vent sites were explored along the Juan de Fuca Ridge in the Northeast Pacific, the East Pacific Rise, the Back-Arc Basins of the Western Pacific, the Atlantic and, very recently, in the Indian ocean (Tunnicliffe et al. 1998, Van Dover et al., 2002). But, even today much of the 60,000 kilometres of the mid-ocean ridge still remains unexplored. Magmatic processes controlling rifting may separate vent sites over many ridge segments, but faunal composition over large distances is not easily predictable, it may relate to larval dispersal and chance recruitment as vent fields may be separated by ten to hundreds of kilometres (Tunnicliffe 1991).

A period of exploration during which seep sites were found on both passive and active margins round the world followed the initial discoveries at the base of the Florida escarpment. The better known cold seeps are in the Gulf of Mexico (400-2200 m), Florida Escarpment (3270), Barbados Prism (1000-5000 m), Laurentian Fan (3800 m), Japan Trench (3800-6000 m), Oregon Margin (600-2000 m), and Peruvian Margin (2600-5600 m) (Tunicliffe et al., 2003). But, highly-reduced habitats supporting chemosynthetically-driven communities also develop in other deep-sea ecosystems.

Whale skeletons release sulphide through microbial reduction of sulphates, sustaining sulphide-oxidising bacteria and communities of invertebrates based on chemosynthetic production (Smith et al., 1989; Smith & Baco 2003). Accumulations of sunken wood and organic matter as well as areas of low oxygen (Oxygen Minimum Zones, OMZ) intersecting with continental margins or seamounts also create highly reduced habitats where chemosynthetic-based communities can develop (Levin 2003). These other ecosystems may be used as 'stepping stones' important to vent and seep fauna distribution.

ChEss (Biogeography of Chemosynthetic Ecosystems) is one of the nine running field projects within the Census of Marine Life (CoML) programme. Through international collaboration and coordination of efforts, it aims to improve our knowledge of the biogeography of species from chemosynthetically-driven ecosystems (i.e., hydrothermal vents, cold seeps, whale carcasses, sunken wood and OMZs) at a global scale, and to understand the forces driving them. Here, ChEss is presented in the context of the work of the international CoML, and how it can provide subsidies to the International Seabed Authority in the establishment of environmental baselines for the purpose of evaluating the possible effects of exploration and exploitation of deep seabed polymetallic sulphides mine sites in the ocean regions outside the countries' jurisdictions (The Area).

Census of Marine Life Initiative

The Census of Marine Life (CoML) initiative has been an international research programme established from 1997 that documents diversity, distribution, and abundance of marine organisms throughout the world's oceans. Internationally, it involves experts in different research fields from over 70 nations around the globe, gathering past information, establishing present exploration research phases, and combining these to predict the future. Considering the dimensions of the world's oceans, each of their major realms (boundaries and central waters - Figure 1) is characterized by known, unknown and unknowable features. In order to facilitate the understanding and study of these realms, the CoML has established research projects that cover them to a certain extent (known and unknown - Table 1) with the help of many scientists from different institutions and nations, with different expertise, and with the use of the best up-to-date methods and technologies.

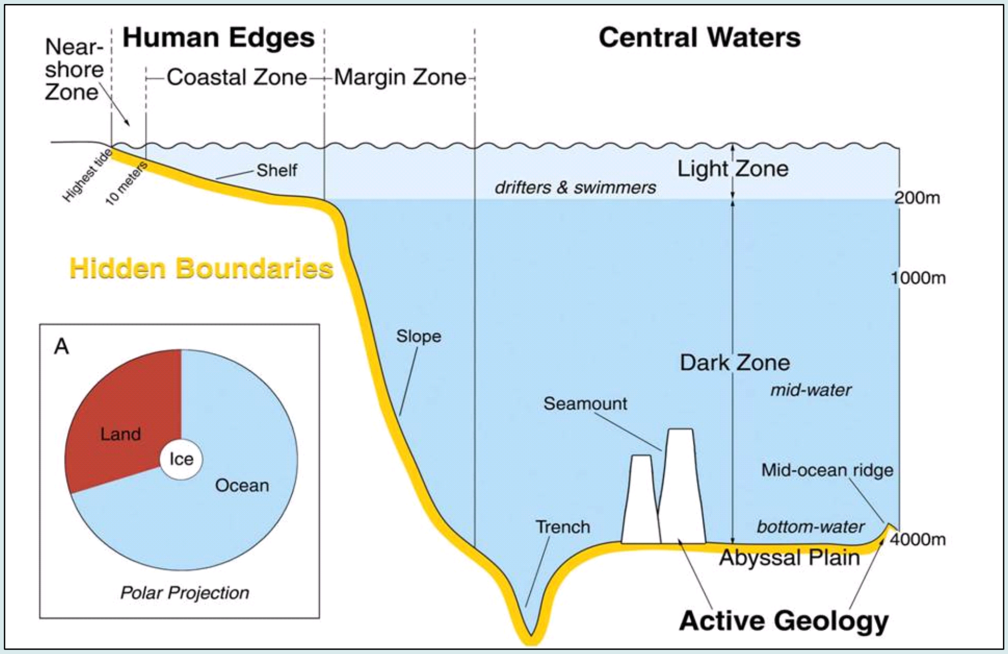

Figure 1: *Realms to explore in the world's oceans (from: O'Dor, 2003, figure location on the web http://www.coml.org/baseline)*

The ambitious overall goal of CoML is to be reached by stimulating well coordinated, dedicated regional research efforts that together provide significant new information on patterns and processes of marine life on a global scale within each topic and region. Much effort has been focused on poorly known or remote ecosystems and/or communities for which new information is important to enhance understanding on diversity and on the marine environment as a whole.

The CoML advances Science through addressing key questions incorporated into each of its research projects: (a) What lived in the oceans?; (b) What lives in the oceans?; and (c) What will live in the oceans? These major challenge questions involve result in the four major component programmes: the History of Marine Animal Populations (HMAP), the new field projects requiring observations and research over 5-10 years, the Future of Marine Animal Populations (FMAP), and the Ocean Biogeography Information System (OBIS). OBIS has been developed to access and visualise data on living marine resources. So far, its portal provides online access to around 5,000,000 species distribution records of high taxonomic quality, and tools for effective research, management and education (data requests, searches, network tools, models, research, and education centre).

The CoML research applies to recommendations for sustainable fisheries, environmental assessments, marine protected areas (finding hotspots), indicates habitat loss and pollution, invasive and endangered species, assists the United Nations Convention on biodiversity, global climate change, and has a strong educational component for public outreach.

TABLE 1: OCEAN REALM FIELD PROJECTS: ONGOING, IN REVIEW, IN DEVELOPMENT

REALMS		PROJECT STATE AT COML		
		ONGOING	IN REVIEW	IN DEVELOPMENT
BOUNDARIES	NEARSHORE	NATURAL GEOGRAPHY IN SHORE AREAS (NAGISA, JAPAN)		CORAL REEF COMMUNITIES, WORKSHOP AUGUST 2004
	COASTAL	• GULF OF MAINE AREA CENSUS (GOMA, USA/CANADA) • PACIFIC OCEAN SHELF TRACKING (POST, CANADA)		
	CONTINENTAL MARGINS			MET AUGUST 2003, IFREMER, FRANCE
	ABYSSAL PLAIN	DIVERSITY OF ABYSSAL MARINE LIFE (CEDAMAR), GERMANY		
	POLAR REGIONS	ARCTIC OCEAN CENSUS OF MARINE LIFE (ARCCOML), USA/RUSSIA		CIRCUM-ANTARCTIC COML (CAML), MEETING IN OCTOBER 2004, AUSTRALIA/BELGIUM/UK/GERMANY/BRAZIL/ARGENTINA/USA
	ACTIVE GEOLOGY	CHEMOSYNTHETIC ECOSYSTEMS (CHESS), UK	SEAMOUNTS, MET AUGUST 2003, NIWA - NEW ZEALAND	
CENTRAL	DRIFTERS		CENSUS OF MARINE ZOOPLANKTON (CMARZ), USA/JAPAN/GERMANY	

	SWIMMERS	**TAGGING OF PACIFIC PELAGICS (**TOPP**), USA**		
	DEEP OCEANIC	**MID-ATLANTIC RIDGE ECOSYSTEMS (**MAR-ECO**), NORWAY**		
	MICROBES		**CENSUS OF MARINE MICROBIAL LIFE (**COMML**), USA/NETHERLANDS**	

ChEss: The Project (www.soc.soton.ac.uk/chess)

The Biogeography of Chemosynthetic Ecosystems programme aims to determine the biogeography of deep-water chemosynthetic ecosystems at the global scale and to understand the forces driving them. ChEss acts as an umbrella programme, providing a large-scale aspect to research being undertaken by different laboratories in different locations of the world. It coordinates efforts amongst scientists and laboratories from the different countries involved, to join efforts for the preparation of new research proposals through its field programme, and to ensure a maximum return from the ongoing science that will benefit the community as a whole. ChEss is being implemented in three phases: (1) planning phase (2002-2004); (2) field phase (2005-2009); and (3) synthesis phase (2010).

The main objectives of the initial planning phase have been to establish the international planning and coordination office at the Southampton Oceanography Centre (United Kingdom), to convene the ChEss international steering committee and to develop a specific science plan from which to develop the field phase.

In parallel, ChEss has created a dynamic relational database with geo-referenced biological information on all species from deep-water chemosynthetic ecosystems (ChEssBase). The first version of ChEssBase will be available online for trials on the ChEss web site from November 2004. ChEssBase includes, at present, data on 716 species from 74 chemosynthetic sites around the globe. These data contain information (when available) on the taxonomy, diagnosis, trophic level, reproduction, endemicity and habitat types and distribution. ChEss has now 949 papers in its reference database. ChEssBase is expected to be integrated with OBIS (www.iobis.org) in late 2004 – early 2005.

The field phase comprises a number of specific research projects for the exploration, discovery and study of chemosynthetic ecosystems in key locations. A number of international research proposals have been (and will be) submitted to different funding bodies. The main objectives of this long-term field phase are to describe the fauna, assess the phylogenetic relationships of species within and between ecosystems, understand dispersal and colonisation potential of chemosynthetic species, and determine biogeographical patterns at the global scale. The long-term field phase involves several programmes, which have advanced in parallel with the refinement and development of new technologies for deep-sea exploration (AUTOSUB, TOBI, ROVs, and new sensors), as well as the use of new analytical techniques such as molecular biology and biochemistry to complement traditional methods for taxonomical, ecological and reproductive studies (Tyler et al., 2003).

ChEss Field Programmes

A number of target sites have been selected for ChEss' field programmes. These were chosen on the basis of the present knowledge of geological, physical and chemical aspect of deep-water ecosystems, and the known distribution and ecology of species from chemosynthetic systems. The target sites have been grouped in two categories.

Category I includes target areas where highest degree of international collaboration and coordination of efforts is required for successful investigation. These include large areas where different chemosynthetic systems and a number of ecological, geological, evolutionary, and topographic parameters are combined, so that faunal relationships can be studied amongst different systems as well as the processes that drive their distribution. In Category I, the combined areas include: (a) the Equatorial Atlantic Belt; (b) the Southeast Pacific region; and (c) the New Zealand Region (Figure 2).

Category II includes locations where there is already interest at national and/or international level, but that are also important to elucidate the biogeography puzzle of chemosynthetic systems. The specific areas for Category II include: (1) the ice-covered Gakkel Ridge; (2) the ultra-slow ridges of the Norwegian-Greenland Sea; (3) the northern Mid-Atlantic Ridge between the Iceland and Azores hot-spots; (4) the Brazilian continental margin; (5) the East Scotia Ridge and Bransfield Strait; (6) the Southwest Indian Ridge; and (7) the Central Indian Ridge (Figure 2).

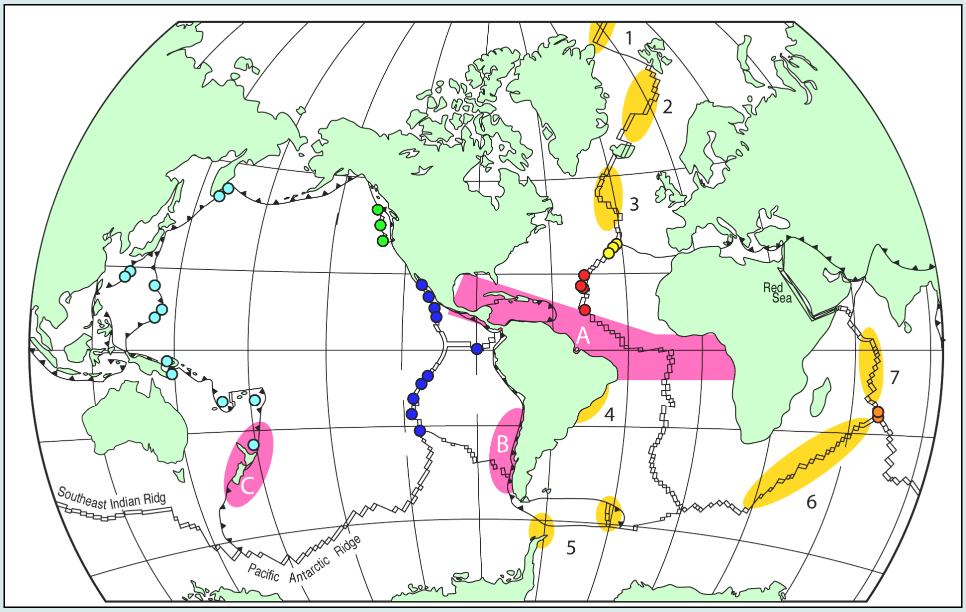

Figure 2: *Key target areas for the ChEss field programme. Category I, combined areas (red): Area A: Equatorial Atlantic Belt region - comprising cold seeps off Costa Rica and the Gulf of Mexico, the Cayman Trough spreading centre, the Barbados accretionary prism, the continental margin off north east Brazil including the Amazon outflow, the MAR north and south of the equatorial Fracture Zones and the West African continental margin; Area B: the SE Pacific region - comprising the East Chile Rise; the Peru-Chile trench; the OMZ region of the Chilean continental margin, and coincident whale migration and wood-fall areas. Category II, specific areas (yellow): 1 – the ice-covered Gakkel Ridge, 2 – the (ultra)-slow ridges of the Norwegian-Greenland Sea, 3- the northern MAR between the Iceland and Azores hot-spots; 4 – the Brazilian continental margin, 5 – the East Scotia Ridge and Bransfield Strait, 6 – the Southwest Indian Ridge, 7 – the Central Indian Ridge.*

Category I Field Programmes

Equatorial Atlantic Belt. (www.soc.soton.ac.uk/chess/equatorial_belt.html). This project is coordinated by Daniel Desbruyères (Ifremer, FR) and Eva Ramirez (SOC, UK). The Atlantic Equatorial Belt extends on a longitudinal gradient, from the Gulf of

Mexico to the continental margin off West Africa, including also the Costa Rica cold seeps in the Pacific for biogeographical reasons. The key sites include the Costa Rica cold seeps, the Gulf of Mexico cold seeps, the ultra-slow spreading Cayman trough, the Barbados accretion prism, hydrothermal vents on the Mid-Atlantic Ridge, North and South of the equatorial (Romanche and chain) fracture zones and cold seeps on the continental margin of West Africa (Angola Basin). This project aims at a better understanding of the biogeography and phylogenetic relationships of fauna from chemosynthetic systems along a longitudinal gradient and across a number of different ecosystems. The study of the Equatorial Belt will help understanding if there is a biogeographic continuity from West to East driven by the circulation of north Atlantic deep water southwards along the Atlantic western boundary and eastwards via major fracture zones. Also, other questions have been addressed, such as: does taxonomic/genetic distance between taxa increase with geographic isolation?; what is the role of isolation by distance and topographic barriers (i.e. Major fracture zones) versus heterogeneity of habitats (i.e. Bathymetry, chemistry, temporal instability)?; and what are the co-evolution patterns between host and symbiont (e.g. Lucinid bivalves)?

New Zealand Region (www.soc.soton.ac.uk/chess/nz_region.html). This project proposal was submitted to NOOA-OE 2005 (Oct. 2004), and is coordinated by Amy Baco (WHOI, USA), Craig Smith (U. Hawaii, USA) and Ashely Rowden (NIWA, NZ) in collaboration with scientists at New Zealand's National Institute of Water and Atmospheric Science, Institute for Geological and Nuclear Sciences, and National Museum. The oceans around New Zealand host a variety of chemosynthetic ecosystem niches, all in close geographic proximity such as the Kermadec volcanic arc, seep sites on the Hikurangi margin east of North Island and off Otago on the South Island, the fjords of the south-west coast in South Island that are potential target regions for OMZs, sunken decaying wood and kelp studies, and also whale carcass' skeleton studies that can be conducted elsewhere in the region. The seas around New Zealand are known as an important whale migration route providing the likelihood of important seafloor deposits in locations where they are particularly abundant (e.g. Kaikoura canyon, at east coast South Island).

INSPIRE - INternational South-East Pacific Investigation into Reducing Environments (www.soc.soton.ac.ac.uk/chess/se_pacific.html). The principal investigators of this project are Christopher German (SOC, UK), Paul Tyler (SOC, UK), Lisa Levin (Scripps Institution of Oceanography, USA), Chuck Fisher (Penn State University, USA) and Victor Gallardo (COPAS, Chile) in partnership with several universities of the Worldwide Universities Network and associated partners from Germany and Chile. This is an interdisciplinary investigation of interacting Earth-, Ocean- and Life Science processes in the Southeast Pacific off Chile where the south Chile Ridge is being subducted beneath the Andes at the Chile Trench. The Peru-Chile margin and subduction zone contains unexplored hydrate deposits and seep sites venting methane-rich fluids. Also, the Chile continental margin is intercepted by a well developed oxygen minimum zone (OMZ) between 200 and 500 m below sea level. Dense mats of oxidising bacteria cover the sediments where this OMZ impinges on the seafloor, and the nutrition of infaunal assemblages in this zone may rely on chemosynthesis as indicated by the occurrence of some symbiotic-bearing species and isotopic evidence (Levin, 2003). The productive waters of the Peru-Chile margin are route migration for many species of whales that feed in this region, and whale carcasses have been falling to the seafloor regularly. Apart from all these sources for chemosynthetic activity, the forests of southern Chile provide potential large amounts of sinking wood.

Category II Field Programmes

Gakkel Ridge: The Gakkel Ridge is an ultra-slow spreading ridge, which lies beneath permanent ice cover within the bathymetrically isolated Arctic Basin. There has been evidence for abundant hydrothermal activity on the Gakkel Ridge in the Arctic Ocean (Edmonds et al., 2003). The deep Arctic water is isolated from deep-water in the Atlantic by sills between Greenland and Iceland and between Iceland and Norway. This has important implications for the evolution and ecology of the deep-water Arctic vent fauna. The Atlantic and Pacific were once connected via the open Arctic Ocean, and their vent fauna could have used this pathway to disperse across ocean basins. In order to test the hypothesis of a past Arctic Ocean link it is important to identify which species are found on the Gakkel Ridge, assess their ecological and phylogenetic relationships with vent species from Pacific and Atlantic vent fauna. Also, exploring the Arctic ridges will enable identification of new species with specific adaptations to unique ecological habitats.

Norwegian-Greenland Sea Ridges**:** The Knipovich, Mohns and Kolbeinsey ridges extend from the south of Svalbard to the north of Iceland. The first two are ultra-slow spreading ridges, and the Kolbeinsey is a slow spreading ridge. There is evidence for hydrothermal venting at both Kolbeinsey and Knipovich (Pedersen et al., 1999; Connelly and German, 2002), but to date there is no information on associated fauna. These ridges are isolated from the Gakkel Ridge by shallow sills connecting to the Arctic Basin, but they are even more dramatically isolated from the MAR by Iceland, where the ridge is subaereal. Thus, this system offers a natural laboratory for evolution on an isolated section of the ridge.

Mid Atlantic Ridge, Azores-Iceland**:** This is the ridge-crest closest section to Northern Europe, forming an important component of the European tectonic plate boundary. Geologically, much of this ridge section should be expected to host hydrothermal activity similar to that found at numerous sites along the northern MAR south of the Azores including variations because of the changing lithology (e.g. Logatchev vs. Broken Spur) volcano-tectonic setting (e.g. Snake-Pit vs. TAG), and decreasing depth toward ocean island hotspots (e.g. Rainbow - Lucky Strike - Menez

Gwen). Biologically, it has been shown previously that at decreasing depth there is increasing invasion of local seabed fauna into the known vent-site communities. Therefore, it is interesting to question whether vent-specific fauna may be displaced so effectively that they are completely absent from the shallowest ridge-crest amongst the Azores islands. If so, this shallow section of the ridge may act as a genetic barrier, which isolates the vent-faunal communities south of the Azores from those to the north, rendering these two distinct ridge-sections as genetically-isolated biogeographic provinces. Also, the possibility remains that predation in shallow sunlit waters prevents any genetic communication between deep-water hydrothermal communities north and south of the Azores, and north and south of Iceland such that this section of the MAR hosts unique vent-fauna isolated between two long-duration hot-spots. For that reason, exploration should also continue north of the Azores until depths comparable to Lucky Strike/Rainbow are reached at the Kurchatov Fracture Zone. The international community has recognized the need to develop conservation and management policies for deep-sea habitats, and in spring 2003, the Portuguese Government and the World Wide Foundation for Nature (WWF) established the first deep-sea Marine Protected Area in the Lucky Strike and Menez Gwen vent sites (MAR). The results that will arise from the ChEss field phase will help provide crucial data on the distribution and functioning of deep-water chemosynthetic ecosystems, providing the necessary scientific data to develop management options for existing and potential new deep-sea MPAs.

Continental margin off central Brazil: there have been both indirect and direct evidence for the existence of cold seeps on the southeast Brazilian continental margin. A vesicomyid shell, Calyptogena birmani collected in Santos Basin has been identified by Domaneschi & Lopes (1990), and erosional events on the upper continental slope have evidenced gas-venting at Campos Basin (Kowsmann & Carvalho 2002). The Brazilian continental margin is currently under development for extraction of gas and oil by Petrobras and other oil companies, who have acquired a wealth of relevant, but un-published 'commercially sensitive' data. This margin also harbours a resident population of humpback whales and probably falls on a migration route for this and other cetacean species. The potential seep and whale-fall communities of the Brazilian continental margin could be linked to communities on the African continental margin through the eastward flow of NADW via the Rio de Janeiro Fracture Zone and with the southern ocean via whale-falls along SE American margin migration routes.

Bransfield Straight/East Scotia Ridge**:** The Bransfield Straight (BS) and East Scotia Ridge (ESR) are isolated back-arc basins located at the gateway from the Pacific to the Atlantic sector of the Southern Ocean where evidence of hydrothermal activity has been recently identified (German et al., 2001; Klinkhammer et al., 2001). The exploration of the BS and ESR to locate individual vent sites and describe their faunal communities is necessary to understand dispersal and colonisation pathways for vent-species between ocean basins.

Indian Ridges (Southwest Indian Ridge, and the Central Indian Ridge): The Indian ridges also play an important role in our understanding of the evolutionary dispersal and colonisation of vent sites at the global scale. The only direct modern pathway between the Pacific and Atlantic ridge-systems is via the Pacific ¬Antarctic Ridge, the Southeast Indian Ridge and the Southwest Indian Ridge (Tunnicliffe et al., 1998). Of these, the Southwest Indian Ridge is of particular importance. Like the Gakkel and Knipovich ridges in extreme North, the SWIR is also an ultra-slow spreading ridge. Despite the associated low magmatic flux, recent studies have shown evidence for abundant venting in both volcanic and tectonic terrenes (German et al., 1998; Bach et al., 2001). Vent invertebrate communities found at the Kairei and Edmond sites in the Central Indian Ridge (CIR) have a high similarity to that of the East Pacific Rise (Ramirez Llodra et al 2003). However, the dominant species at CIR is the caridean shrimp Rimicaris aff. exoculata related to the Atlantic species (Van Dover et al., 2001). If gene-flow is strongly influenced by ridge-spreading rate then vent-sites along the northern CIR should exhibit close similarities to SW Pacific fauna. However, CIR fauna might define yet another discrete biogeographic province or, indeed, may reflect some residual characteristics dating from connection between the modern-day Northwest Indian Ocean and the Atlantic/Mediterranean Sea via the now-closed Tethys Ocean.

ChEss' links with other projects

The ChEss community involves international collaboration and multidisciplinary expertise. It joins efforts with other CoML projects such as MAR-ECO (patterns and processes of the Mid-Atlantic Ridge - ChEss and MAR-ECO share steering committee members ensuring communication amongst the two projects), Seamounts Online-CenSeam (links with database issues and hydrothermally active seamounts), ArcCoML (for a potential research proposal on the Gakkel Ridge). Also, Chess steering committee members have had interactions in the preparation of other CoML project proposals such as the Continental Margins: biodiversity and ecology of continental margins, and the Circum Antarctic Census of Marine Life (CAML).

Other international programmes related to ChEss include the EU MoMAR initiative (collaboration on research in the Mid-Atlantic Ridge), the EC Framework Programme 6 HERMES integrated project on European continental margins (research on cold seeps and anoxic microbial systems), ESF Eurocores MEDIFLUX project (new data on cold seeps in the eastern Mediterranean), the project DEEPSETS within the EC FP6 Networks of Excellence MARBEF (links on data gathering for the Haakon Mosky Mud), the international programme on ridge science InterRidge (coordination of vent science, integration of databases and education), the US programme on ridge research Ridge 2000 (investigations on hydrothermal vents), and other individual research projects led by ChEss participants at the national level.

ChEss education and outreach: informing the public, aiding authorities

ChEss has a multilingual scientific web site (www.soc.soton.ac.uk/chess) and an educational web site (www.soc.soton.ac.uk/chess/edumain.html) in 3 languages (English, French and Spanish) with basic information on hydrothermal vents and cold seeps. This includes virtual dives to characteristic sites around the globe. ChEss aims at bringing the latest knowledge of the diversity and functioning of these poorly known ecosystems into classrooms for all age groups and the general public. To this objective, ChEss has developed an 'Outreach from Sea Programme' where each ChEss cruise can be followed at real time on the Internet with daily explanations, photos and video of the work and discoveries being made while at sea.

In recent years, the international community has recognized the need to develop conservation and management policies for deep-sea habitats. ChEss is collaborating with the wildlife adviser (Joint Nature Conservation Committee) of the Government of the United Kingdom in a project aiming at mapping OSPAR priority habitats in the NE Atlantic. Also, in December 1998, the Endeavour vent field (Canada) was established as the first pilot Marine Protected Area (full MAP since March 03). In spring 2003, the Portuguese Government and the World Wide Fund For Nature (WWF) gave the MPA status to the Lucky Strike and Menez Gwen vent sites (MAR). The results that will arise from the ChEss field phase will help provide crucial data for the development of management options for existing and potential new deep-sea MPAs.

CONCLUDING REMARKS

The potential location of hydrothermal vents and cold seeps at a global scale extends over a vast area of the world oceans, which cannot be realistically explored in its totality (Ramirez Llodra et al., 2003; Tyler et al., 2003). But, studies on the functional diversity of species, nutritional pathways and evolutionary radiation are essential in order to understand the relationships amongst all chemosynthetically-driven communities. It is known that the high degree of endemicity, dynamism and patchy traits of chemosynthetic ecosystems may result in an increased risk of habitat loss or population extinction. Therefore, a thorough knowledge of the biodiversity, biogeography patterns of chemosynthetic species, gene flow, the biotic and abiotic processes that control these patterns, is fundamental to develop management and conservation strategies.

As the ChEss community involves broad international collaboration, high-quality internationally-led research, and diverse expertise (geological, biogeochemical, physical, biological, and from microbes to megafauna, from taxonomy to physiology), it has tools, scientific knowledge, and the necessary framework essential for the development of environmental assessment of chemosynthetic ecosystems. In collaboration with the Authority, and based on its advisory status, ChEss can recommend on management and conservation options for the potential exploitation of deep seabed polymetallic sulphides mine sites in the Area.

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SUMMARY OF THE PRESENTATION

Dr. Campos began her presentation, highlighting that the paper was prepared with Paul Tyler and Christopher German of the Southampton Oceanography Centre. Dr Campos said that Professor Tyler was the Chair of the Biogeography of Deep-Water Chemosynthetic Ecosystems (ChEss) group. She stated that her presentation would be on the Census of Marine Life (CoML) initiative, the projects involved in this initiative, ChEss, other helpful CoML-related programmes that have a link with ChEss, and potential ChEss and CoML collaborations with the ISA.

According to Dr. Campos, the CoML Initiative was always thought of in terms of research. The main objectives of the census were to document diversity, distribution and abundance of marine organisms, in the present and in the past. Dr Campos said that the initiative involved experts in different fields from over 70 countries. She said that CoML had identified some key questions that required observations and research for a 5 to 10 year period. She also said that CoML's lifespan is until 2010.

Dr. Campos noted that questions asked at the workshop addressed the past, present and future. She said that many of the questions related to the existing knowledge about the oceans, including what was unknown and what would remain unknown. She referred to these three items as the KUU (known, unknown and unknowable) questions. She said that many of the unknowns are because of the absence of technology. She also said that trying to answer these questions might facilitate, inter alia, the identification of endangered species, the detection of important breeding areas, especially fisheries, the discovery of some pharmaceutical and industrial bioproducts, and also help authorities in the development of effective strategies for sustainable management of marine resources.

Dr. Campos informed the participants that there is a programme called History of Marine Animal Populations (HMAP) whose objective was to gather information from the past to answer the question "what did live in the oceans?" Another programme was the Future of Marine Animal Populations (FMAP) that put together information from the past with new programmes and ecological models and projects to try to answer what would live in the oceans in the future.

Dr. Campos said that in addition to the programmes that she had mentioned, the field programmes, or "Realms to Explore", as seen by the Census of Marine Life were:

- "Natural Geography in Shore Areas" (NaGISA) coordinated in Japan;
- "Coral Reef Communities" (CReefs) had a workshop in August 2004 and was in development;
- "Gulf of Maine Area Census" (GoMA) coordinated by USA and Canada;
- "Pacific Ocean Shelf Tracking" (POST) in Canada;
- The Continental Margins group (CoMargE) was in development and was likely to be run by IFREMER;
- "Census of the Diversity of Abyssal Marine Life" (CeDAMar) coordinated by Germany;
- "Arctic Ocean Census of Marine Life" (ArcCoML) coordinated by USA and Russia;
- "Circum-Antarctic CoML" (CircAnt CoML) was in development;
- "Biogeography of Deep-Water Chemosynthetic Ecosystems" (ChEss);

- The Seamounts group (CenSeam) which was discussed in another presentation;
- Census of Marine Zooplankton (CMarZ);
- "Tagging of Pacific Pelagics" (TOPP);
- "Mid-Atlantic Ridge Ecosystems" (MAR-ECO) run by Norway;
- "Census of Marine Microbial Life" which was under review in the USA and Netherlands.

Dr. Campos noted that some of these are currently underway and some are in development.

Dr. Campos explained that in order to access and visualize all the data on marine resources, the Census used the Ocean Biogeography Information System (OBIS). She said that OBIS compiles all the information on species obtained from different locations to provide access to about 5 million species distribution records of high taxonomic quality. She said that currently, close to 1 million species have been registered on the OBIS by the Census.

Dr Campos said that some of the applications from CoML's research are:

- Sustainable fisheries;
- Marine-protected areas;
- Habitat loss and pollution;
- Environmental assessments;
- Invasive species from different areas;
- Endangered species;
- United Nations Convention on Biodiversity;
- Global climate change;
- Education.

Dr. Campos also informed participants that CoML had several components and links to different oceanographic programmes, as well as a strong outreach component.

According to Dr. Campos, the primary aim of ChEss was to determine the biogeography of deep-water chemosynthetic ecosystems at a global scale and to understand the forces driving them. She said that outreach and education are important components of ChEss, which had a multilingual website in French, Spanish, Portuguese and English. She also said that the general education and outreach office for CoML is at Rhode Island University. She said that the Office's aim is to inform the public about news and discoveries of CoML projects.

Dr. Campos stated that the approach taken by CoML for vents and seeps species was to develop a relational database called ChessBase. She said that all available information was bio-referenced and geo-referenced, and available online. She said that the articipation of most large research programmes was expected. She also said that within ChessBase there is information on taxonomic identifications, the groups and institutions carrying out research and the locations where the organisms were found.

Dr. Campos informed participants that ChEss is a long-term project for the discovery and exploration of new chemosynthetically driven sites at key locations. She said its aim is to describe the fauna, to assess phylogenetic relationships of species within and between ecosystems, to understand dispersal and the colonization potential of chemosynthetic species and ultimately to determine biogeographical patterns at a global scale.

Dr. Campos informed the participants that there is a plan to implement a project in the equatorial belt of the Mid-Atlantic Ridge coordinated by Daniel Desbruyères. It involved different national initiatives and international cruises in the next four to five years. She said that the project's objective is to determine the relationships between species found in different ocean areas, to determine if there had been migration, ascertain how migration occurred, and to optimize the use of proposed cruises. She also described another project in the Chilean Pacific called INSPIRE (International South-East Pacific Investigation into Reducing Environments), that will investigate the importance of the oxygen minimum zone in this area. She said that the purpose of the project is to study the diversity of chemosynthetic ecosystems within and between the oxygen minimum zone, the seeps and the Chilean Margin. She informed participants of the discovery of wood from the forests of Southern Chile in the deep ocean with an associated chemosynthetic community. She said that at the same deep ocean area, there are whalebones on the seabed, again, with hydrothermal vents or seeps species. Dr Campos said that another area of interest is the Brazilian continental margin where there is a register of cold seeps and other fauna possibly related to chemosynthetic activity. In Antarctica, around the peninsula, Dr Campos said that there is hydrothermal venting activity that is yet to be studied.

According to Dr. Campos, other relevant CoML programmes that provided information on chemosynthetic environment are:

- MARECO as it studied the patterns and processes of the Mid-Atlantic Ridge;
- CeDaMAR;
- CenSeam as oxygen minimum zones were often associated with seamounts;
- Continental Margins. The Continental Margins were very diverse in terms of topography and environmental processes. The overarching question was what were the scales of habitat heterogeneneity and which processes were important in creating and maintaining the high bathyal diversity. Diversity increased and biomass decreased as you go down the slope. When trying to

understand the process and which processes affected biodiversity all of the spatial and temporal patterns needed to be understood as ecosystem functioning could affect biodiversity.

Dr. Campos concluded her presentation informing participants that ChEss and CoML could be of use to the Authority in an advisory capacity. She said that both organizations conduct high quality, geographic diverse, and internationally-led research using state of the art technology in different fields (geological, biogeochemical, physical, biological and from microbes to megafauna, from taxonomy to physiology). She felt that this was probably the main potential for collaboration with the International Seabed Authority.

SUMMARY OF THE DISCUSSION

In response to a question regarding coordination between different groups within the Census of Marine Life, Dr. Campos said that coordination was carried out by the Census of Marine Life itself. Dr. Campos stated that the Ocean Biogeographic Information System (OBIS) is the information component of the Census of Marine Life. She said that OBIS is a Web-based portal with links to databases for explaining ecological relationships in the oceans. She said that there is some overlap in the work of groups such as ChEss and the Continental Margins group because continental margins contain chemosynthetic environments. Dr. Campos believed that many questions could be answered using different approaches by the groups. In response to a question regarding liaison between groups studying biology and those investigating other disciplines, such as geology or geophysics, Dr. Campos confirmed that collaborations between the different groups would take place since the integrated approach is required to respond to certain questions.

A participant asked why wood carried to the sea by rivers was so important when rivers carried many items into the oceans. Dr. Campos replied that wood is sometimes associated with chemosynthetic activity, and organisms found on sunken wood are often similar to those in other chemosynthetic environments. Thus, wood falls may be stepping stones for these organisms to move between chemosynthetic environments, such as hydrothermal vents.

A conclusion drawn by a participant because of Dr. Campos' talk was that people had the impression that CoML was all about biodiversity and counting how many species there are in the world without worrying about the physical environment. Dr Campos stated that this is not the case and stressed the importance of ensuring that there is a structure where geologists interact with biologists and vice versa.

Dr Campos informed participants that if an institute wished to participate in the work of ChEss, it should contact Professor Paul Tyler at the Southampton Oceanography Centre, United Kingdom, who is the coordinator of the group.

Dr. Campos concluded the discussions informing participants that CoML did not provide financial support for projects but brought scientists together.

Part III

COBALT-RICH FERROMANGANESE CRUST DEPOSITS IN THE AREA

Chapter 10 The physical environment of cobalt-rich ferromanganese crust deposits, the potential impact of exploration and mining on this environment and data required to establish environmental baseline

Professor Aike Beckmann, Division of Geophysics, University of Helsinki, Helsinki, Finland

Chapter 11 The physical environment of polymetallic sulphides deposits, the potential impact of exploration and mining on this environment and data required to establish environmental baselines in exploration areas

Professor Huaiyang Zhou, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Wushan, Guangzhou, People's Republic of China

Chapter 12 The biological environment of polymetallic sulphides deposits, the potential impact of exploration and mining on this environment, and data required to establish environmental baselines in exploration areas

Dr. Julian Anthony Koslow, Senior Principal Research Scientist, CSIRO Marine Research, Wembley, Western Australia, Australia

Chapter 13 Proposed census of marine life seamounts project: Towards a global baseline and synthesis of seamount community data – Its applicability in minimizing impacts from crusts mining

Dr. Malcolm Clark, Principal Scientist, Deepwater Fisheries, National Institute of Water & Atmospheric Research, Wellington, New Zealand. Additional authors not present at the workshop are Ashley A. Rowden (National Institute of Water and Atmospheric Research Wellington, New Zealand) and K. Stocks (San Diego Supercomputer Center, University of California, San Diego, California, USA).

CHAPTER 10 THE PHYSICAL ENVIRONMENT OF COBALT-RICH FERROMANGANESE CRUST DEPOSITS, THE POTENTIAL IMPACT OF EXPLORATION AND MINING ON THIS ENVIRONMENT, AND DATA REQUIRED TO ESTABLISH ENVIRONMENTAL BASELINES

Professor Aike Beckmann, Division of Geophysics, University of Helsinki, Helsinki, Finland

Introduction

Seamounts are submarine topographic features that rise more than 1000 metres above the deep ocean floor, often with very steep flanks (slopes up to 50%) and with summits close to sea level. They have diameters between 20 and 100 kilometres, thus belonging to the oceanic mesoscale to sub–mesoscale. A typical seamount shape is conical with a circular or elliptical base. The actual geometry may be quite complicated due to terraces, canyons, calderas and craters (see Figure 1.1). A special class is the so-called Guyots (table mounts) with comparatively flat summits, formed by wave erosion when the top was at sea level.

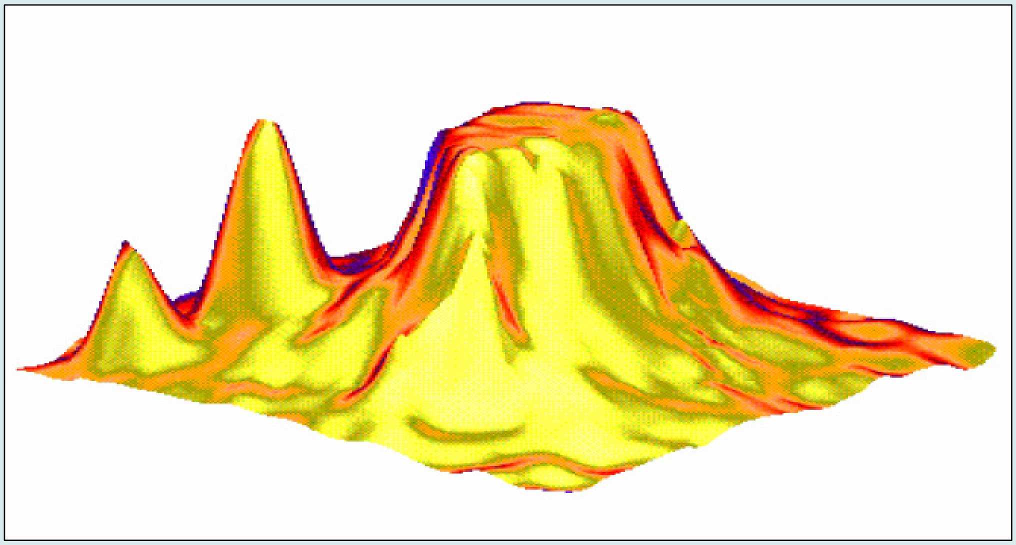

Figure 1.1: Example of a typical Guyot: the Meteor seamount complex (29◦24'N; 28◦58'W) featuring the Great Meteor Bank and two smaller companion seamounts.

Seamounts occur scattered throughout the global ocean. They can be found rather isolated, or clustered in groups or linear rows, the so-called seamount chains. The number of seamounts has been estimated to exceed 30,000 in the Pacific Ocean alone (Smith and Jordan, 1988) and their abundance has been confirmed by recent satellite gravimetry-based bottom topography data (Smith and Sandwell, 1997).

The physical environment at seamounts represents a special case of rotating, stratified flow over variable topography, which is further complicated by non-uniform and unsteady forcing and a high degree of nonlinearity.

Observational material has been collected from numerous field studies: vertical profiles of hydrographic fields (temperature and salinity, from which the density field and the baroclinic flow can be inferred), as well as current meter data (for the determination of absolute velocities) have been obtained from many seamounts. A number of comparatively well-studied seamounts has been listed by Rogers (1994), including the Great Meteor Seamount in the North Atlantic, Fieberling Guyot and Cobb Seamount in the North Pacific and Maud Rise in the Southern Ocean.

Strong currents and a generally enhanced variability above seamounts has been observed in many cases (Horn et al., 1971; Huthnance, 1974; Hunkins, 1986; Genin et al., 1989; Eriksen, 1991; Noble at al., 1994; Codiga and Eriksen, 1997; Mohn and Beckmann, 2002). In addition, pronounced doming of the density surfaces (isopycnals) related to anticyclonic flow was detected above many seamounts (e.g., Meincke, 1971; Vastano and Warren, 1976; Genin and Boehlert, 1985; Genin et al., 1989; Roden, 1991; Bersch et al., 1992).

Finally, regional (mostly downstream) effects of seamounts in the path of western boundary currents were reported by Roden and Taft (1985) for the Kuroshio and Vastano and Warren (1976) for the Gulf Stream; the deflections and modifications of the flow have been confirmed by Richardson (1981) and Cornillon (1986) using surface drifting buoys and satellite imagery, respectively.

To summarize, two different classes of effects of seamounts on the circulation and thermohaline structure of the ocean can be distinguished:

- As obstacles in the path of large-scale flow, they will cause current deflections, wakes, and a meandering (lee-side Rossby waves) occasionally accompanied by eddy formation, thus increasing downstream variability [see Hogg (1980) for an overview];

- In addition, most seamounts have their own isolated local environment with flow and tracer distributions quite different from near-by surroundings. These special conditions also affect the dynamics of marine ecosystems and the conditions for sediment deposition.

In the following we concentrate on the physical regime trapped to the seamount.[1]

Processes and phenomena

Ocean currents encountering a seamount generate upwelling on the upstream flank of the obstacle. The flow crosses the summit and descends again on the opposite side. This dipole pattern of vertical motion begins to rotate anticyclonically (clockwise on the northern hemisphere) around the seamount. For steady forcing, or if frictional effects are large, the dipole pattern may evolve into a stationary state. Figure 2.1a shows such a "butterfly pattern" caused by weak steady flow encountering a circular seamount. The resulting flow field is dominated by local enhancements of horizontal currents, featuring counter rotating cells on either side of the seamount. The basic mechanism is the generation of a dipole wave pattern which is locked in place due to frictional effects.

If frictional effects are less important or if the forcing is periodic in time (at sub-inertial frequencies), the dipole pattern may rotate continuously around the seamount. These seamount trapped waves (Chapman, 1989; Brink, 1989; Brink, 1990) are the special form of coastally trapped waves (see LeBlond and Mysak, 1978) adapted to the special geometry of isolated topography. The restoring force is the ambient potential vorticity gradient related to changes in water depth. Detailed considerations of the properties of these waves have been presented by Codiga (1996).

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1 Although many seamounts occur in groups, it seems that in most cases clusters or chains of seamounts influence each other or even the background currents only in the abyss.

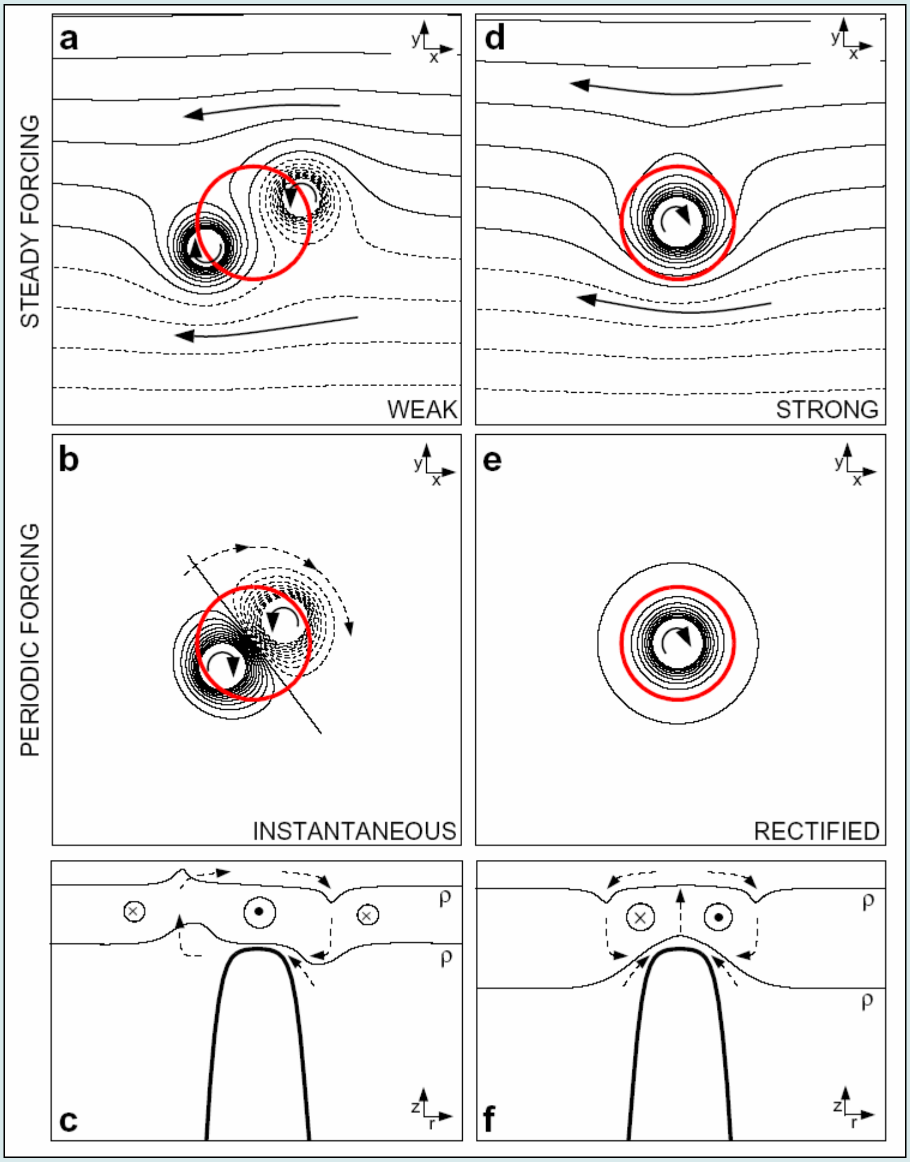

Figure 2.1: *Principal Eulerian flow pattern (streamlines) about a circular seamount on the northern hemisphere: (a) butterfly pattern for weak impinging flow; (b) first azimuthal mode trapped wave pattern (rotating clockwise); (c) isopycnal doming and secondary circulation (in the radial–vertical plane) for (a) and (b); (d) Taylor column for strong impinging flow; (e) time-mean rectified flow due to seamount trapped waves; (f) isopycnal doming and secondary circulation for (d) and (e). Encircled crosses and dots denote flow in and out of the page, respectively. The broken arrows in the latter two cartoons indicate the instantaneous or tidally induced fluxes of buoyancy; time-mean flows in the steady state are directed opposite (from Beckmann and Mohn, 2002).*

The gravest mode of these seamount trapped waves is a dipole (see Figure 2.1b). Unlike the continuous along-slope spectrum of coastally- trapped waves, the special geometry of seamounts (with their small radius of curvature) demands discrete along–topography (i.e., azimuthal) wavelengths, resulting in an even number of lobes. Higher modes in radial and vertical direction are theoretically possible, but are not easily excited by impinging oceanic currents. Seamount trapped waves exist only for sub-inertial frequencies ($\omega < f$) and are bottom intensified with a typical vertical scale determined by the strength of the stratification. A continuous excitation of these waves at their characteristic frequency (e.g., by alternating tides) can lead to resonance effects, with substantial amplification (first investigated by Haidvogel et al., 1993).

The vertical motion associated with both the stationary butterfly pattern and the seamount trapped wave is illustrated in Figure 2.1c. Up- and downwelling circulations above the seamount flanks lead to doming/dipping isopycnals on either side of the obstacle. Note that the dominant horizontal flow is located in between the density anomalies above the seamount, which is closed by counter-rotating recirculations in deeper water (into and out of the page in Figure 2.1c). The vertical overturning motion is closed by weak horizontal currents crossing the seamount top. Owing to small scale mixing, there is some entrainment of mid-depth water masses into this overturning cell.

Stronger steady currents impinging on a seamount will lead to the formation of a Taylor column above the obstacle. The basic mechanism is that steady, linear and inviscid flow follows isobaths; areas with closed depth contours and smaller (larger) fluid depth exhibit anticyclonic (cyclonic) circulation (Figure 2.1d), the so-called Taylor column. Even though unsteadiness, nonlinearity and viscous processes in the real ocean will break this constraint, the underlying physical mechanism is often dominant and can be found in the ocean in many circumstances. In a generalization of Taylor's theory, trapped water bodies of arbitrary shape above seamounts in stratified fluids are called Taylor caps (see Schär and Davies, 1998).

Seamount trapped waves of large amplitude (caused by either large amplitude forcing of by resonant amplification) may generate a substantial residual current through a process called nonlinear rectification. This time–mean flow is also anticyclonic and has largely the same spatial structure as the Taylor cap (Figure 2.1e). These currents and the corresponding isopycnal doming are generated by the tidally-induced buoyancy fluxes of the fluctuating currents (Haidvogel et al., 1993).

The isopycnal doming above the seamount, characteristic for many seamounts is caused by two counter-rotating overturning cells with upwelling above the seamount and downwelling over the flanks (Figure 2.1f). It needs to be emphasized that the time–

mean vertical motion is directed opposite and does not indicate the direction of long–term material transport.

Tidal flow amplification at seamounts is one source of variability that may lead to higher levels of turbulence. In addition there are internal tides that can be excited on the flanks of a seamount, with some being reflected into the deeper ocean, some being transmitted into the shallower areas of the seamount. The density perturbations caused by internal waves can be of substantial amplitude; in observations they may mask many longer period phenomena. For internal tides, the critical latitude and the critical slopes are of particular importance. The critical latitude separates trapped from freely propagating wave solutions, so the geographical location determines the existence or non-existence of these wave forms. Optimal generation of internal tides occurs in areas where the topographic gradients and the wave characteristics have equal (the "critical") slope. Finally, there are breaking internal waves, originating elsewhere but contributing to the mixing at the flanks of the seamount.

The turbulent vertical mixing at seamounts is of particular interest, as it seems to be essential for the large-scale tracer balance in the ocean. Turbulent diffusivities at seamounts are significantly larger than in the surrounding ocean: turbulent vertical mixing has been found to be enhanced by one to two orders of magnitude over seamounts (see, e.g., Toole et al., 1997; Eriksen, 1998).

Consequences for material transport

The three ingredients of seamount flow regimes (recirculating Taylor column flow, seamount trapped waves and enhanced turbulence) have implications for material transport, with important implications for other areas of marine science. Both transient processes and their time-mean effects above a seamount's summit, over its steep slopes, and in the bottom boundary layer generate special conditions for marine biology, marine geology and atmosphere–ocean interaction. Although many recent research activities have focused on these issues, we have only begun to explore the effects of flow at seamounts on, e.g., primary productivity, sediment distribution and air-sea exchange.

Seamount ecosystems

Marine biologists have been interested in seamounts for many years (see, e.g., Boehlert and Genin, 1987; Rogers, 1994). Attracted by the abundance of life (biomass and biodiversity) frequently observed above isolated seamounts, they have looked at so-called "seamount effects" like trapping in closed recirculations (Mullineaux and Mills, 1997), nutrient supply and deepened surface mixed layers through enhanced vertical mixing (Genin and Boehlert, 1985; Dower et al., 1992; Comeau et al., 1995) stress caused by elevated levels of turbulence (Dower and Mackas, 1996), as well as downstream effects of seamounts. The effects of the seamount circulation on the general distribution of biogeochemical parameters have been discussed (e.g., Loder et al., 1988; Perry et al., 1993). Following are some well established facts:

- Seamounts can represent oases in otherwise desert-like oligotrophic oceans (Rogers, 1994);
- Seamounts act as a locus for large aggregations of migratory and non-migratory animals (Boehlert et al., 1994);
- Seamount biodiversity often covers a wide range of species from autotrophic organisms to top predators (Haney et al., 1995);
- Seamounts can exhibit a significant level of endemism (e.g., Richer de Forges, 2000);
- Seamounts are stepping stones for the trans-oceanic dispersal of pelagic organisms (Wilson and Firing, 1987);
- Seamount ecosystems are of interest for commercial exploitation (Koslow, 1997).

Yet, the detailed role of physical processes at seamounts on pelagic and benthic ecosystems, factors that influence the structure of seamount communities, and the establishment, maintenance and genetic isolation of populations at seamounts are still far from being well understood.

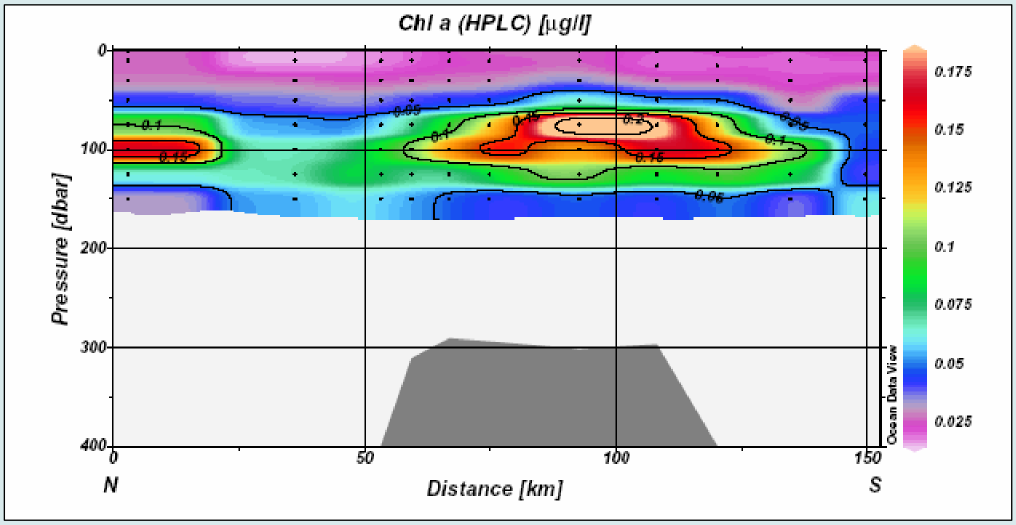

Figure 3.1: Chlorophyll-a concentration on a North South transect crossing the summit of Meteor Seamount (M. Kaufmann, pers. comm.) Note the pronounced isolation of the chlorophyll above the summit plain from the surrounding ocean.

One of the topical questions is related to the trapping of particles in the closed circulation of a Taylor column/cap[2] (e.g. see Figure 3.1). Studies that address the trapping potential at seamounts have used passive Lagrangian particles in configurations with steady forcing (Chapman and Haidvogel, 1992), as well as combined steady and periodic forcing (Goldner and Chapman, 1997). Results of the latter indicate that for steady forcing, most of the particles are swept past the obstacle; only particles from a limited area upstream can enter the seamount summit region and are retained there for several advective timescales. An additional periodic forcing merely leads to a larger scattering of particles in the vertical and to a stronger trapping near the bottom (Goldner and Chapman, 1997). Similar results have been obtained by Beckmann and Mohn (2002), who included zooplankton migration and wind effects in their numerical investigation of the Great Meteor Seamount.

We have to conclude that particle retention above seamounts is quite likely, at least temporarily. The potential of particle trapping at tidally-forced seamounts is generally larger than for seamounts in a steady current field. It should be pointed out that the retention is not related to the existence of a quiescent region with weak currents over the summit, but rather to the closed recirculations generated by large amplitude trapped waves. Intermittent, strong currents or extreme wind events may flush the area above the seamount (Lewis et al., 1994; Beckmann and Mohn, 2002), thereby increasing the physical and biological patchiness in the surrounding ocean.

Summarizing our present knowledge of seamount biology, there are strong indications that the increased biomass and the level of endemism above many seamounts is profoundly influenced by hydrodynamic processes and phenomena (upwelling, turbulent mixing, closed circulation cells).

Sediment dynamics

Erosion, transport, and deposition of sediment are some of the main concerns of marine geology. Two processes that require a combined physical–geological approach are the long-term sediment distribution patterns as induced by non-uniform current fields in the deep ocean and the occurrence of turbidity plumes found over steep slopes.[3]

The main effect of suspended sediment on ocean dynamics is through an increase of the fluid's density. A particulate matter concentration of about 1 kg m^{-3} leads to an excess density of 0.6 kg m^{-3} (which translates to a salinity equivalent of about 1 psu). While this feedback can be ignored for long-term sedimentation studies, the

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2 Note that in general, the consequences of trapping can be either advantageous or disadvantageous for marine life.

3 This latter process is also relevant for physical oceanography as the down-slope movement of sediment laden water masses contributes to the deep water formation and renewal.

dynamics of turbidity currents over variable terrain depends critically on the density changes due to a sediment load.

Seamounts play a role in both processes: the non-uniform near bottom current around seamounts will lead to characteristic patterns in sediment distribution (von Stackelberg et al., 1979), and the high velocities of trapped waves are able to erode sediment for sediment-laden plumes to occur over the steep slopes, contributing to the ventilation of the deep ocean. A schematic illustration of the latter process is given in Figure 3.2.

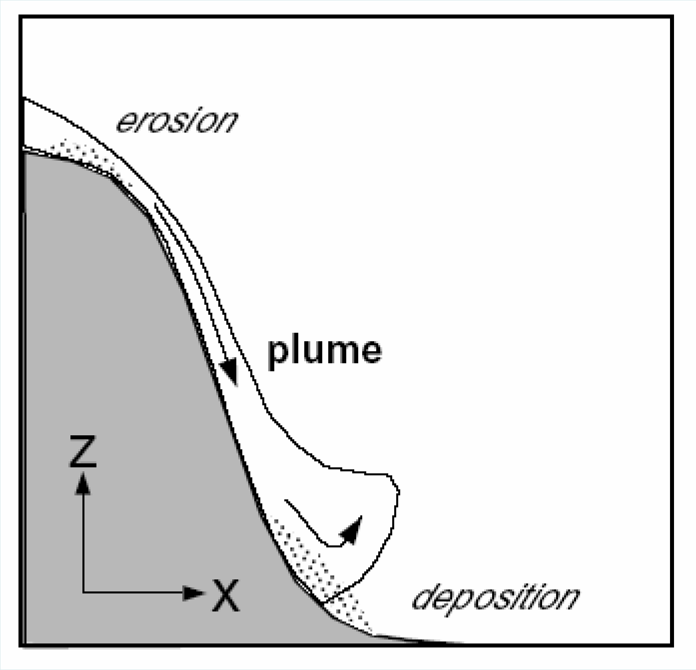

Figure 3.2: Schematic illustration of a sediment plume over steep topography.

Plume-like down-slope flows can reach substantial velocities near the bottom, depending on the density contrast relative to the ambient water masses the steepness of the topographic slope, and the sediment load. This must be of concern if the amount of suspended material in the lower water column is increased.

Effects on air–sea interaction

Air-sea interaction as an important mechanism in the global climate system is modified by the presence of seamounts and their flow regimes. This is a result of the fact that circulation at seamounts changes the stratification and hence the mixed layer depth above them, by strong and systematic up- and downwelling and increased vertical mixing. Thus, a so-called topographic preconditioning of the water column will be the result of circulation patterns at seamounts. If the surface mixed layer is sufficiently disturbed, it will alter the air-sea fluxes, and in high latitudes, the oceanic response to atmospheric forcing may lead to deep ocean convection.

One such example was studied by Beckmann et al., (2001), who investigated the effect of Maud Rise on sea ice cover. They showed that significant, even large-scale, consequences can be found in some areas of the World Ocean. One of the potentially important seamounts in this respect is Maud Rise in the Weddell Sea (Southern Ocean), which might be able to affect the sea ice thickness and distribution on a much larger scale. This study confirmed earlier speculations (e.g., Gordon and Huber, 1984; Martinson, 1990) that upwelling of relatively warm Weddell Sea Deep Water (WSDW) may have caused the Great Weddell Polynya, a major climate event observed in the mid-1970s.

Parameter dependencies

Each seamount is unique in shape and geographical location, embedded in ambient water masses and large-scale circulation patterns.

Although the primary physical processes are the same, their relative importance varies substantially with geometry, rotation rate and stratification as well as type and strength of forcing. Seamounts can be located in areas with (quasi-) steady flows (usually broad, relatively weak westward flows in the subtropics), variable flows (e.g., meandering currents that may hit the seamount occasionally and only for a limited time). Tidal motion may be a significant factor in the area. Stratification may be strong (in low- to mid- latitudes) or relatively weak (high latitudes). The influence of the Earth's rotation increases poleward.

The parameter space

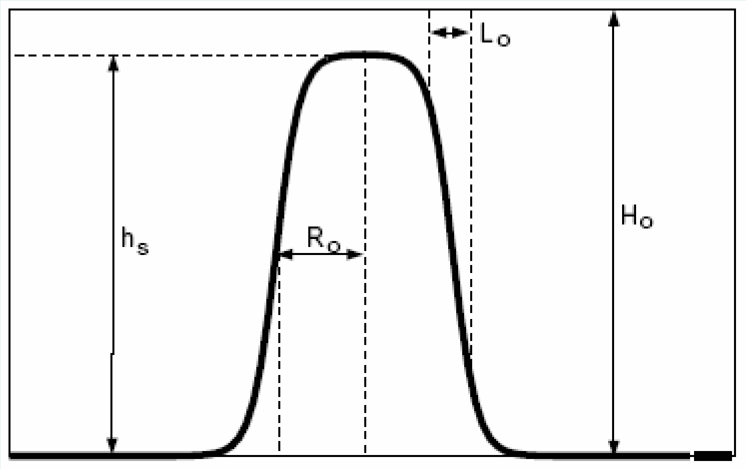

Figure 4.1: Geometry of the idealized tanh-shape seamount.

The physical environment at seamounts in a rotating, stratified fluid, forced by an impinging flow depends on a number of non-dimensional parameters, relating the geometric scales and parameters (seamount height h_s, seamount radius R_o and slope scale L_o), its environment (water depth H_o, Coriolis parameter f_o, stability frequency N_o) and the forcing (frequency ω_o, velocity amplitude U_o) (see Figure 4.1). The resulting numbers span the parameter space for the problem. The most important of these are:

The fractional seamount height:

$$\delta = \frac{h_s}{H_o}$$

The seamount steepness:

$$\alpha = \frac{h_s}{L_o}$$

The Burger numbers:

$$Bu_L = \frac{N_o H_o}{f_o L_o} = \frac{r_D}{L_o} \quad ; \quad Bu_R = \frac{N_o H_o}{f_o R_o} = \frac{r_D}{R_o}$$

The frequency ratio:

$$\nu = \frac{\omega_o}{f_o}$$

The Rossby number associated with the ambient flow:

$$Ro = \frac{U_o}{f_o L_o}$$

The role of numerical modelling

Three-dimensional ocean circulation models have contributed significantly to our understanding of seamount flow regimes. Realistically tall and steep topographic features in a stratified rotating fluid can be routinely modelled since the early 1990s, and can be used to explore the parameter space in general or to investigate one particular setting. Numerical modelling is an excellent tool to assess the various contributing processes, and in particular:

- To extrapolate observational results into three dimensions;
- To map the location and magnitude of the strongest currents as well as the turbulent mixing;
- To quantify the retention capacity of the circulation, and the timescales related to the dispersal of material from and to the seamount; and finally
- To determine the sensitivity of the regime to changes in topography, forcing and water masses.

Beckmann and Haidvogel (1997) have shown that quantitative results for realistic topography can be obtained, if the horizontal resolution is between 500 and 1000 metres and the vertical resolution does not exceed 10 metres in the bottom boundary layer. Preferentially, a terrain-following vertical coordinate should be used to optimally describe the processes in the bottom boundary layer over sloping topography. The model has to use a domain which is large enough to exclude interaction with the computational boundaries. In most cases it is sufficient to use a single state variable and to initialize the model with a horizontally uniform density profile and no flow. Sophisticated state–of–the–art vertical mixing parameterizations have to be employed, to adequately account for the small scale turbulent effects. The Coriolis parameter can be held constant. The model has to be integrated for a few weeks, to obtain a statistically steady regime at the seamount. Then, the effects of background flow, tidal motion and typical wind events can be quantitatively assessed.

Parameter studies for idealized configurations serve to improve our understanding of the likelihood and conditions of the occurrence of certain phenomena in nature. In particular, it is the determination of local extremes in parameter space, where special or particularly strong effects can be expected. Some generally valid parameter dependencies will be presented in this section.

Seamount shape

In theoretical seamount studies, the topography has been assumed to be of Gaussian, cosine (Chapman and Haidvogel, 1992), or parabolic (Brink, 1989; 1990) form. A first investigation of the influence of seamount shape was performed by Chapman and Haidvogel (1992) in the context of steady forcing. They showed that the Taylor cap existence does not strongly depend on the exact form; there seems to be no clear preferential shape for these processes to occur. On the other hand, the seamount height was identified as the crucial factor: a certain height is required for a closed circulation to develop.

By assuming a tanh-type shape, Beckmann (1995) was able to separate steepness from radius and height. The influence of variation in these three parameters for a typical seamount is shown in Figure 4.2. In all cases resonance with diurnal frequency forcing was found; the critical value being $Bu_R = r_D/R_0 = 0.5$, $Bu_L = r_D/L_0 = 1.0$ In this example, the seamount-trapped wave currents easily reach 20-fold amplification over the 1 cm/s barotropic background flow.

The rectified mean flow is found to be directly proportional to the wave amplitude, except for very wide seamounts, where the lobes of the seamount trapped wave are separated and cannot interact effectively. Very thin seamounts, on the other hand, seem to have a smaller perturbing effect on the barotropic tidal flow, thus resulting in generally weaker resonance.

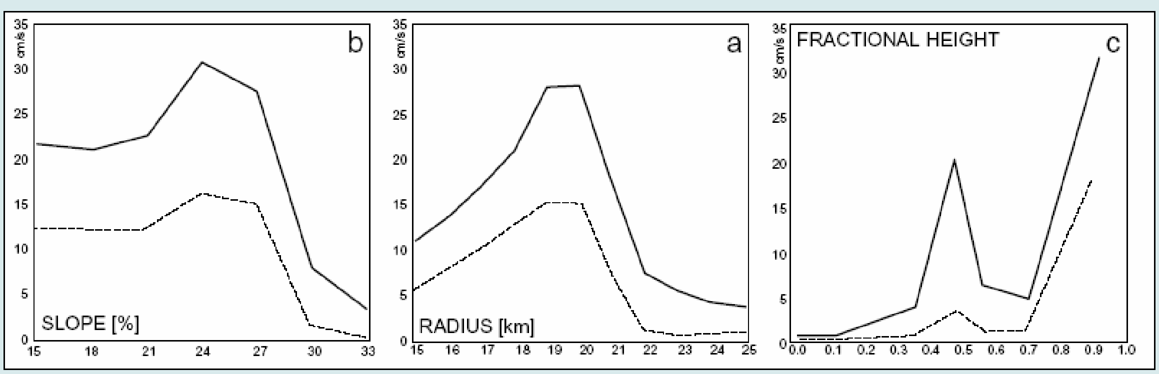

Figure 4.2: *Resonant amplification (solid line) and mean flow generation (dashed line) as a function of (a) seamount radius R_0, (b) seamount slope h_s/R and (c) seamount height h_s. Note the relatively narrow resonance peaks.*

In support of Chapman and Haidvogel's (1992) results, the seamount height is also of crucial importance for periodic forcing (Figure 4.2c). As expected, the maximum response is found for very tall seamounts (fractional seamount height $\delta > 0.9$), due to the large change in depth. But there is another, almost equally strong amplification maximum located at $\delta \sim 0.5$, caused by the weaker stratification at the seamount summit and upper flanks due to the exponential stratification.

The effect of non-symmetry was also investigated. The results show that azimuthal asymmetry generally reduces the wave and mean flow response. Hence, a symmetric seamount has to be regarded as the "optimal geometry" for resonant amplification and rectification. Asymmetries and random irregularities tend to weaken the coherence of the seamount trapped wave and lead to reduced mean flow. Also, the orientation of an asymmetric seamount with respect to the main axis of the forcing is not important to determine the flow regime at the seamount. The same holds for varying degrees of bottom roughness (representing, e.g., canyons, banks, etc.).

The influence of rotation and stratification

The rate of rotation, as the overall strength of stratification and horizontal and vertical length scales, is combined in one non-dimensional parameter: the Burger number. Therefore, the dependence on rotation and stratification can be cast as a Burger number dependence. Note that the dependence on rotation translates into a latitudinal dependence, with $f = 0$ at the equator and maximum at the poles. Stratification also varies with latitude, but there are also significant differences between ocean basins, time of the year and as a function of distance form the coast. Note also the limitation to sub-inertial frequencies plays a major role in this context, e.g., there will be no trapped waves of diurnal period equatorward of 30° geographical latitude.

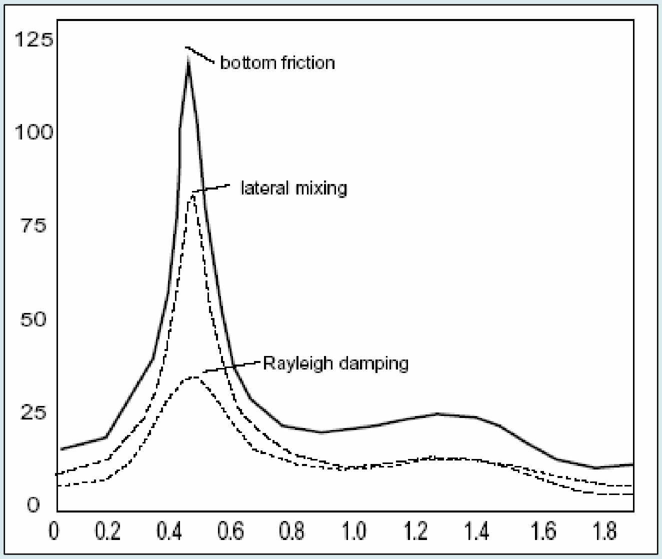

Figure 4.3: Resonant amplification of diurnal tides as a function of Burger number (after Haidvogel et al., 1993). Each curve represents the dominance of a different friction mechanism.

Haidvogel et al., (1993) were the first to explore the resonance conditions for a varying Burger number. The response at the seamount was found to vary considerably for different Burger numbers (see Figure 4.3). There is a peak as *Bu*=0.5 and a smaller maximum at higher Burger numbers (between 1.3 and 1.4). As can be seen from the Figure, the amplification factor can exceed a factor of 100 for sufficiently small frictional effects. These maximum velocity amplification factors produced near resonance in the numerical solution are consistent with those computed by Brink (1990). (In Brink's study, the kinetic energy ($\frac{1}{2}(u^2 + v^2)$) of the free trapped wave near resonance was found to be 10^4 to 10^5 times greater than that in the incident flow.)

Forcing frequency and amplitude

The occurrence of resonant amplification at a seamount depends on the "sharpness" of the resonance peak. It turns out that a substantial resonance is possible for a range of frequencies, as long as there is a "close enough" match between the forcing frequency and the frequency of an admissible free (sub-inertial) wave.

Figure 4.4 summarizes the results of a set of solutions in which forcing frequency and Burger numbers were simultaneously varied. The results confirm the existence of significant amplification of currents over the seamount for a wide range of subinertial frequencies and Burger numbers. Note that an impinging flow will accelerate as it moves past a seamount even in the absence of a resonantly forced trapped wave. Thus, the local flow is "amplified" even in the super-inertial regime.

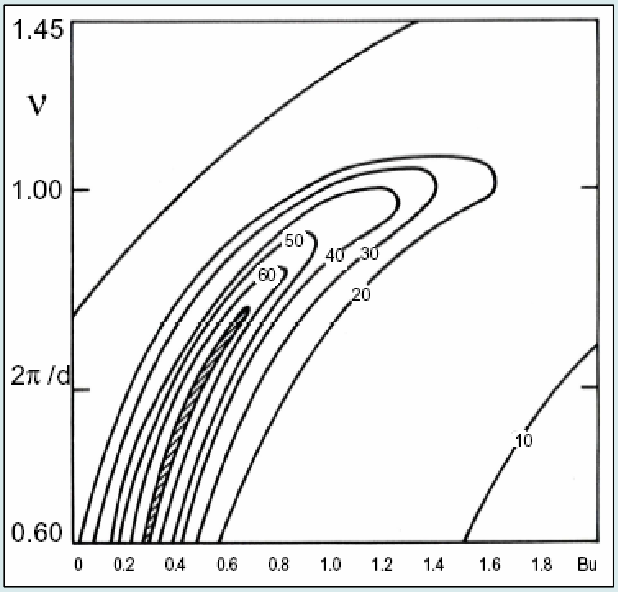

Figure 4.4: Resonant amplification as a function of Burger number Bu and forcing frequency (scaled by f_o; after Haidvogel et al., 1993).

For infinitesimal forcing amplitudes the amplitude of the linear wave will be directly proportional to the strength of the applied forcing; the resulting rectification, however, will depend on the forcing amplitude in a nonlinear way.

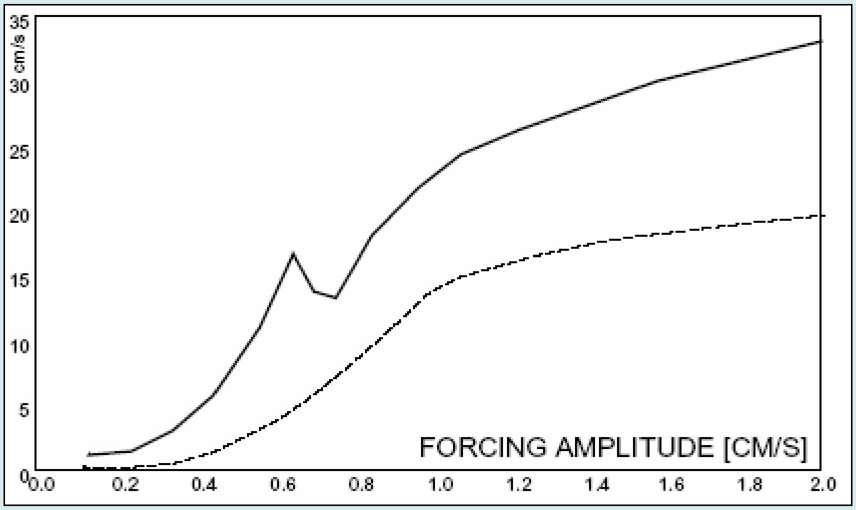

Figure 4.5: *Resonant amplification (solid line) and mean flow generation (dashed line) as a function of forcing amplitude.*

Figure 4.5 shows that the wave amplitude increases approximately quadratically with forcing amplitude until the time-mean flow has reached sufficient strength. A further increase in the background flow then leads to a reduction of wave amplitude. Finally, both the transient and the time-mean response grow only proportional to the square root of the forcing amplitude. This is the result of the competition between the rectification process (which sets up the mean flow by nonlinear wave interaction) and the combined effects of the Doppler shift and the modified stratification (that weaken the wave by pushing it out of phase with the forcing). This is the mechanism that prevents catastrophic amplification; even for a close match between the forcing and geometry the dynamical processes will remain finite.

Synopsis

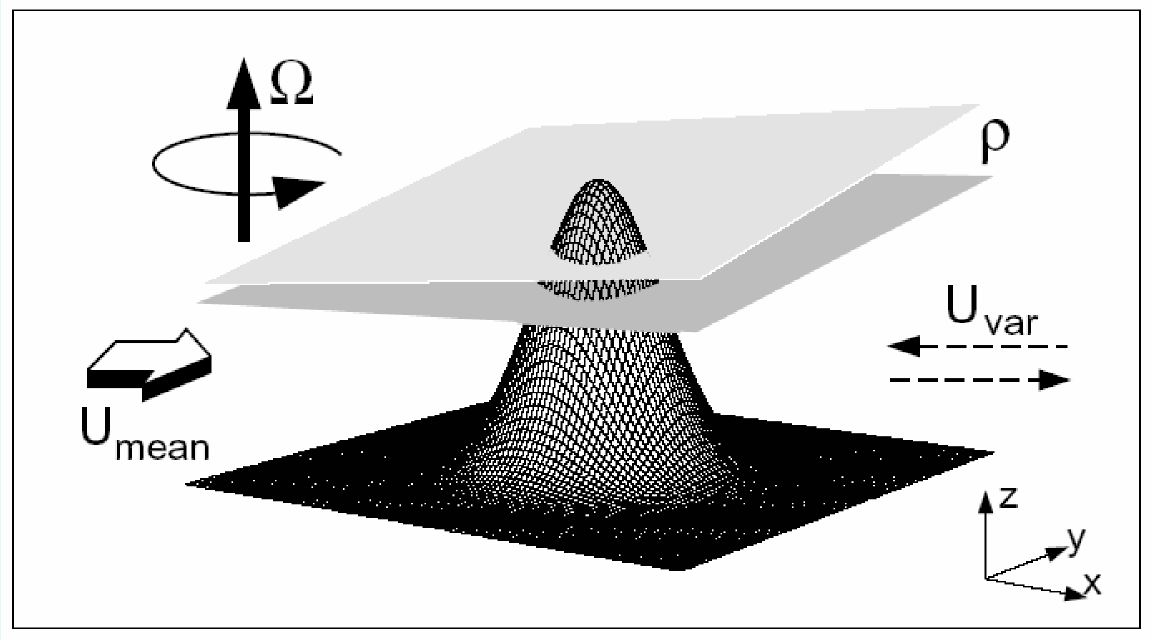

Figure 4.6: *Cartoon illustrating the physical ingredients of flow around seamounts.*

As shown in the introduction of this chapter, the parameter space for seamount flow regimes is multi-dimensional, involving geometry, rotation, stratification and ambient flow (see Figure 4.6 for a summarizing illustration). Strong sensitivity exists for most parameters. To summarize, the basic results of this sensitivity studies are:

- First azimuthal mode seamount trapped waves, propagating anticyclonically around the seamount, exist over a wide range of parameters for subinertial forcing. The period (and thus the phase speed) is set by the forcing, the vertical and radial scales adjust to the geometry of the seamount, and the environmental situation as expressed by the Burger numbers (related to the lateral scales of the topography). An optimum is found for $Bu_R = 0.5$, $Bu_L = 1.0$.

- A resonance peak exists for every seamount, where the forced wave frequency matches the free wave characteristics. A second peak may be found for larger Burger numbers, where waves with higher modes in the radial/vertical direction are excited. The amplitude of the resonance peak depends on the turbulent dissipation.

- The inclusion of nonlinear terms causes the rectification of a time-mean anticyclonic flow. This residual flow is bottom intensified but may have a significant barotropic component as well. The dependence on forcing amplitude is approximately quadratic until the nonlinear feed-back becomes important.

- Smooth symmetric seamounts represent the optimal shape for wave propagation and rectification.

The generation of seamount trapped waves and anticyclonic flow at seamounts appears to be a fairly typical and wide-spread phenomenon and is expected to occur at many seamounts. Amplification of the ambient flow by at least an order of magnitude can be considered as typical. This may lead to typical currents of several tens of cm/s horizontally and several cm/s vertically.

Monitoring requirements

Experiments such as TOPO (a multi-institutional programme to study the physical, chemical and biological properties of oceanic flow near abrupt topography, conducted in 1991) have set the baseline for a monitoring strategy. The specific focus of TOPO was the Fieberling Guyot, a tall and isolated seamount located in the eastern North Pacific Ocean at 32°26’N, 127°47’W. Profiles were collected over the summit and flanks, with XBTs XCPs. In addition, year-long current meter observations were obtained from selected stations, both on the seamount, at its flanks and in the surrounding deep water. For a more detailed description of observational strategy, instrumentation and analysis techniques see Kunze and Toole (1997). The results from TOPO allowed, for the first time, a quantitative characterization of the linear and non-linear flow enhancement processes. At the same time, the observational studies (Roden, 1994; Brink, 1995; Kunze and Toole, 1997) led to a unique data set of high quality measurements and provided an unprecedented opportunity to validate numerical model results over steep topography.

Following this and other similar examples of intense measurement surveys at seamounts, we conclude that in order to establish reliable baselines of the physical environment at a specific seamount current meter moorings are required for the duration of at least one week, in order to capture the variability of the current fields in the diurnal band. At least two far field moorings are necessary to obtain the background flow characteristics and a number of XBT transects across the seamount have to be carried out to obtain a reliable picture of the mass field.

These data need to be analysed and used for the initialization and validation of a numerical simulation, from which a fully three-dimensional picture of the physical environment will emerge.

SUMMARY AND CONCLUSIONS

The phenomenology of seamount flow regimes consists of three major patterns: seamount trapped waves, propagating anticyclonically about the seamount, Taylor columns and caps as the result of low frequency background currents or non-linear wave interaction, and generally enhanced levels of turbulence leading to increased vertical mixing.

The described mechanisms are robust; it is safe to assume that trapped waves, closed circulation cells and enhanced turbulence can be found at all mid- to high-latitude seamounts. The strength of the resulting flows will depend on the forcing amplitude, the geometry of the seamount and the ambient situation (stratification, rotation), best expressed in form of a Burger number. A particularly strong response occurs if the forcing frequency matches the eigenfrequency of the stratified rotating fluid at the isolated topography.

The physical regime at a given seamount is potentially fragile in the sense that changes in stratification, ambient flows and seamount shape might lead to significant changes in their characteristics, especially if they are close to resonance.

It has been shown that the topographically-induced flow at seamounts can have a profound influence on many aspects of the local marine environment: ecosystems, sediment transport and air-sea interaction.

It seems feasible to obtain a comprehensive picture of the physical environment at any given seamount based on the deployment of an array of metres, XBT casts, data analysis and a suite of numerical experiments.

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SUMMARY OF THE PRESENTATION

At the beginning of his presentation, Professor Beckmann reconfirmed that seamounts were numerous and showed two topographic maps of the oceans. The first showed the seamount chains that formed the basis for understanding the locations of seamounts and the second was a more recent map with improved technology showing that there were many more seamounts than initially thought. According to Professor Beckmann, as seamounts are not a rarely-occurring phenomenon, physicists were interested in understanding the physical processes related to them.

Professor Beckmann stated that to consider flow past seamounts, the idealised seamount shaped as a cylinder must first be examined. In an idealised case of a cylinder, which was infinitely long with fluid coming from one side, he said that the fluid would have to go around both sides of the cylinder. Therefore, Professor Beckmann said that the earth's rotation played no part since no rotation is involved. He also said that flow would accelerate on the flanks of the seamount and rejoin the far field at a distance of a few radii of the cylinder once it had gone beyond the cylinder. He noted that if rotation existed in the geophysical setting flow would move on one side of the obstacle and create a closed circulation cell around the cylinder.

According to Professor Beckmann, the geophysical problems were more complicated. In this regard, he pointed to the rotation of the earth and, in contrast to a cylinder, to the fact that seamounts did not reach the sea surface resulting in special features at their summits. He identified several other differences between a cylinder and seamounts, which made matters more complicated. One of these differences is that the slopes of seamounts while rather steep with topographic gradients of more than 30% in some cases, differed from cylinders, which had infinitely steep slopes. Other differences that he identified included stratification on seamounts, variable and alternating currents, and eddy-like structures.

Professor Beckmann structured these processes and phenomena in three parts. The first part that he described is seamounts in quasi steady flows where it is assumed that one general current hits the seamount and results in a Taylor column that rises as closed circulation. The second is seamounts in alternating flows, which are mostly tidal, creating seamount trapped waves, which could have large amplitude due to resonance processes. Finally increased turbulence around seamounts, which is very important for vertical mixing in the ocean in general.

According to Professor Beckmann, no flow on the earth is without change. He presented a diagram showing a circular seamount high in the water column. Seawater was lifted upward by the impinging current, which not only travelled around the seamount but also went partly over the top increasing the density lines. On the other side of the seamount, the seawater needed to sink, therefore depressing the density lines. Professor Beckmann said this constituted a polar pattern, one positive, one negative, which subsequently rotates about the seamount. He informed participants that in the northern hemisphere a clockwise circulation results and in the southern hemisphere, counter clockwise. He described this as the seamount- trapped wave phenomenon, which he said would lead to closed circulation on top the seamount. Professor Beckmann said that the trapped wave phenomenon would intensify even further while the flow removes the other lobe of the seamount-trapped wave. According to Professor Beckmann, other more distant effects of seamounts in quasi-steady flows were that if the current were strong it would produce a meandering of flow behind the seamount. Therefore, seamounts could have local effects due to processes in the immediate vicinity, and have downstream effects if the current were strong. He said that this case is applicable to seamounts in the Gulf Stream or the Antarctic polar current; elsewhere, he said that the generation of downstream meanders would be not as pronounced.

Dr. Beckman stated that the second physical setting is alternating tidal flows. Tidal flows in the deep ocean are rather weak, but certain processes described by Professor Beckmann can amplify them. According to Professor Beckmann, when a flow encounters a seamount it produces a double cell with one lobe breaking off to form a vortex downstream of the seamount, and the other forming a trapped wave. If the flow came from one direction and then reversed its direction, it may result in an amplification of the system if the frequency of rotation was in phase with the forcing. According to Dr. Beckman, this was not as uncommon as it might seem, as there are tides in many parts of the ocean which, given the right seamount height, diameter and other parameters, would lead to strong amplifications possibly reaching a hundred times the current outside of the trapped wave. The horizontal currents could easily reach 0.5 metres per second on top of the seamount even though the rest of the ocean was rather dormant. Vertical currents, which have a relationship with upward currents at the side of the seamount facing the mean flow, and downward moving currents on the leeward side, could easily exceed 1,000 metres per day, which are very high compared to most oceanic environments. Since there are strong amplitude waves, Dr. Beckmann said that there was also the possibility of rectification of flows that may strengthen the isolation of the interior part of the seamount from the rest of the ocean. He said that this is because the flow would not permit radial exchange between the seamount and the surrounding ocean.

Professor Beckmann informed participants that for weak currents, approaching flow would create some up-welling and some down-welling cells and they would either rotate or be locked in place depending on the friction mechanism. This, he said is called the butterfly pattern. He said that if the current increased, free circulation would occur, a phenomenon known as a Taylor column due to the first hydrodynamic principles by G.I. Taylor in the early 20th century. He also said that if there is a coordinating force and seamount trapped waves are formed, rectified flow may occur, which is similar to a Taylor column, as it constituted a closed circulation. According to Professor Beckmann, what was very interesting for biological systems and for vertical-mixing scenarios was the overturning motion, which is associated with these horizontal circulation patterns. He said that as long as there are waves, there would always be vertical circulation. Professor Beckmann informed participants that strong vertical currents occur over the upper flanks of the seamount with some entrainment from deeper levels. He spoke of the enhancement of the exchange between the deep ocean and the surface levels near seamounts because of entrained water in the overturning circulation.

Professor Beckmann described the third physical ingredient of seamount regimes as seamount-induced turbulence. He said that the seamount-trapped wave is a kind of small-scale fluctuating motion, and used as an example observations and measurements at the Ampere Seamount. His slide illustrated smooth fields of current fluctuations on one side and strong fluctuating currents along the vertical profiles on the other. He noted that in general, the diffusivity is much higher on top of the seamount than in the surrounding ocean. Stating that the eddy kinetic energy might be 10,000 times as large as the surroundings, Professor Beckmann said this translated into currents, which are 100 times larger, and energy dissipation of the same order of magnitude. According to Professor Beckmann, there is a lot of mixing at seamounts that is important for the global ocean and marine eco-systems. He attributed this to nutrients brought up from deeper water. Another example of seamount turbulence as described by Professor Beckmann is the location of seamount-induced vertical mixing, which he said is in the thin part of boundary layers above the flanks, where currents are as high as $2 \times 10^{-3} m^2/s$. He compared this with the surrounding ocean where currents are about $10^{-5} m^2/s$.

Professor Beckmann showed some slides to give examples of closed circulation cells, retention and the effects of strong currents, and upwelling and mixing of marine systems. An example was of a chlorophyll area at the Great Meteor Bank, which showed isolated patches of high concentrations of chlorophyll. He said that other subsurface maxima in this oligotrophic part of the ocean outside the seamount occur because of interruption over the upper flanks, which creates the isolation of the ecosystem living above the seamount.

Professor Beckmann informed participants that he and his colleagues had done numerical experiments using a model that included all the ocean physics necessary for this kind of scenario. He said that the group carried out passive tracer experiments to illustrate how particles on top of the seamount or near the seamount move and whether the movement would spread out or be confined. In one example, he said that the majority of a tracer originally located in the water column on top of the seamount was still in the centre of the region after 50 days of simulation. He said that a part of the tracer was in the form of eddies which were still near the seamount. He said that upon an examination of the vertical profile, it revealed that most of the tracer had not escaped into the surroundings and remained trapped on top of the seamount. He said that this was especially true for the surface mixed layer where the very strong wind-induced currents were less important. He also said that both particles and tracers would show the same pattern.

Professor Beckmann indicated that he would not talk about the consequences for sediment transport, but noted that taking into account trapping, large currents and increased vertical mixing or turbulence, it is obvious that sediment transport is important in seamount regimes. On a larger scale, Professor Beckmann said that because seamounts are obstacles to horizontal flow and with the increased current speed, sedimentation would not take place uniformly, but would show different patterns as a function of distance from the seamount. What was more important in Professor Beckmann's opinion was that seamount summits are often sediment depleted due to strong currents. He observed however, that because of the steep slopes of seamounts, high sediment loads could easily lead to down slope turbidity currents. In this regard, he said that if sediment loading is increased by some mechanism, the suspended material in the bottom boundary would remain suspended for a long time due to the increased turbulence. He also said that this situation might lead to down slope plumes, which would then alter the deep ocean pattern in this area.

According to Professor Beckmann, many seamounts are not isolated and the main conclusion of all numerical studies that he had conducted is that the interaction between neighbouring seamounts was relatively small as their physical regime is concentrated on the upper slopes in the summit plain. He said that this is true as long as the distance between two seamounts is larger than the diameter of either seamount.

Professor Beckmann said that the ingredients for the physical environments at seamounts are the same, but the relative contribution of each of the ingredients depended on parameters such as the seamount's geometry (height, diameter, steepness, the shape of the base, the degree of symmetry), and the smoothness of topographic features. He also mentioned the direction of the incident flow relative to a non-symmetric seamount as another important parameter.

Professor Beckmann noted that when there are alternating currents creating seamount-trapped waves in phase with the forcing, resonance could occur. He stated that seamount height, slope and radius govern resonance. He said the level of amplification produced by resonance at any seamount would have an effect on dispersal.

Professor Beckmann discussed the TOPO project of the early 1990s that focused on the Fieberling Guyot in the Northeast Pacific Ocean. He said that the seamount was sampled very closely using several different methods. For physical environmental analyses, Professor Beckmann said that one of the methods was the use of the meters on the summit plain and upper flanks of the seamount to determine the ambient conditions if the seamount was not present. In addition, he said there was a large number of radial transects crossing the seamounts in various directions. He said that the duration of the experiment was several months for the determination of large-scale features near the moorings.

Professor Beckmann said that in a corresponding study, the physical regime was numerically modelled using a high resolution ocean circulation model. In the area of investigation, he said that the tidal forcing was dominant. According to Professor Beckmann, the model produced a good representation of seamount-trapped waves, which corresponded to observations from the meters. He said there was excellent quantitative agreement between the model and the observations that enabled the group to validate the model.

In summary, Professor Beckmann noted that the physical environment at a seamount was quite different from the surrounding ocean. There is a strong dominance of a number of physical processes, which included strong horizontal flows due to the large amplitude seamount trapped waves. There is substantial upwelling and downwelling along the upper flanks bringing water and nutrients from the deep ocean to the surface. There are strong radial density gradients and closed circulation cells which lead to retention of the material on top of the seamount. Finally, a significantly enhanced level of turbulence and vertical mixing occur in support of all these phenomena.

According to Professor Beckmann, the consequences for marine ecosystems such as the influence on the nutrient supply, retention of nutrients and organisms, and endemism from the minimum change are well known. However, he believed that the complex world of biology was far too difficult to understand in all cases.

Professor Beckmann was confident that it is possible to determine the regime and also monitor the evolution of the physical regime at seamounts by combining observational methods with numerical simulations.

In conclusion, Professor Beckmann stated that an urgent requirement is a method for describing the shape, height and steepness of the slopes of seamounts or seamount geometry. In this regard, he said that while it is easy to describe the geographical latitude of a given seamount, information is also required on the stratification of the water column and the ambient ocean currents. He said that with this information, numerical methods that have been available for ten years could assist in determining the typical physical environment at a given seamount. In addition, he also said that the numerical model could facilitate information on the consequences of the flow fields. These included, where transport occurred, retention or otherwise of particles in the near field, and the amount of vertical upwelling. Professor Beckmann said that this would provide a good basis for establishing baselines for the physical environment around seamounts.

SUMMARY OF THE DISCUSSIONS

Dr. Beckman was asked what the impact would be if a seamount occurred on a ridge, as was often the case. He was asked how the impact of flow past the seamount would interact with the impact of flow past the ridge as a whole. Professor Beckmann replied that as long as seamounts are separated by more than one diameter of a seamount then the interaction between the seamount regimes near the summit would be limited. Alternatively, he said that there might be some topographic waves travelling along the ridge establishing communication between the seamounts. A participant followed-up by stating that, if seamounts were in close geographic proximity, as had been shown in a previous presentation, they may be subject to the same physical, chemical and biological conditions. Therefore part of those seamounts, or the ridge where they were found, could be used as a reference for mining or exploration that might take place on the others in that area. A participant asked Dr. Beckman whether the interaction between seamounts on a ridge was unknown because numerical modelling of such a configuration was more complicated than for isolated seamounts, or whether the required study had not been undertaken. Dr. Beckman replied that the configuration described is amenable to numerical modelling with sufficient resolution. He said that the physical processes that occur when one seamount influences another might result in amplification of the regime or the interactions may cancel each other. With a typically shaped seamount, Professor Beckmann said it would be possible to predict the circulation.

One participant pointed out that a previous presentation defined seamounts by their height and asked whether there is a particular elevation, at which the trapped waves mentioned by Professor Beckmann could not occur. Professor Beckmann replied that trapped waves would always occur. The question was whether resonant amplification would occur.

In response to a question regarding whether knolls usually tended to have large sediments accumulated on top because they had a different hydrodynamic process, Dr. Beckman said that they would be associated with large amounts of sediment if they had not been subject to strong forcing. He concluded his presentation stating that horizontal currents and vertical turbulence are high on tall and steep seamounts. He said these factors cause the erosion of most of the sediment over geological timescales. He also said that no drastic change would occur because of mining or other human activities.

CHAPTER 11 THE CHEMICAL ENVIRONMENT OF COBALT-RICH FERROMANGANESE CRUST DEPOSITS, THE POTENTIAL IMPACT OF EXPLORATION AND MINING ON THIS ENVIRONMENT, AND DATA REQUIRED TO ESTABLISH ENVIRONMENTAL BASELINES IN THE EXPLORATION AREAS

Professor Huaiyang Zhou, Guangzhou Institute of Geochemistry, Chinese Academy of Sciences, Wushan, Guangzhou, People's Republic of China

Ferromanganese (Fe-Mn) crusts occur universally on hard substrate rocks in the world's oceans. Crusts have different origins (hydrogenetic, hydrothermal or diagenetic), different occurrences and different mineral/chemical compositions. Based on a preliminary worldwide survey, it appears that crusts occurring on seamounts (most of them as guyots) in the western and central Pacific Ocean and of hydrogenetic origin have generated the highest commercial interest. This paper addresses and discusses the characteristics of this type of crusts deposit and possible environmental problems from exploration and exploitation of these resources.

The following information is a prerequisite to planning a monitoring programme aimed at environmental protection.

- Fauna and the nature of biological communities that inhabit seamounts
- Physical oceanographic characteristics, especially the currents and the movement of water masses nearby or around individual seamounts
- Chemical/biogeochemical status in seamount area
- The mineral/chemical characteristics of crusts and their impact on the seamount ecosystem and the pelagic deep sea during deep-sea mining.
- Exploration instruments
- Potential technology and methodology that might be used for future deep-sea mining

Seamounts, cobalt-rich crust and biology

The oligotrophic western and central Pacific Ocean is mainly located between westbound North Equatorial Current (NEC, 25 ~10^0N) in the south and the subarctic current in the north.

The high plateaus in the area are mainly seamounts and atolls. Cobalt-rich crusts occur generally along the slope of seamounts consisting of basalts and basaltic pyroclastic rocks. Seamounts have flat summits (guyot) or irregular peaked summits. Paleontologic evidence and radiometric dating of the basalts suggest that the seamounts were formed in the Cretaceous period. The summits or flat slopes of the seamounts are covered with shallow-water carbonates or limestone.

Crusts could occur in a range of 800-4000 metres water depth with a thickness varying between a few millimetres to more than 20 centimetres on seamounts where there are no sediments. In some locations, crusts could exist under sediments. This occurs either because the sediments are deposited after crusts deposition or sediments are temporarily deposited.

The metallogenetic minerals in crusts are mainly iron-rich δ-MnO2 (ferruginous vernadite), intergrown amorphous iron oxyhydroxide (δ-FeOOH, feroxyhyte), as well as small amounts of goethite. The detrital minerals, such as quartz, plagioclase, potassium-feldspar, pyroxene, phillipsite, and authigenic carbonate fluorapatite (CFA), in different layers of crusts constitute less than 5% of the crystalline phase. Some older sequences of crusts may contain 20-40% of CFA because of their frequent phosphatization.

Although Fe-Mn crusts are enriched over seawater in nearly all elements except bromine, chlorine, and sodium, the elements with potential economic significance among them are cobalt, nickel, platinum, and the rare earth elements. Enrichment of these elements in crusts represents the exchange equilibrium between crust minerals and seawater in geological history. The elements occur as isomorphisms in the crystalline phase, metal compounds, or are even absorbed on the surface of iron-manganese oxyhydroxide particles in crusts. Differing from the enrichment process in polymetallic nodules, cobalt in crusts is positively correlated with manganese

TABLE 1: MAJOR CHARACTERISTICS OF CHEMICAL COMPOSITION OF CRUSTS

Water content:	Up to 30 wt. %
Manganese:	About 20% ~24%
Iron:	About 15% ~ 18%
Iron/manganese ratios:	0.4 and 1.2, most commonly 0.7 ± 0.2
Cobalt:	Range 0.05-1.7% with averages between 0.19% and 0.74%
Nickel:	Up to 1.1%
Platinum:	Up to 1.3 ppm
Rare earth elements	Up to 1000s ppm
Yttrium:	Up to 100s ppm

Based on radiometric or paleontological dating of the substrate rocks and crusts, estimates are that the earliest hydrogenetic Fe-Mn crusts began to grow 75 millennia ago in the latest Cretaceous with a very slow growth rate of 1-6 mm/Ma.

Hein et al. proposed criteria for the exploration and exploitation of Fe-Mn crusts:

Regional criteria:

1. Large volcanic edifices shallower than 1,000-1,500 m;
2. Volcanic edifices older than 20 Ma;
3. Volcanic structures not capped by large atolls or reefs;
4. Areas of strong and persistent bottom currents;
5. A shallow and well-developed OMZ; and
6. Areas isolated from input of abundant fluvial and eolian debris.

Site-specific criteria:

7. Subdued small-scale topography;
8. Summit terraces, saddles and passes;
9. Slope stability;
10. Absence of local volcanism;
11. Average cobalt contents = 0.8%; and
12. Average crust thicknesses = 40 mm.

Limited biological surveys to date have been mainly carried out on seamount summits or at the summit margins. Preliminary results indicate that the density of fauna on seamounts is low. Very sparsely distributed corals were observed on slopes by camera and video tows. Because of a lack of sampling, there are virtually no reports about the fauna in rocks, crusts or sediments from the summits/slopes.

Nevertheless, the determination of biological communities and their distribution on seamounts would be complicated. This information is of great interest to science, because of the unique habitat on the seamounts, as follows:

- Water depth from 800-4,000 m encountered with different chemical/biogeochemical status in the profile
- Varying and complicated topography
- Coverage of sediments
- Various composition and thickness of sediments
- Various outcrop and hard substrate rocks
- Various thickness and composition of crusts
- Various food structures from summit to base of individual seamounts

One major reason is the very strong currents or eddies in local mesoscale around the seamounts, which gives rise to low biomass and density of the biological community related to seamounts. There should be no sediments during the growth of crusts (up to 75 Ma) because of either gravity or hydrodynamics. During intermittently strong peaks in flow of >40 cm s-1 the top few millimetres of sediment may be completely stripped in the flat area (Hollister and McCave, 1984; Hollister et al., 1984). The complicated topography with irregular depth gradients makes deep water movement quite unstable.

Crust exploration, exploitation and environmental impacts

Exploration instruments for crusts could include the following:

- Multibeam echosounder
- Side-scan sonar
- Single- or multi-channel seismic systems
- Gravity and magnetic surveys
- Video and photography
- Gamma radiation surveys
- Dredges
- TV-grabs
- Corers for crust
- Box corer, multiple corer and gravity corer for sediment
- CTD and ADCP
- ROVs, AUVs and manned submersibles
- Current-meter and sediment trap mooring systems
- Plankton nets
- Water and particulate samplers;
- Equipment for laboratory analysis and data processing

For reconnaissance work, 15-20 dredge hauls and cores need to be taken per seamount to determine crust composition and thicknesses, hard rock and sediment types and their distributions.

In contrast with manganese nodules, which rely on soft sediments, crusts are attached to hard rock. An economic way of mining would be to collect crusts without or with less substrate. According to the situation in the metal markets, technical difficulties and environmental considerations, it seems too early to consider developing technologies and methodologies for deep-sea mining of crusts. However, the procedures for potential crusts deposits mining will include three steps: collection of crusts on seamounts, transportation to the sea surface, and processing at sea, on land, by in-situ metal extraction or using new technological developments.

As a result, the direct environmental impacts from potential crust mining may include:

- Slight change of seamount topography
- Benthic plumes around seamount resulted from dredging or crushing
- Accumulation of crusts and substrates fragment at the foot of seamount or on the nearby pelagic sediments.
- Creating plumes in surface ocean or intermediate water zone
- Release of metals into seawater and change of chemical flux and interaction between boundaries or layers

At an annual production rate of 300,000 tons of dry crust ore, daily production requires an area of 16 km^2, with 4 cm thickness of crusts (without substrate rocks). It is difficult to estimate the amount of dispersed mineral particles from mining since the mining technology is unknown. The problem is further complicated because dispersal could be at different depths in the water column. It might be a significant amount in view of the mean total mass flux of 13.2 ~ 25.7 mg m~2 day~1 composed mainly of carbonate and opal in the oligotrophic Western Pacific (Sites 4 and 10) reported by Kawahata et al. (2000).

Oxygen minimum zone, biogeochemical cycling and iron fertilization

Oxygen minimum zones form because of the biological degradation of organic matter sinking from surface production and poor water circulation. Dissolved oxygen starts to decrease below about the 100 m water depth and reaches its minimum level from 800 to 1,200 m in the Western and Central Pacific Ocean. Some seamounts penetrate or are just underneath the oxygen-minimum zones in the area.

Oxygen minimum zones not only act as a biogeographic barrier between populations, creating a strong vertical gradient in physical and biological parameters, but also affect the Redox cycle of metals through anaerobic metabolism or chemical potential.

In contrast with their deposition in crusts on seamount slopes, the release of metals and some other elements or compounds into seawater during mining is expected. The expected products will include, soluble ions, chelate complex and biogenic ligands, especially in cases where Redox conditions change in the oxygen minimum zones. Conversely, the soluble metals influence the biological processes, production and community structure.

Phytoplankton play a key role in adjusting organic carbon cycling, CO_2 of the atmosphere, fisheries and marine inorganic chemistry. Studies show that some metals partly control the growth of organisms and their cycling of major nutrients, such as carbon (C) and nitrogen (N). The best example to elucidate the biogeochemical controls and feedback on ocean primary production is iron.

The mean elemental ratio of marine organic particles is highly conserved as 106C/16N/1P by atoms. The debate of macronutrients limitation among nitrogen (N) and phosphorus (P) cannot explain the maintenance of ''high-nutrient, low-chlorophyll'' (HNLC) conditions in some central oceanic gyres.

Martin first postulated that iron (Fe) probably acts as a prime limiting element in HNLC areas. For such areas far away from land, besides a limited supply from hydrothermal activity, a major source of iron is wind-blown, terrestrially derived dusts. Occasionally Aeolian dust input could give rise to phytoplankton blooms in an HNLC area.

Recent mesoscale, iron-enrichment experiments conducted in the equatorial Pacific Ocean (IronEx I and II) and the Southern Ocean (SOIREE and SOFeX) confirmed that the iron limitation hypothesis is true in these regions.

Actually, J.R. Christiana et al. (2002) developed a coupled physical–biogeochemical model of the tropical Pacific Ocean with simultaneous iron and nitrogen limitation and suggested that iron limitation is ubiquitous in the equatorial Pacific, and extends further west than is generally believed, unless there are significant inputs of geothermal iron at quite shallow depths.

The most interesting result is from the in situ experiment SEEDS performed in the subarctic North Pacific Ocean (48.5°N, 165°E) by Tsuda et al. (2003). The annual atmospheric iron fluxes in the test site are 10 to 100 times higher than those in the other HNLC areas. Iron concentration in the mesopelagic layer in the western subarctic Pacific is also relatively high. A single enrichment of dissolved iron of 350 kg of iron as FeSO4 caused a large increase in phytoplankton standing stock and decreases in macronutrients and dissolved carbon dioxide. This experiment clearly demonstrates that iron availability controls phytoplankton abundance, thereby regulating biogeochemical processes in high-nutrient areas of the western subarctic Pacific that are similar to other HNLC waters.

Potential anthropogenic addition of metals released from crust fragments will almost certainly affect the spatial and taxonomic distribution of oceanic biota as well as their photosynthetic activity. However, the potential advantages of enhanced fish stocks, increased carbon cycling and reduced carbon dioxide (CO_2) in the atmosphere require further study.

First, the mechanism of iron addition adjusting primary production should be further identified. Because all nitrogen transformations involve metalloenzymes, iron is required in nitrogenase obtaining additional energy and reducing power for N2 fixation. Low iron availability may also inhibit nitrate and nitrite reductase activities both in the assimilatory pathway of phytoplankton (as mentioned above for diatoms) and in the dissimilatory pathway of denitrifiers. The low productivity in Fe-depleted regions of the oceans is primarily due to the low efficiency of the light reaction of photosynthesis, which requires a host of Fe-containing electron transfer intermediates. Electron transfer in respiration also becomes inefficient at low Fe, and heterotrophic bacteria then convert less of the C they consume into biomass.

Second, addition of N, P, or Fe has been shown to increase the rate of photosynthesis in samples of surface water from various parts of the world. However, these additions do not accelerate equally the growth of all phytoplankton taxa, and the acquisition of major nutrients is not independent of the availability of trace metals that catalyse their transformations. The dearth of Fe that has been shown to limit primary production in the Equatorial Pacific inhibits diatom growth most effectively. In the SEEDS experiment, the dominant phytoplankton species shifted after the iron addition from pennate diatoms to a centric diatom, Chaetoceros debilis, showed a very high growth rate, 2.6 doublings per day. The net growth rate of C. debilis was 1.8 times higher than that of pennate diatoms observed in Iron Ex II and net algal growth rate in SOIREE. The phytoplankton species composition of the pelagic ecosystem strongly influences the ecosystem's response to an increase in iron supply and determines the growth rate of diatoms, aggregation processes, and export flux.

Third, there is still no evidence that the increased organic particulates are effectively transported to the deep ocean or into the sediments. There is a great fear that if the Redox condition is dramatically changed it will damage the benthic habitat if tremendous amounts of organic matter from phytoplankton blooming should drop into the deep sea.

Fourth, contamination of metals from crust mining also includes other elements, such as Mn, Co, Ni, Zn, Cd, Pt, etc., besides iron, which has a biological role. Whether or not they have a function similar to iron or have some other multiple effects on the marine ecosystem and biogeochemical cycling is not quite clear.

Scientific strategy of environmental protection aims at crust exploration and potential exploitation

Geologic surveys on seamount crusts for alternative metal resources have been carried out for more than 30 years worldwide and will be continued in the near future. The major objective of this exploration is to mine the crust ore and extract useful metals. There seems to be no obvious or serious harmful impacts from geologic exploration activities.

The question at this stage is how to assess the potential impacts from crusts mining based on our knowledge about the ecosystem and to establish a monitoring programme under the guidance of the precautionary principle. However, frankly speaking, we know little about this complicated ecosystem with sharp gradients, especially the mechanism adjusting the function of this ecosystem. We do not know when crusts mining will start. We do not know what kinds of technology and methodology will be developed for mining this resource.

Nevertheless, we have some knowledge with which we can devise a flexible, scientific and practical monitoring programme. For instance, Ellis (2003) reported the assessment results for biodiversity recovered from mine tailings after recovery of a muddy/sandy sediment seabed. Island Copper Mine, in northern Vancouver Island on the west coast of Canada, discharged its non-toxic tailings (mill residues) to a fjord at 50m water depth over 25 years from 1971 to 1995. The discharged tailings flowed into the deepest basin in the fjord from the end of the pipeline as a meandering density current. Even under active deposition, some organisms could survive or settle with a critical deposition rate of ~20 cm/year.

Seabed biodiversity assessments were made annually from pre-discharge in 1970 to post-closure in 2000. At a site impacted by the discharge of mine tailings, a suite of ~6 primary opportunist species (mostly polychaete worms) had started to sustain itself within 1–2 years after discharge ceased (1995), within the mix of 100+ other species which were not sustaining themselves. By 2000, some secondary opportunistic species had entered the succession, and the species richness of the impacted area had come to equal that of the reference areas. The start of a sustaining ecological succession is easily measurable by repeat surveys, and requires only the services of one taxonomic identifier to demonstrate the consistent presence and numbers of a limited range of species.

As a consequence, Ellis proposed that the recovery of biodiversity of an impacted muddy seabed can be determined by drawing on a concept termed ‘‘sustainable ecological succession’’. However, the above-mentioned result would be difficult to apply to assessing the potential impacts of crust mining in deep sea.

What we know is that the ecosystem associated with seamounts is highly sensitive to environmental disturbance. Damage or change to the ecosystem could result in the pelagic habitat and some taxa becoming extinct or taking a long time to recolonize.

Another aspect of the acquired knowledge is that most of the species occur in patches. Because they do not occur evenly (nor even randomly), it is difficult for benthic biologists to use their distributed population counts for statistical probability tests of quantitative differences. For economic reasons, the crust mining might also be based on a patchy or banding distribution pattern.

The last subject relates to the natural variability of the ecosystem at different spatial and temporal scales. The seabed ecosystem is constantly fluctuating or progressively changing in its physical and chemical oceanographic parameters, and perhaps the most important change is with its biological parameters through seabed populations being affected by whatever species were previously present (Matthews et al., 1996). Studies on natural variability will provide a standard to evaluate the degree of anthropogenic impacts, and provide a better understanding of the factors controlling this ecosystem.

Furthermore, many studies in recent decades reveal a huge chemolithoautotrophic microbial society in the deep sea and deep in the earth. Such microbial biomass can act as primary producers for local ecosystems in the Area, such as seamounts vents and seeps, although their relationship with the photosynthetic system is still not clear. Besides, chemolithoautotrophic microbial processes within the ocean crust are of potential importance in controlling rates of chemical reactions and thereby affecting chemical exchange between the oceans and lithosphere.

In conclusion, to have a better understanding of environmental impacts related to potential crust mining, we can do something, such as environmental monitoring to explore the nature of a specific ecosystem through efforts either by individual scientific groups worldwide or international cooperation. Meanwhile, we should admit our preliminary knowledge about the complicated ecosystem and be modest in our environmental management actions.

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SUMMARY OF THE PRESENTATION

Professor Zhou introduced himself as a geochemist who knew little about biology and biochemistry. He said he would therefore focus on chemical and biogeochemical aspects. He stressed that the information required to measure the impact of crusts mining on the environment is which fauna was present at the minesite, and the physical oceanography, chemical conditions and geology of the region. In addition, he said that a mining method and associated technologies would need to be identified. He pointed out that currently no technology has been selected for mining.

According to Professor Zhou, crusts deposits have thicknesses that range from millimetres to more than 20 centimetres. Their composition is primarily ferruginous vernadite, iron oxyhdroxide and detrital minerals, but that some of the crusts contain the carbonate fluorapatite. He said that of interest to industry is their very high cobalt content. In addition to cobalt, Professor Zhou said that crusts contain other metals of potential commercial value, such as nickel, platinum and the rare earth elements.

Professor Zhou said that, although crusts are usually found on slopes where there are no sediments, they are also known to occur under some sediment. Sediments stop the accumulation of crusts. Crusts could occur anywhere that had the conditions for precipitation. What was needed was material supply, certain chemical conditions and a stable substrate. The function of microbes was not clear, but Professor Zhou believed that this could be determined in the future. Professor Zhou said that cobalt crusts derive from fluvial and eolian debris; biogenetic particles and material of hydrothermal origin. He also said that there are three types of crusts: hydrogenetic that dominate, hydrothermal and diagenetic.

Professor Zhou noted that it is possible to see very delicate structures in crusts using a microscope or with the naked eye. He said that these structures varied according to hydrological, chemical and biological conditions. He also said that crusts occur on two types of seamounts; flat-topped seamounts, also called guyots, and conical seamounts. Professor Zhou also noted that for the most part, both types had the crusts on their slope.

Professor Zhou suggested that scientists should investigate why thick crusts occur mainly in the Central and Western Pacific and how to protect the environment, from the impacts of mining.

Professor Zhou said that occasionally, fish are observed on the slopes of seamounts. Rhetorically, Professor Zhou asked why the fish are at the seamounts and what they eat. He said that surveys of the environment with cameras or videos have revealed that organisms are sparsely distributed and difficult to find, especially on the slope. He said that seamounts provide a unique and complex ecosystem because there are many changes in the environment with depth. He also stated that the summits of seamounts vary from several hundred to thousands of metres below sea level, and the depths of the base of seamounts varied.

According to Professor Zhou, seamounts have a varied and complicated topography; different coverage, different composition and thickness of sediment; various outcrops of hard substrate rocks; varying thickness and composition of crusts; and varying food structures from summit to base.

In the view of Professor Zhou, before monitoring of the consequences of commercial activity is undertaken, the natural variability of the ecosytem needed study.

Professor Zhou said that the technologies/techniques likely to be used during exploration were:

- Multibeam echosounder;
- Side-scan sonar;
- Single or multi-channel seismic systems;
- Gravity and magnetic surveys;
- Video and photography;
- Gamma radiation surveys;
- Dredges;
- TV-grabs;
- Corers for crust;
- Box corer, multiple corer & gravity corer for sediment;
- CTD & ADCP measurements;
- ROVs, AUVs and manned submersibles;
- Current-meter and sediment trap mooring systems;
- Plankton nets;
- Water and particulate sampling;
- Laboratory analysis and data processing.

He said that, while the applicable technology is unknown, there are three stages to exploitation, namely, collection, transport to the processing station and processing (which could occur at sea or on land).

Professor Zhou listed a number of possible impacts from crust mining. He said that these would include, inter alia, a slight change in seamount topography, benthic plumes around the seamount resulting from dredging or crushing, and accumulation of fragments of crusts and substrates at the foot of the seamount or on nearby pelagic sediments. He also included the creation of plumes in the surface ocean or intermediate water zone, the release of metals into seawater creating a change in the chemical flux, and the interaction between water bodies. Compared to normal material fluxes in the Pacific Ocean, Professor Zhou concluded that the potential impact of mining is huge.

Professor Zhou reminded participants that crusts had precipitated at a rate of 1-6 millimetres per million years for 70 million years.

He suggested that any release of material into the surface waters may assist the biological pump, that being the process by which phytoplankton removed carbon dioxide from the atmosphere and transported it to the deep ocean. Professor Zhou informed participants about a hypothesis that some areas in the ocean had high nutrients but low chlorophyll content because of micronutrient limitation. He said however that there might be micronutrients in the material released into the surface waters. If this is the case, he concluded that it would allow phytoplankton communities to bloom, and remove carbon dioxide from the atmosphere with positive effects on the global warming situation.

Professor Zhou suggested that there should be a crust-monitoring programme different to that proposed for sulphides, as the two deposits are very different. In this regard, he referred to differences in magnitude and the areas covered by viable hydrothermal and crusts deposits. He said that the deposits also differed in longevity, in mineral and chemical composition, and Redox conditions. Professor Zhou said that crusts had oxygen and oxidized conditions, whereas hydrothermal sulphides had sulphides and no oxygen. He also said that the biodiversity, primary productivity, biological flux and natural variability in both time and space are also very different at the two deposits. Professor Zhou suggested that the group should try to identify what would need to be monitored in the future (not necessarily only during the early stages of exploration), so that natural variability could be determined and also because some of these measurements may take a long period of time.

With regard to chemical measurements, Professor Zhou said he wished to focus on the nutrients, the transmitters, some organic chemicals, sedimentation and particulates. He noted that not many laboratories would be able to carry out transmitter analysis at present.

Professor Zhou concluded by saying that he believed it important to encourage contributions from individual scientists, groups, national, and international scientific organizations. He recommended the establishment of an international cooperative monitoring programme coordinated by the International Seabed Authority involving standardization and unification of protocols and equipment.

SUMMARY OF THE DISCUSSIONS

A participant recalled that, in his presentation, Professor Zhou had said that crusts deposits could occur beneath sediment, so that a mining device may not necessarily encounter crusts as an exposed body. This participant wanted to know how this could affect the efficiency of the mining system. Another participant asked Professor Zhou whether he knew how deep beneath sediments crusts could occur. He responded that it is difficult to present an exact value, as it depended on the hydrodynamic regime of the area. He believed that that some collaboration with the Ocean Drilling Programme (ODP) or the Deep Sea Drilling Project (DSDP) would help in providing answers to these questions.

One participant asked whether encouraging international cooperative monitoring programmes was realistic. Professor Zhou responded that for polymetallic nodules, the Authority had held workshops on that subject and scientists from all over the world had discussed the problems and shared their knowledge to aid standardization. Professor Zhou thought that this would continue for crusts and sulphides in addition to nodules. Another asked whether that meant that, in practice, there would be a field programme with different groups specializing in different groups of organisms conducting work, and then the groups would combine putting their data to determine the environmental impact for a particular system. Another delegate responded that the guidelines for polymetallic nodules had been prepared in hindsight because of workshops organized by the Authority, since exploration for polymetallic nodules had started before the Authority was established. The delegate believed that the Authority could probably have a set of guidelines and mechanisms, so that there would be some kind of a cooperative mechanism to investigate the environment. This delegate said that given the Authority’s experience with polymetallic nodules, in order for activities related to cobalt-rich crusts and polymetallic sulphides to proceed in a manageable fashion, agreement on standards and guidelines for purposes of comparability, needed encouragement. The delegate said this would provide the Authority with the means to administer the development of these resources. In response to a delegate’s question as to whether the Authority would coordinate the cooperative monitoring programme, the Secretariat said that this would not appear to be a problem, but that the first stage was to define the programme.

A member of Legal and Technical Commission (LTC) stated that, as Professor Zhou had suggested, collaboration is the most cost-effective way to proceed and should be a recommendation of the workshop. The LTC member also said that while the practicalities of collaborative work may be complex, the Authority has to suggest the ideal situation. Reference was made to the lack of collaboration between contractors for polymetallic nodule exploration. In this regard the member pointed out that contractors submitted annual reports to the Authority outlining their programme of work, including an environmental component, but the information was not shared amongst the contractors, as the regulations did not require it. It was suggested that the Authority may have a responsibility to collate the data and help to arrange its analysis if contractors were uncomfortable about sharing data. It was noted that the Authority might not be able to do the analysis itself, but may be able to pass that responsibility to organizations that could provide a collective understanding to the Authority that could be downloaded from the Authority’s website to the industrial and scientific community.

It was noted that a monitoring programme would have several components. Some experiments, such as examination of the impact of the sediment plume and trace metals, would not need to be carried out by every contractor. In the opinion of the delegate, it is sensible that certain large questions, such as these generic issues, be organized and developed internationally through cooperation. The delegate who proposed this believed that, just as there were a number of contractors looking at nodules, there could be a number of different groups looking at seamount crusts mining in various locations. The participant felt that contractors would probably have to take responsibility for components of the programme, particularly in assessing the fauna of their exploration areas, whereas other issues might be amenable to cooperative and international research. The delegate stated that this is the approach being taken with polymetallic nodules where there are proposals to look at big, broad, generic issues collaboratively, with each contractor carrying out some baseline assessments of the fauna within its own exploration area.

Part of the discussions focussed on whether there should be different monitoring programmes for polymetallic sulphides and cobalt-rich crusts deposits, because of their differing environments. A view expressed was that, while the variables that are measured would be similar to those for polymetallic nodule surveys, the strategy of the sampling would vary depending on the localized conditions.

Professor Zhou agreed with all the points put forward by the various participants and stated that, before impact assessments were carried out, the natural variability should be known.

The cost of cobalt was discussed and. although an exact figure was not known, it was stated that the value had been very high when the mines in Zimbabwe were closed.

It was noted during the discussion that the spatial scale of the mining operation would be more important than actual tonnage mined. Professor Zhou stated that he had introduced the component of spatial scale because 16 square kilometres of individual seamounts could have a huge impact on what was biologically a very spatial fauna, so it would be important to consider the spatial scale of any operation.

One of the participants had attended the Underwater Mining Institute meeting in London the week prior to the current workshop and mentioned that there had been some presentations on cobalt crusts and that the issue of technology had been raised. It was noted that once the environmental baselines were established in order to assess the impact of mining, the method of mining would need to be known. A participant asked Professor Zhou whether he had any information on mining methods, including the separation of crusts from the substrate rock. Professor Zhou said that he was unsure, but that he imagined it would be similar to how manganese nodules were processed, as had been suggested by Dr. Sharma.

There was a discussion on the effect of activities on the water column. One participant informed the workshop that he is a water column biologist who had just started studies in the Clarion Clipperton fracture zone in order to understand the positive and negative affects that mining activities posed on the ecosystems. The participant noted that mining activity had the potential of having a positive impact on the water column communities, transporting nutrients from deep water to shallower water, possibly increasing phytoplankton productivity. It was noted by another participant that the nutrients would be trapped in the sediments and not in the rock brought to the surface, and that it would be more likely for particles to be introduced, rather than nutrients leaching from the material.

CHAPTER 12 THE BIOLOGICAL ENVIRONMENT OF COBALT-RICH FERROMANGANESE CRUSTS DEPOSITS, THE POTENTIAL IMPACT OF EXPLORATION AND MINING ON THIS ENVIRONMENT, AND DATA REQUIRED TO ESTABLISH ENVIRONMENTAL BASELINES

Dr. Julian Anthony Koslow, Senior Principal Research Scientist, CSIRO Marine Research, Wembley, Western Australia, Australia

Introduction

Cobalt-rich ferromanganese crusts are found on hard-rock substrates in the deep sea, generally on seamounts, ridges and plateaus. Because of their slow growth (generally <1 – 11 mm/Ma), thick crusts are typically found on old seamounts and ridges, where topographically enhanced currents have maintained the substrate free of sediment for many millions of years.[i]

Seamounts were first sampled by the *Challenger* expedition (1872-1876), but only after the Second World War, with the advent and widespread use of echo sounders, was their abundance estimated and distribution characterized. There are an estimated 30,000 seamounts greater than 1,000 metres in height and an estimated 600,000 – 1.5 million of any size greater than 50 metres in the Pacific Ocean,[2] but only about 810 greater than 100 metres in height in the North Atlantic.[3] There is no estimate of the number of seamounts in the Indian Ocean, but the number is believed to be intermediate and closer to the situation in the North Atlantic. Most interest in cobalt-rich crusts has been in the equatorial Pacific Ocean, within the exclusive economic zone of Micronesia, Marshall Islands, Kiribati, Hawaii and Johnston Island, and on the Mid-Pacific Mountains in international waters. The thickest crusts have generally been found at depths between 800 and 2,200 metres and appear to be associated with the oxygen minimum zone.[4]

Physical and biological environment

The abrupt topography of seamounts and ridges greatly modifies and amplifies the slow ambient currents and tidal flows generally observed in the deep sea. A variety of currents may be generated: eddies (Taylor columns or caps) directly above the seamount, eddies released in the wake of the seamount, trapped waves and internal tides, and upwelling.[5,6,7,8,9,10] These currents are typically strongest near the summit, where the thickest crusts are generally found. The currents winnow away the sediments, leaving bare hard substrate where ferromanganese crusts grow.

Interest in the study of seamounts was largely stimulated by the discovery in the late 1960s of substantial fish aggregations associated with them around the Emperor and other seamount chains in the North Pacific.[11,12] Initial studies largely focused on the ichthyofauna and the physical and biological conditions that might lead to enhanced productivity in the vicinity of seamounts. The American ichthyologist, Carl Hubbs, first grasped the potential importance of seamounts for marine biogeography in 1959.[13] However, the hard substrate fauna of seamounts remained very poorly studied until recently, in part because of the difficulty of sampling this rugged environment with standard trawls. Wilson and Kaufmann (1987)[14] recorded 597 species of invertebrates sampled from seamounts worldwide over the century since they were first sampled by the *Challenger* expedition (1872-1876). Most reports to that date were extremely limited, typically recording the occurrence of only a few species, often from a single group of special interest to the investigator (e.g. the molluscs or fishes). Only five seamounts accounted for 72% of the species recorded. Levels of endemism appeared modest: around 15%. However many of the seamounts were relatively shallow and near continental land masses, and higher levels of endemism were noted for some more oceanic seamount chains. Only 27 species were recorded from the Southwest Pacific region.

The first major expeditions to focus on seamount benthic communities were mounted by the Soviets in 1979, 1980 and 1987 on the Nazca and Sala y Gomez ridges of the Southeastern Pacific.[15] French scientists undertook an extensive series of cruises dedicated to the study of the seamount fauna within the exclusive economic zone of New Caledonia in the Southwest Pacific region beginning in the late 1980s.[16] In the last decade, Australian and New Zealand scientists, working within their respective exclusive economic zones, have considerably expanded studies of the Tasman Sea/Southwest Pacific seamount fauna.

The hard substrates of seamounts and ridges are characterized by a unique deep-sea fauna, dominated by suspension-feeders, in marked contrast to the predominantly deposit-feeding fauna characteristic of the soft sediments that blanket most of the deep sea.[17,18,19,20] A variety of hard and soft corals, including scleractinians, gorgonians, and antipatharians, typically dominate the hard-substrate benthic megafauna. Suspension-feeding sponges, anemones and hydroids, bryozoans, echinoderms (e.g. crinoids, brisingid starfish, ophiuroids), and others are generally present as well.

The water column around seamounts contains a characteristic nekton, often with commercial quantities of benthopelagic fishes that may be uncommon elsewhere: e.g. alfonsino (*Beryx* spp), orange roughy (*Hoplostethus atlanticus*), oreos (especially *Pseudocyttus maculatus)*, rockfishes (*Sebastes* spp), pelagic armourhead (*Pseudopentaceros wheeleri*), and deepwater snappers (*Etelis* spp*, Pristipomoides* spp*, Lutjanus* spp). Rogers (1994) [21] listed some 76 species of crustaceans and fishes that are commercially fished from seamounts. Ecosystem box models indicate that the substantial fish aggregations associated with seamounts receive only a small fraction of their energetic requirements from the productivity of the water column directly overhead.[22,23] Rather they depend, like the benthic fauna, on the advection of prey past the seamount. Seamount-associated fishes have also been observed to feed on vertical migrators intercepted by the shallow topography.[24,25] Seamount-induced eddy fields and upwelling may also support increased primary production over seamounts.[26,27] However, it is unclear whether the residence time of water over seamounts, such as within a Taylor column, is sufficiently long to sustain enhanced populations of zooplankton and micro-nekton, the prey of fishes aggregated over seamounts. Seamount-induced currents may also physically aggregate prey, which may contribute to the heightened concentrations of mesopelagic fishes, such as *Maurolicus muelleri,* and higher pelagic predators, such as tunas, commonly observed over seamounts.[28,29]

A little more than a decade following the Wilson and Kaufmann (1987) review, Richer de Forges et al., (2000)[30] reported some 850 species from ten seamounts on the Lord Howe Rise and Norfolk Ridge and from a cluster of seamounts on the continental slope off Tasmania, all in the Coral and Tasman Seas in the western Southwest Pacific. That study, conducted in a limited sector, thus recorded about 40 % more species than had been recorded from all previous studies of seamounts throughout the world's oceans. Furthermore, they found no asymptote in the relationship between the number of species and number of samples per seamount, indicating that many more species were present. About a third of the species were new to science, apparently limited to the seamount environment and potentially endemic to the region. Remarkably, there was no overlap in species recorded from the Norfolk and Lord Howe seamounts in the southern Coral and northern Tasman Sea and the Tasmanian seamounts in the southern Tasman Sea, a distance of approximately 2,200 kilometres. The apparently restricted distribution of many of these species is highly uncharacteristic of the deep sea, where the lack of barriers and similar environmental conditions over vast spatial scales leads generally to widespread species distributions.[31] The topographically rectified currents associated with seamount and ridge systems may lead to the genetic isolation of their sessile fauna, much of which has a limited dispersal phase.[32] This has profound conservation implications: severe disturbance, such as from trawling or mining, over the relatively limited spatial scale of a ridge system or seamount cluster could lead to the extinction of a portion of its fauna.

Russian scientists working on seamounts of the Nazca and Sala y Gomez ridge systems of the Southeastern Pacific have reported even higher levels of endemism: 51% for benthic invertebrates and 44% for fishes.[33] The fauna had broadly Indo-Pacific affinities, which indicated colonization from the west, probably using the various island and seamounts chains that spread across the Pacific as "stepping-stones," as Hubbs (1959) hypothesized. However, the fauna had largely evolved and speciated, *in situ.*

The isolation and more restricted distribution of seamount faunas can also be seen at larger spatial scales. One of the most characteristic features of the deep sea is the cosmopolitan distribution of its fauna at the generic level. Thus, while particular species are generally only found in a single oceanic basin, the dominant genera tend to be globally distributed (e.g. the macrourid *Coryphaenoides)*.[34] In contrast, the dominant benthopelagic fishes of seamounts exhibit convergent morphology (deep-bodied fishes capable of strong burst swimming, adapted to the strong currents) but have evolved from a great variety of families and orders in the different oceans and climatic zones: alfonsino (*Beryx* spp) (Berycidae, Order Beryciformes) in tropical and sub-tropical waters, the oreos (Oreosomatidae, Order Zeiformes) and orange roughy (*Hoplostethus atlanticus*) (Trachichthyidae, Beryciformes) in temperate waters of the southern hemisphere, the pelagic armourhead (*Pseudopentaceros wheeleri*) (Pentacerotidae, Order Perciformes) on temperate North Pacific seamounts, the rockfishes (*Sebastes* spp.) (Scorpaenidae, Order Scorpaeniformes) along the margins of North America, and so on.[35]

The benthic seamount communities in the region around New Caledonia, south-eastern Australia, and New Zealand are characterized by an underlying reef matrix, typically comprised of a single dominant scleractinian coral (e.g. *Solenosmilia variabilis* around Tasmania and New Zealand).[36] This provides a three-dimensional structure for a great variety of associated species, living within the interstices (e.g. galatheid crabs and other crustaceans) or as epifauna. Most suspension feeders in the community grow on and over the coral matrix.[37] Off Tasmania, living *S. variabilis* reef was only found down to a depth of about 1,400 metres. Remnants of dead reef below that depth indicate possible temporal variability in the conditions suitable for coral growth.

Grigg et al (1987)[38] surveyed the benthic megafauna of Cross Seamount, one of the west Hawaiian seamounts (actually a guyot), about 250 kilometres south of Oahu, to assess the potential impact of crust mining. They reported that the fauna was sparse, particularly below 500 metres depth, where the thickest crusts were found, and low in diversity. Their collecting gear - photography, a rock dredge and tangle nets - mostly sampled the corals and other large megafauna. More recent precious coral resource surveys found an estimated 4,750 colonies of commercially exploitable red coral (*Corallium regale*) and gold coral (*Gerardia* sp) over the seamount summit.[39] Given the differences in sampling methods, it is difficult to compare the Cross Seamount fauna with those in the South Pacific, although the impression remains that the Cross Seamount fauna is sparser and less diverse. Cross Seamount, at 18° 45’ N latitude, is within the oligotrophic central gyre of the North Pacific, whereas the seamounts around the productive deepwater fishing grounds of New Zealand and Tasmania, at approximately 35° to 45°S latitude, lie beneath more productive waters. Grigg et al (1987) also speculated that the relative isolation of Cross Seamount contributed to its reduced diversity.

I found no other comprehensive benthic faunal surveys for seamounts in the region of interest for mining of cobalt-rich ferromanganese crusts. Hein (2002)[40] lists some 46 research cruises carried out since 1981 by the United States of America, Japan, France, Germany, Korea and other nations dedicated to the study of cobalt-rich ferromanganese crusts, but they appear to have focused entirely on geological investigations.

The abundance, diversity and species composition of seamount faunas appears to differ considerably depending upon seamount depth, topography and characteristics of the currents, the productivity of the overlying water column, biogeographic province and proximity to neighbouring seamount and ridge systems. With the present paucity of data for seamount biological communities in the equatorial Pacific, it is not possible to define more precisely the biological environment of cobalt-rich crust deposits. Clearly there is an urgent need for such research. Until more data are available, it would be precautionary to assume that a substantial proportion of the benthic fauna on seamounts with cobalt-rich crusts will prove to be endemic to the local ridge system.

Potential impact of mining seamount crusts

The clearest impact of seamount mining will be the direct removal and loss of the hard-substrate community, along with the cobalt-rich crust, in areas that are mined. The process of mining the crusts and transporting them to the surface will also presumably release sediments and metal species onto adjacent portions of the seamount and into the water column. The potential impact of this on the benthic fauna on unmined portions of the seamount and on water column processes, such as primary production and grazing, is not known.

In considering these impacts, the key issue is the risk that mining will lead to the extinction of a portion of the impacted fauna. The likely timescale for recovery of the seamount fauna also needs to be assessed, both on portions of the seamount that are directly mined and adjacent portions that may be affected by enhanced sedimentation and release of metals.

To assess the risk of extinction, it is critical to take account, first, of the scale of the potential mining operation in relation to the spatial scale of the seamount fauna. The mining of seamount crusts may be far more localized than, for instance, the mining of nodules on the abyssal seafloor. However, the distribution of seamount benthic species is also far more restricted, being limited largely to the seamount hard-substrate habitat and for some fraction, to the local seamount cluster or ridge system. Management of mining impacts must also be undertaken within a regional context that takes account of additional activities that may affect seamount communities.

To assess the potential impact of mining seamount crusts, the following issues need to be resolved:

- What is the diversity and biogeography (i.e. distributional range) of the hard-substrate benthic community in areas of potential mining interest?
- How many seamounts, and what proportion (depth range) of each seamount, will be mined?

- Are there additional seamounts in the local region that will not be mined? How similar are the faunas of disturbed and undisturbed seamounts?
- Are there additional activities (e.g. fishing and coral harvesting) that may also impact the region's seamount fauna? Mining impacts must be assessed within the context of other potentially disturbing activities, since the impact of mining on the local benthic fauna will be greater if some seamounts are fished and others are mined. On the other hand, the impact of mining, per se, will be reduced if it is carried out in areas already subjected to trawl disturbance.
- If only a portion (e.g. a particular depth zone) of seamounts will be mined, what is the relationship between the faunas of disturbed and undisturbed portions of these seamounts? Seamount benthic communities typically display vertical and topographic zonation.[41,42,43]
- Will enhanced sedimentation from the mining operation, along with the potential release of metals bound up in the crusts, affect the seamount fauna on adjacent, unmined portions of the seamount?
- Will a proportion of the local seamounts be set aside in a reserve? What proportion of local seamounts should be protected from disturbance to reduce the risk of extinction to an 'acceptable' level and how is this to be assessed?

The time-scale of recovery from a mining operation is highly uncertain. The processes of colonization and recruitment are poorly known for the seamount fauna. Genetic studies to examine the relationships between populations of hard-substrate benthic invertebrates along a range of spatial scales would be very useful. Molecular genetic studies from seamounts in the Hawaiian archipelago and around New Zealand indicated little population differentiation between seamounts but significant levels of inbreeding, indicating that the populations were largely self-recruiting.[44,45] Much of the fauna is slow-growing and extremely long-lived, some with life spans on the order of a century or centuries.[46,47,48,49] Many species have limited planktonic larval periods, when they might disperse to colonize other seamounts, or none at all.[50] It is likely that the recovery time for a severely impacted seamount will be on the order of centuries, if not millennia.

Data required for the establishment of environmental guidelines

To assess the potential risk of extinction due to mining activity requires information on the fauna of the potential mining sites that will be most directly affected, the fauna of adjacent portions of the seamount(s) that may be indirectly affected, and on the distributional range of the potentially impacted fauna, based on surveying seamounts and ridges that will remain undisturbed.

Hard-substrate communities vary with depth, topography and current regime, so sampling needs to be carried out over a range of depths and potential topographically defined habitats, for example, the summit, rim or crest, flanks, and base of seamounts and ridges. If the currents are predominantly from one direction, sampling should be carried out on the upstream and leeward sides of the seamount. Complementary sampling tools should be employed: photographic or video transects, which provide an overview of the community and its structure but limited species resolution, combined with dredging and trawling with a reasonably fine-mesh cod end, such that both the macro- and megafauna are adequately sampled. Sampling tools and taxonomy need to be standardised to facilitate comparability between studies. It is essential that the animals obtained in dredges and trawls are identified to species. The hard-substrate deep-sea fauna contains organisms from a wide range of taxonomic groups, so proper identification requires the collaboration of a substantial team of taxonomic specialists. The Australian study of the Tasmanian seamounts involved some 30 taxonomic specialists; the French work based in New Caledonia involved more than 200.

To assess the distributional range of the fauna - and hence its vulnerability to extinction - comparable seamounts within the seamount chain or cluster must be similarly surveyed. These must include seamounts that are <u>not</u> to be mined and that can be set aside as potential reserves or reference sites. Sampling needs to be carried out along a range of spatial scales. Seamounts in an adjacent chain or cluster should be surveyed. Samples need to be preserved both for taxonomic resolution to species and for analysis of their population genetics, to assess genetic exchange (and hence dispersal) between seamounts within a chain or cluster and between chains/clusters.

Given what is now known about the endemism levels and restricted distribution of the benthic seamount fauna, a considerable portion of the seamounts within a proposed mining region should be set aside as a reserve, in which no other potentially disturbing activities, such as bottom fishing or coral harvesting, are permitted. The fauna of mined and reserve areas need to be compared to ensure that the regional seamount fauna is adequately conserved.

To assess the possible impacts of mining on the surrounding fauna, sedimentation rates and water chemistry in surrounding areas need to be monitored during pilot mining operations. Impact assessment monitoring should follow a BACI (Before-After Control-Impact) design to properly assess the impact on the fauna in adjacent areas. Controlled experiments should be carried out on key faunal groups to assess the impact of enhanced sedimentation by mine tailings.

Presumably the mining operation will release a plume of sediment and mine tailings into the water column, the impact of which on the phytoplankton and zooplankton grazers should be monitored. Again, monitoring should follow a BACI design and be combined with controlled experiments to assess these impacts.

Conclusions

Fisheries conducted since the 1960s have shown that seamounts can support large aggregations of commercially valuable fishes from a number of different families and orders. Only recently, however, has it been recognized that seamounts may also support a unique, abundant and diverse benthic fauna dominated by a variety of coral and other suspension feeders. The biology of this fauna is poorly known, but studies to date indicate that the corals and sponges are generally long-lived and very slow growing due to limited productivity in deep water, with limited dispersal and recruitment between seamounts. As a result, the benthic fauna often contains a high proportion of endemic species with highly localized distributions, which considerably increases the risk of extinction from activities such as bottom trawl fishing or mining that may remove and destroy the benthos over a widespread area. Recovery from such activities is uncertain but likely to be extremely prolonged.

To date, however, comprehensive studies of seamount benthic communities have been carried out mostly in the southeast and southwest Pacific. The fauna of seamounts in the equatorial Pacific region, where there is most interest in mining cobalt-rich crusts, is poorly known. To evaluate the likely impacts of exploration and mining will require baseline faunal surveys of seamounts in the proposed impact and surrounding region to establish the local fauna's broader-scale distribution. Controlled studies need to be carried out to assess the impact of mining activity (i.e. increased sedimentation, particularly of crust material) on the fauna of adjacent unmined portions of the seamount. The impact of plumes from mining activity on water-column processes should also be assessed.

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SUMMARY OF THE PRESENTATION

Dr. Koslow began his presentation by referencing a report that had come out a few months before the workshop. Sponsored by the United Nations Environmental Programme, according to him, the report gave an excellent review of cobalt coral reefs. He said that much of it was with reference to Atlantic Margin reefs, but there was also a good deal on seamounts.

Dr. Koslow showed a map highlighting about 250 sites where seamounts had been sampled. Despite the fact that there were tens of thousands of seamounts in the oceans, predominantly in the Pacific, he said they had not been well sampled. According to Dr. Koslow, the number is misleading, in that comprehensively sampling has occurred in very few seamount sites. He also said that among the vast majority of sampled sites, the investigator was often only interested in one item, such as fish, and may have recovered few specimens. In the Eastern Pacific, he informed the workshop that Australian and French researchers have sampled a group of seamounts. He also said that in an area in the Equatorial Pacific where there is interest in the cobalt-rich crusts on seamounts, there are no biological data available.

Dr. Koslow said that some seamounts had sedimented areas, but that there were typically hard substrates on seamounts and ridges. He said that this is essentially due to enhanced currents. He recalled that a prior presentation indicated that generally weak ambient currents amplify when they encounter an obstacle. He also said that around seamounts, complex hydroactive currents occurred that withered away the sediments, leading to a unique environment in the deep sea.

Dr. Koslow informed participants that the review paper that Dr Hein had prepared for the International Seabed Authority a few years prior to the current workshop had indicated that 800 to 2,200 metres are the depths where the thickest crusts occur. Dr Koslow said that crusts are often associated with the oxygen minimum zone in the Pacific Ocean, and that the Equatorial Pacific Ocean tended to contain the thickest and most valuable crusts. In this regard, he said that the most prospected areas are the mid-Pacific mountains, around Micronesia, the Marshall Islands, Kiribati, Hawaii and Johnston Island.

Dr. Koslow stated that he would focus on the seamount communities in general, as there is limited information about the seamount communities in the crusts bearing areas. He started with studied seamount communities in areas around the Tasman Sea, Tasmania and New Zealand.

Noting that there is considerable commercial fish potential around some seamounts, Dr. Koslow said that Rogers, in 1994, had reviewed the biology of seamounts and listed about 80 species of fishes. From his studies, it was determined that the species were quite different from one region to another. A key issues was that this was unlike the flat seafloor, whether on the slope or the abyss, where genera tended to be distributed in a cosmopolitan manner, meaning that Coryphaenoides was probably the dominant deep-water fish in the deep sea on the flat seafloor. Coryphaenoides had a thin tail adapted to slow cruising on the seafloor. Dr Koslow said that the fish on seamounts, on the other hand, came from different taxonomic groups along very different evolutionary paths. However, they had converged to very similar morphology with strong bodies and fins for swimming against currents. Dr. Koslow gave examples of the orange roughy and Oreos. He said that pelagic armourhead and species of Sebastes might be found on seamounts. According to Dr Koslow, in different oceans, seamounts have different species from very different orders and families. In the North Pacific, Dr Koslow said pelagic armourhead is one of the major seamount fisheries; in the Temperate South Pacific, he said it is the orange roughy and oreos and in the Sub-Antarctic, it is the Patagonian tooth fish. He informed participants that these fish are from different families and orders, so it is an indication of the isolation of the seamounts in different ocean basins.

According to Dr. Koslow, deposit feeders, such as worms, dominate the soft-sediment seafloor, whereas on the seamount, environment suspension feeders, such as hard and soft corals, sponges, hydroids, anemones, crinoids and brisingid starfish, are dominant.

Dr. Koslow informed the participants that seamounts had first been sampled back in the *Challenger* deep-sea expedition, but they had been generally poorly sampled historically. The widespread distribution of seamounts was only apparent after the Second World War, when echo sounders had come into widespread use. Dr. Koslow's impression is that the rugged hard seamount environment had discouraged biologists from looking at it in the past. A major review of seamount biogeography had been carried out by Wilson and Kaufmann in 1987. They put together information on seamounts sampled since the time of the *Challenger* expedition. Dr Koslow reported that the researchers and found that 597 species were identified from all seamount sampling worldwide, in the preceding 100 years. He said that an indication that detailed sampling has taken place in a handful of seamounts is that 72% of the species came from only five seamounts. He said that for the entire Southwest Pacific Ocean, which is an area that includes New Zealand, Southeast Australia and the Tasman Sea, only 27 species have been recorded and the work has indicated a modest level of endemism – about 15%. Endemism referred to species restricted to a particular area.

Dr. Koslow said that during the five to ten years prior to the workshop, there has been a change in thinking about seamounts. This was because of several comprehensive studies of seamount environments. He identified some of the papers, including a paper by Richer de Forges, Koslow and Gary Poore, published in 2000 on the investigation of seamounts in the Tasman/Coral Sea area. He said that the authors reported on 850 species of macrofauna and megabenthic species from 24 seamounts in that area. Dr. Koslow reminded the participants that the world total had previously been just below 600. Therefore, more species were found in this one sector of the world's oceans than had been previously reported globally for seamounts. What is also important is that about one third of those species were new to science and potential endemics. He said the study revealed strong indications of vertical zonation, or that the living reef-forming coral is limited to depths shallower than 1,400 metres. In the Eastern Pacific Ocean, Dr. Koslow said that Parin and others published a paper in 1997 reviewing a number of Soviet studies carried out in the Southeastern Pacific Ocean, around the Nazca and Salas y Gomez ridges. He said that they reported approximately 51% invertebrate endemism in the East Pacific Ocean seamounts. He provided another example of the diversity of deep-water fauna contained in a report by Stephen Cairns. Describing Cairns as a world expert on coral taxonomy, Dr. Koslow said that his paper pointed out that there are more cold-water corals than warm-water corals.

Dr. Koslow noted that, with the discovery of 850 species in the Tasman Sea area, it is clear that the number of species found in each divisional seamount is a function of the number of samples taken. In other words, if sampling were to continue, it was quite clear that it would lead to the discovery of many more species. Dr. Koslow said that there is much greater diversity on seamounts than previously thought. He said that perhaps more important than the number of species is the fact that endemism is exceptional for the deep sea. Dr. Koslow suggested that most species appeared to be largely restricted to a particular ridge system. He noted that French scientists had sampled four seamounts on the Lord Howe Rise and six on the Norfolk Ridge, separated by about 6,000 kilometres. Their results indicated 21% overlapping species between any two seamounts within a ridge system, but only about 4% when comparing seamounts between those ridge systems. He said that there were no common species between those seamounts and the ones south of Tasmania. On the other hand, sampling of the soft sediment fauna in this Southeast Australian region revealed that about 60% of the soft sediment fauna had basic Indo-Pacific affinities with the Tropics. He concluded that there is a much higher level of endemism than had been previously thought.

Dr. Koslow informed participants that this had led scientists to term seamounts as "The Galapagos of the Deep". The hypothesis put forward to explain this is that the high endemism is due to a high degree of reproductive isolation, which leads to local evolution and speciation. With regard to the influence of topography on currents, Dr. Koslow suggested that the topography rectifies or guides the currents, and that rectification isolates seamount chains from each other. He said that it also appears that the species on seamounts had evolved reproductive strategies to limit their loss outside seamount ridge systems.

According to Dr. Koslow, the conservation implications of this are that there is the threat of extinction to localized heavily impacted species from widespread disturbance, whether it was fishing or mining. In his experience, unfished seamounts have 50% coral cover and heavily fished seamounts are about 95% bare rock. It was clear to Dr. Koslow that, if all the seamounts within a particular chain or region were denuded, more species would face extinction.

Dr. Koslow said the there are limited data from seamounts bearing cobalt-rich crusts. He referred to a paper published in 2002 that pointed out that while there have been more than 46 research cruises since 1981 to study cobalt-rich crusts, there was not a single comprehensive benthic formal survey amongst them. Dr. Koslow concluded that there is an urgent need for such research. He also referred to a paper by a scientist named Grigg working out of Hawaii. Dr. Koslow recalled that in the 1980s, there had been interest in the crusts on Cross Seamount, which is south of Hawaii. He said that Grigg reported sparse fauna, although on the summit, there appeared to be some potential for precious coral harvesting. Dr. Koslow questioned the low diversity. He suggested a number of reasons: maybe the currents are weaker; maybe there is reduced surface productivity, maybe it is because the area is in an oligotrophic portion of the Pacific; or maybe there is reduced oxygen or negative interactions of biota with the cobalt crust. Dr. Koslow said that Grigg thought that the seamounts might be relatively isolated. Dr. Koslow noted that the study revealed significant vertical zonation, suggesting that the portion of this seamount with the thickest crust is at a higher level on the seamount than the area with the most fauna. He said that this situation would result in less impact from mining. He said that it is to be determined how representative the Cross Seamount is of the Equatorial Pacific.

Dr. Koslow proposed that, in the absence of formal surveys, it is necessary to take a precautionary view in case a substantial proportion of the benthic fauna on seamounts bearing cobalt-rich crusts proved to be endemic to the local ridge system. He said that while this is a hypothesis amenable to testing, there is enough evidence of high endemism in other areas to assume the potential for high endemism on Equatorial Pacific seamounts.

Dr. Koslow then discussed the potential impacts of cobalt-rich ferromanganese crusts mining. He felt that the most significant impact would be the loss of epifauna on the mined crusts. He said that while he did not know whether an estimate presented by another participant of 16 square kilometres of mining per day was realistic, he believed that mining would involve stripping very large areas. He identified enhanced sedimentation or the release of metal particles as an activity with the potential to affect benthic fauna in regions adjacent to the seamount. He also said that this activity could affect water column processes, such as primary productivity. Dr. Koslow described enhanced sedimentation as a key issue, saying that, even if the crusts are fauna poor, if fauna are richer above the crusts, then mining may have an impact.

Dr. Koslow believed that the primary issues for consideration were the risk of extinction to endemic seamount species and the timescales for recovery of mined areas of seamounts and adjacent areas affected by enhanced sedimentation. Dr. Koslow made the point that fauna on seamounts are generally suspension feeders, which are susceptible to impacts from enhanced sedimentation.

In this regard, Dr. Koslow suggested the need to determine the diversity and the biogeography, or the distributional range of the seamount fauna in potential mining areas. He recommended addressing the following questions:

1. How many seamounts would be mined?
2. What proportion and depth range would be mined?
3. Would additional local seamounts be mined?
4. Would there be protected and unmined areas?
5. How similar are the faunas of disturbed and undisturbed seamounts?
6. What is the relationship between faunas of disturbed and undisturbed portions of these seamounts?
7. What is the vertical and topographic zonation?

Dr. Koslow noted that additional activities, such as fishing and coral harvesting, might also impact the seamount fauna within a region. He said that it is important for mining activities to be considered in a multisectorial management framework, as all potential impacts on the fauna would need to be examined. He said that if mining were proposed on a seamount on which fishing has occurred or corals harvested, there would be less impact from mining on the fauna. On the other hand, if mining is proposed to exploit new seamounts on a ridge adjacent to seamounts, on which fishing has occurred, or corals harvested, then the impacts would be potentially greater.

Dr. Koslow said that there has been active coral harvesting in the Equatorial region. He said that precious corals, such as pink coral and gold corals, have been harvested and that at one point, about 100 boats were involved in this activity. He described coral harvesting as destructive and wasteful. He said in coral harvesting, a combination of blocks of concrete called tangle nets are used up and down the slopes of the seamounts breaking up and entangling the corals.

According to Dr. Koslow, other impacts include the effects of enhanced sedimentation, and the release of metals on benthic fauna adjacent to seamount mining area. He also said that other issues to address are questions such as whether local seamounts would be set aside in a reserve or in a preservation site for monitoring, and the proportion to be set aside to reduce the risk of extinction to "acceptable" levels.

Dr. Koslow said that it is unclear what the potential impact of mining on the water column might be. He provided a number of potential pluses and minuses. On the plus side, he said there could be enhanced micronutrients such as iron, which could enhance primary productivity. It was not clear whether seamounts tended to be starved for iron, but they may be starved for nitrates. On the negative side, he said that bringing up a lot of material and releasing it in the upper water column could decrease the light available for primary productivity and interfere with grazers. He also said that there would be a mix of trace metals released in the water. He stated that some of the trace metals might enhance primary productivity, and that others might poison it.

Dr. Koslow informed participants that while the timescale for recovery is unknown; expectations are that it will to be quite long. He identified the slow growth of deep-water corals as compared to the growth of corals in shallower tropical waters as an important factor. He said that recruitment from adjacent seamounts would be uncertain and likely to be restricted, because many seamount species had evolved to limit their dispersal.

Dr. Koslow told participants that the data requirements for environmental baselines should include determining, *inter alia*, the species of fauna at potential mining sites and adjacent areas, the levels of endemism, and the distributional ranges of species.

Dr. Koslow noted that, in terms of seamount communities, it is necessary to assess the abundance, diversity and species composition of the fauna. He suggested stratified sampling based on depth and topography (including samples from the summit, rim, slope and base of the seamount). He identified a key issue as standardization of sampling tools and taxonomy, commenting that studies between different areas needed to be comparable. According to Dr. Koslow, it is proving to be extremely difficult in biological work to compare different studies without comparable sampling tools. Reiterating a point made in an earlier presentation, he said that there are very few taxonomists in the world qualified to look at much of the fauna. With regard to sampling tools, he said that the standard methods used usually involved photographic transects but suggested dredging or some other form of sample collection to sample the macro- and megafauna.

Dr. Koslow said that photographic transects by themselves did not work with certain species. In Australia, Dr. Koslow said there is a group of over 20 taxonomists that collaborate. He said that each taxonomist specializes in a different group. He said that some of the work performed by the French scientists acknowledged 200 collaborators looking at different groups of animals.

According to Dr. Koslow, in order to assess and minimize extinction risk, it is necessary to survey potential mining and protected sites with comparable fauna. The levels of endemism and distributional range of the fauna would need to be assessed. This would involve surveys of seamount ridge systems and assessments of the biogeographical relationships to regional fauna. He recommended that either the International Seabed Authority or the Census of Marine Life Project collaborate in these assessment efforts. Dr. Koslow said that if data on species composition are centralized in this fashion, if will facilitate examination of biogeographical relationships. He stated that it is easy to look at genetic exchange within and between ridge systems if all of the samples are collected and properly preserved.

Dr. Koslow noted that, to examine impacts on adjacent, unmined portions of a seamount, it is necessary to monitor water quality and obtain data on sediment load and water chemistry under test-mining conditions. He suggested the use of controlled field and lab experiments to assess the potential impacts on phytoplankton productivity, species composition and zooplankton grazing.

In conclusion, Dr. Koslow suggested the need for an overall framework for managing the effect of all sectors that cause impacts to occur at seamounts, including mining, fishing and coral harvesting. He also suggested the creation of a network of protected areas based on the potential impacts, including faunal diversity, endemism and species distribution. He stressed that faunal diversity; endemism and distribution require further studies and investigations.

SUMMARY OF THE DISCUSSIONS

There was discussion regarding the larval stages that Dr. Koslow had mentioned as part of his presentation. He noted that there have been relatively few studies on the reproduction of seamount species. He said that these studies indicate that some species appear to have non-feeding larvae that stay for a limited time in the water column and that others seemed to have directly produced juveniles. While it seemed that some organisms bred their young and protected them, Dr. Koslow said that the biology of these species is unknown, and that there seems to be a pattern of reduced local dispersal among some of them.

Asked about the relationship between the growth of crusts and the occurrence of sedimentary species, Dr. Koslow said that thick crusts do not occur where there is thick coral growth. He said that organisms associated with the crusts may inhibit the settlement of other organisms, or the crusts areas may not foster coral growth. He also said that the science of this process is unknown.

Dr. Koslow presented the Cross Seamount as an example that isolated seamounts have little endemic life. A participant offered another example, referring to the seamounts around the Pitcairn Islands. He said this is a very isolated location where there are young volcanoes, not old seamounts. On these, the participant stated that there are low temperature vents producing iron oxides, but that the volcanoes harboured little or no life.

A participant noted that, as part of his presentation, Dr. Koslow had mentioned the possible extinction of some species and the possibility of no recovery at all. The question of whether the extinction of one or a few species was important was posed. The participant noted that with land-based mining, sometimes the environment never returns to its original state, which may result in the extinction of species. Dr. Koslow was asked whether this should be addressed and what he thought the consequences would be. Dr. Koslow thought that it was a matter of scale and a "deep and difficult philosophical issue". He said that in the sampling he conducted, an important aspect was that although they found more 800 species, relatively few were common. He said half of the species occurred only once or twice in the samples. Dr. Koslow felt that it would be impossible to guarantee whether those species would become extinct if any kind of disturbance occurred. He said that it was a matter of scale and that seamounts are potentially one of the most diverse and interesting ecosystems on the planet. Dr. Koslow said that the Authority, with its mandate to protect the environment, could not permit a mining operation to proceed if there is a risk that the operation would make the fauna become extinct. He also thought that it is different on land, as seamounts and vents have unique fauna. He said that since the fauna are not on the seafloor away from the seamounts, stripping of the species of a ridge system could easily occur. In terms of biotechnology, Dr. Koslow felt that there may be benefits from these organisms that had not yet been identified and would never be identified if they were made extinct.

A participant suggested that most benthic animals on seamounts have a role and function to remineralize organic matter. He said that benthic fauna reintroduced organics in other forms to facilitate the process. The participant also said that and if the benthic animals were not present, the process would not occur. The participant emphasized that how much species removal the system can tolerate and allow the process to continue is unknown.

With regard to the map that was shown of seamounts, it was asked whether all of the dots were actually seamounts or other structures. Dr. Koslow responded that his understanding was that there were several different definitions of a seamount. A seamount has to be 1,000 metres high otherwise; it is a knoll or a hill. Dr. Koslow thought that it would be best to go to the web site that the map came from with questions regarding specific regions.

Asked about the greatest depth at which corals can grow, Dr. Koslow said that it was several thousands of metres. He thought that it was about 3,000 to 4,000 metres, but the depths of coral gardens and reefs on the seamounts are typically less than 1,500 metres.

One participant summed up the discussion by saying that the main question was what is going to happen when clear seawater turns cloudy from mining, and said that the oceans are a natural laboratory to test this. This participant stated that seamounts are extinct volcanoes, and that many chains of seamounts have active volcanoes on them that created a plume of fine ash. The participant felt that it might be worth investigating those active portions of seamount chains and what colonized them, because anything that managed to live on the flanks of an active volcano was living in a very "dirty" environment. Secondly, because of tectonics, the participant said that seamounts are moving across the earth, getting closer to areas of active volcanic activity. He said that this situation results in particles in the water column similar to those produced by a contractor during mining. The participant felt that it might be worth investigating the similarity between seamounts close to active volcanoes and those further along the chain away from the volcanic activity. In this regard, he said it would be a controlled experiment and that it would be easier to observe the natural system than to mine a seamount in order to investigate the impact.

The final question posed related to the fact that on land, certain areas were open for mining, while others were protected. A participant asked Dr. Koslow whether this concept is applicable to mining seamounts. Dr. Koslow said that this was this is the idea he proposes, since it is employed by the fishing industry.

CHAPTER 13 PROPOSED CENSUS OF MARINE LIFE SEAMOUNTS PROJECT: TOWARDS A GLOBAL BASELINE AND SYNTHESIS OF SEAMOUNT COMMUNITY DATA – ITS APPLICABILITY IN MINIMIZING IMPACTS FROM CRUSTS MINING

Dr. Malcolm Clark, Principal Scientist, Deepwater Fisheries, National Institute of Water & Atmospheric Research, Wellington, New Zealand. Additional authors not present at the workshop are Ashley A. Rowden (National Institute of Water and Atmospheric Research Wellington, New Zealand) and K. Stocks (San Diego Supercomputer Center, University of California, San Diego, California, USA).

Background

The Census of Marine Life (CoML) is an international science research programme with the goal of assessing and explaining the diversity, distribution and abundance of marine life – past, present and future. CoML field projects are sampling understudied marine realms with the goal of creating a synthetic understanding of the patterns of life in the oceans by 2010.

Seamounts are very prominent features of the world's underwater topography, but relatively few have been studied, and their faunal composition is poorly known. Seamounts have been recognized as significant habitat, yet threatened by human activities, and recent reports commissioned under the auspices of organizations such as WWF, IUCN, UNEP, WCPA, and Conservation International, have highlighted these issues. As such, seamounts currently have a high political profile, especially on the high seas, with submissions concerning a moratorium on bottom trawling on seamounts being made to the United Nations in 2004. A lack of understanding of deep-sea species, habitats, ecosystems, and biodiversity was also identified as a key obstacle to improving the management of deep-sea fisheries in a major conference, entitled "Deep Sea 2003: Shaping the way ahead" that was held in New Zealand in 2003.

In August 2003, a workshop held in Newport, Oregon (USA), had brought together over 30 seamount scientists from 11 countries to overview the current state of knowledge on seamounts and to evaluate the usefulness and timeliness of developing a new CoML field programme on seamounts. The workshop participants concluded that such a programme could have a significant impact by energizing seamount science globally and by contributing fundamental new knowledge of a major and understudied ocean habitat to CoML efforts. This has lead to a proposal for a CoML seamounts programme (named CenSeam, for "A Global **Cen**sus of Marine Life on **Seam**ounts"), which is to be submitted in 2004.

Seamounts: What is known

Seamounts are features of elevated seafloor topography. They are usually isolated, often cone-shaped and generally caused by volcanic activity, and their summits can vary from a few metres to several kilometres below the sea surface. While the true number of seamounts is unknown, because much of the ocean floor remains unmapped in detail, it is estimated that there are more than 50,000, and potentially up to 100,000, seamounts over 1 kilometre high and many more of smaller elevation (Wessel 2001; Figure 1), making them ubiquitous deep-sea habitats.

It is important to clarify here what is meant, in the present context, by the word “seamount”. Three main types of submarine rise are formally recognized (Eade & Carter (1975)): “Seamount” - an isolated elevation rising 1,000 m or more from the seafloor and of limited extent across the summit (not flat-topped as a ‘guyot’); “Knoll” - an isolated elevation rising less than 1,000 m from the seafloor, and of limited extent across the summit; “Pinnacle” - a small pillar-like elevation of the seafloor. However, in recent years, the term “seamount” has been applied more generally to topographic “hill” features regardless of size and elevation (e.g., Epp & Smoot, 1989, Rogers, 1994). The ecological significance of elevation is uncertain, but it is likely that a feature containing hard substrate rising clear of the surrounding (frequently soft) sediment of the general seafloor is an important habitat, whether small or large. Therefore, we are proposing to accept the broader use of the term “seamount” for this programme.

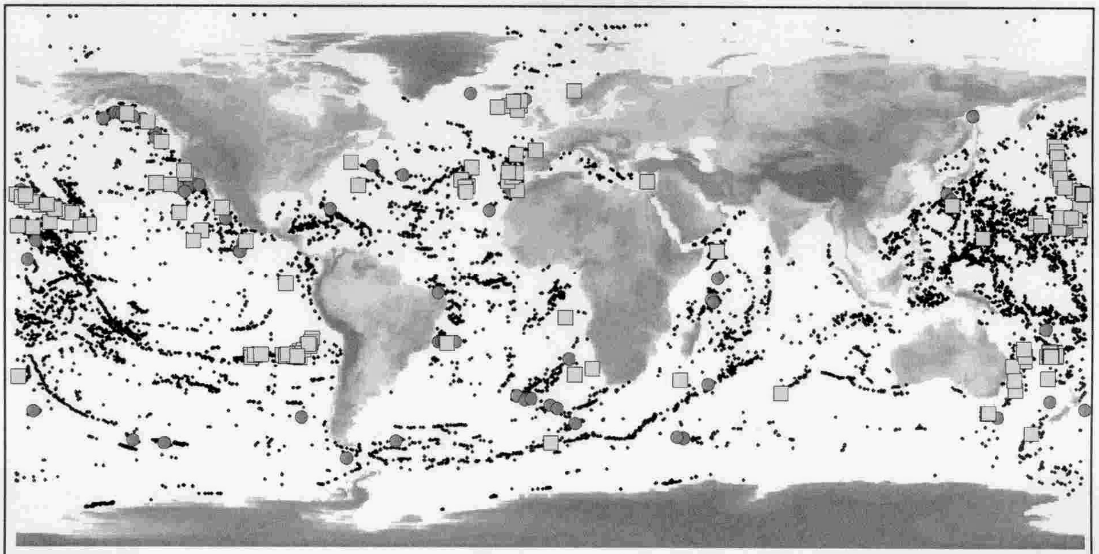

Figure 1. Existing Seamount Sampling. Yellow squares indicate 163 seamounts for which biological data are available in SeamountsOnline (seamounts.sdsc.edu; Stocks 2003) – many of these have been only partially or opportunistically sampled. Blue circles indicate 90 seamounts for which data are not currently available in SeamountsOnline, but which have been sampled at varying levels. They do not include ~100 fisheries-related cruises in the Southern Indian Ocean by Ukranian vessels for which data, including full sample location information, are unavailable. The small black dots indicate ~10,000 seamounts over 1000m high that have been located (courtesy of Adrian Kitchingman, Sea Around Us Project, Fisheries Centre, University of British Columbia, and Christopher Small, Lamont-Doherty Earth Observatory).

Seamounts have been sampled since the time of the *Challenger* expedition, but only in the last few decades have deep-water sampling gear and underwater vehicles (towed cameras, ROVs, submersibles) allowed for detailed sampling of associated biota and mapping and imaging of the seabed. Only about 250 seamounts have been sampled biologically, although this includes many that have received only opportunistic observations of a few species and those for which the data are lost or currently inaccessible. From the sampling undertaken to date, a picture has begun to emerge of the biological communities that exist on seamounts. Rather than provide an exhaustive review of the state of knowledge of seamount communities (for which we refer to review papers by Keating et al., 1987, Rogers 1994, and to the paper by Tony Koslow at this workshop), we will summarize below the key points that are most relevant to the CoML mandate.

Seamounts support unique biological communities

The species composition of seamounts often differs from those of the surrounding deep-seafloor and continental margins of similar depth. The winnowing of currents over seamount topography means that many seamounts have rocky substrates (unusual in the deep sea) where emergent epifauna such as corals, crinoids, and sponges can live. Some deep-sea coral reefs and sponge beds have been aged at hundreds to thousands of years, and can support a large number of associated species (Rogers 1999; Kelly and Rowden 2001). Seamounts are often sites of elevated biomasses, and can therefore act as feeding grounds for migrating fishes, marine mammals, and seabirds (Hui 1985; Blaber 1986; Haney et al., 1995).

Seamounts are particularly known for supporting high numbers of endemic species (species found only on one seamount or seamount chain and, as far as is known, nowhere else in the ocean). In several recent seamount studies, 30-50% of species found were new to science and potential endemics (Parin et al., 1997; Richer de Forges et al., 2000; Koslow et al., 2001). Other studies have reported lower rates of endemism, at 5-15% (Rowden et al., 2002, 2003, 2004), but given the large number of seamounts in the world's ocean, their contribution to marine biodiversity may be significant. "Relict" faunas – lineages previously thought long extinct – have also been discovered on seamounts (Kelly and Rowden, 2001; Schlacher et al., 2003). Because of the geographic, hydrographic and topographic isolation of most seamounts, the probabilities of finding novel species, physiologies, ecologies and chemistries with future study is high.

Seamount research can advance understanding of marine biogeography

The mechanisms of faunal dispersal across ocean basins are key unknowns in our understanding of the present-day biogeography of deep-sea fauna. It has been proposed that seamounts play several important roles in determining basin-scale patterns of marine biogeography, by acting as regional centres of speciation, stepping-stones for dispersal across ocean basins and boundary currents, and refugia for populations with shrinking range (Hubbs, 1959). Seamounts, with their wide distribution and abundant fauna, offer ideal case studies for evaluating the importance of large-scale currents, meso- and local-scale eddies, life history characteristics, geographic settings and geological history to community structure and rates of gene flow for establishing and maintaining biogeographic patterns.

Seamount fauna are vulnerable to exploitation

Over 76 species have been commercially harvested from seamounts (Rogers, 1994), including major fisheries for orange roughy (*Hoplostethus atlanticus*), pelagic armourhead (*Pseuodopentaceros* spp.), oreos (*Pseudocyttus maculatus*, *Allocyttus niger*), roundnose grenadier (*Coryphaenoides rupestris*), rockfish (*Sebastes* spp.), and alfonsino (*Beryx splendens*). To date, most of these fisheries have not been sustainably managed, with many examples of fisheries rapidly developing and declining within a decade (e.g. Uchida and Tagami, 1984; Koslow et al., 2000; Clark, 2001). There are considerable efforts being made to improve management of seamount-related fisheries, with regional fisheries management organizations and bilateral and multilateral agreements arising to restrict fishing pressure or issue moratoriums. However, in most cases, there is insufficient information on the target fish species, let alone the seamount ecosystem, to provide an adequate basis for good management. Furthermore, there is growing concern over the damage that deep-sea trawling can have on the benthic communities on seamounts (e.g. Probert, 1999, Koslow et al., 2001, Clark & O'Driscoll, 2003). Individual countries have now started to protect the benthic fauna on seamounts through marine protected areas or by restricting fishing activities. In 2004, the United Nations General Assembly began discussions on a mechanism for declaring protected areas on seamounts in international waters. However, all of these efforts require a scientific foundation that does not currently exist. For example, at present, it is not known whether seamounts should be managed individually or as chains or groups that interact, nor can hotspots of diversity or endemism be mapped outside of a few well-studied regions. While CenSeam will not make management recommendations, it can play a critical role in providing the science required for management and policy decisions.

Rationale for CenSeam

Seamount ecology has been recently energized, first by the discovery of highly endemic and unusual fauna, and secondly by growing concern over the impacts and sustainability of commercial deep-sea fisheries on seamounts. Many seamount activities are already ongoing or in development globally, and millions of dollars are being contributed to new expeditions. Figure 2 shows areas of current seamount research, and also regions where there are existing or well-advanced proposals to carry out sampling.

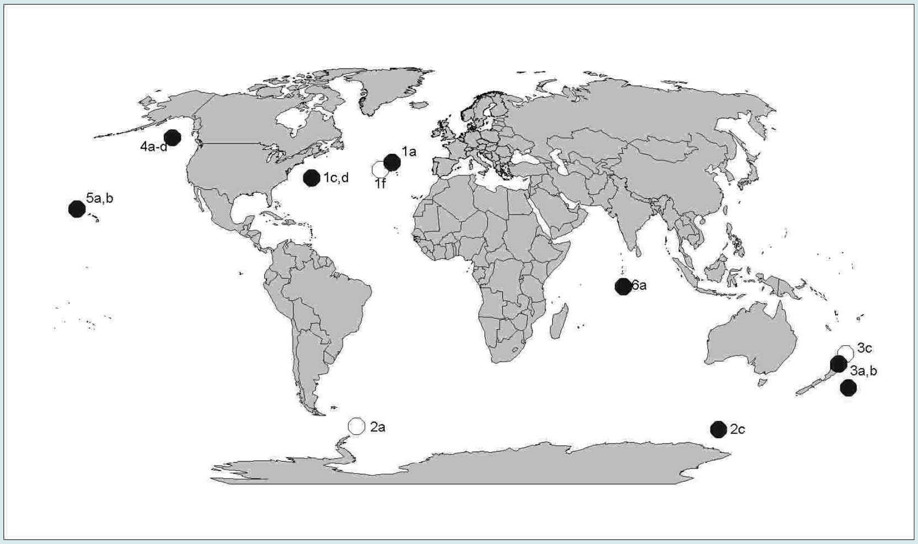

Figure 2: *Areas where seamount research programs are currently being carried out (blue filled circles) or have well-advanced proposals for carrying out ecological research on seamounts (open circles). The labels alongside the circles refer to the numbering system in an appendix in the program proposal.*

However, in large parts, these efforts are uncoordinated, resulting in inefficient sampling, data that cannot be compared across regions, lost opportunities, and major gaps in sampling coverage. Furthermore, because it is not feasible to sample all 50,000+ seamounts, future sampling must be strategically guided by a global perspective to fill critical knowledge gaps and target understudied regions and types of seamounts. Thus, in addition to new sampling, CenSeam will also work to consolidate and synthesize existing data. In many cases, these data are functionally inaccessible to the scientific community, being distributed in hundreds of publications, "grey literature" reports, and unpublished institutional holdings. Accessing and analysing these data for emergent patterns (and using them to help guide future research) will be an important means of increasing our knowledge of seamount ecosystems.

It is proposed that CenSeam will provide the framework needed to integrate, guide, expand, and leverage off these efforts in order to build towards a global understanding of seamount ecosystems and their biodiversity.

CenSeam science priorities: the "knowable unknowns"

Despite research efforts to date, there still remains much to be learned about seamount ecosystems. The August 2003 CoML seamounts workshop concluded that individual research programmes operating independently would not readily provide the required information to address key research and management questions regarding the dynamics and functioning of seamount communities, and the workshop moved to identify priorities for a global research programme. These questions will form the science foundation of CenSeam. (For more complete details, see the workshop report: Stocks et al., *in press*; seamounts.sdsc.edu/workshop). Overall, CenSeam will seek to answer:

What roles do seamounts play in the biogeography, biodiversity, productivity, and evolution of marine organisms and what is their effect on the global, oceanic ecosystem?

This question is broken down into the following specific research themes:

A. *What factors drive seamount community structure, diversity, productivity, and endemism, both at the scale of whole seamounts and individual habitats within seamounts?*

The biodiversity of benthic fauna on seamounts can be high, but community composition and structure can also vary considerably between seamounts, even those in close proximity. Rates of endemism can be high, but again variable between seamounts. We want to determine what factors (e.g. depth, shape and size, location, spatial isolation, surface productivity, hydrology, geological age, substrate type, etc.) influence seamount biodiversity and communities. Can this understanding be used to predict the community composition and structure on unsampled seamounts?

B. *What are the key processes influencing the differences in communities observed between seamount and non-seamount regions, among seamounts, and among habitats within an individual seamount?*

The preceding questions in A are broadened here by moving to a larger spatial scale of function. To what degree are seamount communities genetically isolated and their composition limited by dispersal and recruitment dynamics? To what degree do seamounts interact with surrounding deep habitats? In other words, what is the ecological and spatial "footprint" of a seamount in the surrounding ocean with respect to productivity sources and sinks, food web connectivity, and physical factors that influence biology (e.g., shedding productive eddies)? Broadening the scale further: What part of the ocean's biodiversity is held by seamounts? Are seamounts significant centres of speciation in a global context? Are they sources or sinks of productivity? What are the key processes?

C. What are the impacts of fisheries on seamount community structure and function?

Many offshore fisheries are known to exploit seamounts, but our knowledge of how many seamounts, where, and how frequently they are fished, is lacking on a global scale.

In some parts of the world effort is high on seamounts – for example in the New Zealand region, over 250 out of 800 seamount features are fished by bottom trawl, and about 80% of those at orange roughy depths (500-1,000 m) are regularly trawled (Clark & O'Driscoll, 2003). The key questions under this theme are: to what degree do seamounts represent already-impacted systems? What is the dependence of various fisheries on seamounts? What is the likely impact of fishing activities on seamount communities?

The questions posed under these themes are included in several research programmes on seamounts in various regions of the world. For example, the New Zealand seamounts programme has primary objectives to address issues of seamount biodiversity and function, and the impacts of fishing. The OASIS project in the North Atlantic has five objectives, all of which contribute largely or in part to the questions posed above. Similarly, objectives of the "Mountains in the Sea" research on the New England seamount chain are to address questions of biodiversity, species relationships, and physical impact of bottom trawling. Geological studies and community ecology are the focus of the 2004 Gulf of Alaska seamounts expedition. The list could go on, but the important point is that there are a lot of seamount-directed studies that are, to an extent, "doing their own thing". CenSeam can have a pivotal role in helping to coordinate such programmes. CenSeam itself will not necessarily directly answer all of the questions in terms of funding the active research, but will provide the focus for the requisite data collection, and subsequent analyses of these data, at a global scale.

Proposed goals and activities

The overall goal of CenSeam is to provide a framework to coordinate existing and planned programmes for maximum benefit, catalyse new seamount sampling activities, align data collection where possible, ensure that opportunities for collaboration between programmes are maximized, and integrate and analyse incoming information to create new knowledge.

Goal 1: Coordinating and expanding existing and planned seamount research

A main goal of CenSeam will be to maximize the synergies and effectiveness of the many existing and planned seamount projects. Activities will include:

- Standardized methods and data reporting. Existing methods being used will be discussed, and means of standardizing these, when appropriate, will be explored. New technology will also be considered (e.g., multibeam mapping, AUVs). It is recognized that sampling methods will vary depending on the resources available to the particular programme, but gear modifications, sampling design, sampling collection protocols, and the type and format of data recorded should be made as consistent as possible.

- Community networking. This will involve a listing of experts interested in participating in seamount research, forming agreements with other research programs, informing the global science community of ongoing or planned activities, creating an electronic newsletter and bulletin board, and obtaining information on existing raw samples/data.

- Mini-grants to expand the scope of otherwise-funded expeditions. This might cover addition of taxonomic staff to a survey, or funding further examination of samples taken.

Goal 2: Fostering new field expeditions

The programme will identify priority regions and opportunities for attracting funding to launch new field programmes. CenSeam will assist the community to assemble the resources and expertise required for successful projects by (1) identifying regions or types of studies that are of high priority to the global knowledge base and which have potential for funding; and (2) providing seed funding for development activities. A CenSeam network has the potential to build multi-institution and multi-national collaborations that are expected to be highly competitive for funding. Planned activities under this goal include:

- Community workshop. An initial workshop is planned for 2005, and this will link with a proposed seamount ecology meeting in May 2005 in the Azores. A side meeting to this workshop would work to prioritize regions and types of studies, identify proposal opportunities for new seamount expeditions, and assemble working groups to pursue those proposals.

- Proposal planning support. Following the Community Workshop, target regions will be identified for proposal writing activities, and CenSeam would support such writing efforts.

Goal 3: Data management and data analysis

As important as new field sampling is, the research will be incomplete without synthesizing and analysing both existing and incoming data to create new knowledge about the patterns and processes operating on seamount communities. Activities will include:

- Seamount database and information systems. We will expand the existing, open-access SeamountsOnline database and information system (Stocks, in press; also seamounts.sdsc.edu) to include data from more seamounts, bathymetry maps, and descriptive information on sampled and unsampled seamounts (geological characteristics, age, substrate type etc.). SeamountsOnline is already serving data freely through its own website and through the Ocean Biogeographic Information System (OBIS) and will, at least initially, continue to serve as CenSeam's primary contribution to OBIS.

- Mini-grants for data digitization/preservation/translation/quality control. Many large and high-quality datasets are not currently available, being in undigitized form or insufficiently documented for use. Support will be given to making these data available.

- Comprehensive analysis and synthesis. A group will be established to evaluate and review available data and analysis techniques. Identification of key "missing" data is a priority. Guided by the programme's science priorities, the focus will be on understanding patterns in seamount biodiversity, endemism, community structure, and genetic structure. The first activity will be descriptive: what are the patterns, where are the hotspots, where are the gaps? The second phase will be mechanistic: relating community structure to factors such as geological age, depth, geographical location, hydrology, larval dispersal, and evolutionary processes.

Goal 4: Public education and outreach

The general public, non-seamount scientific community, environmental groups, the fishing industry, and resource managers all have an interest in the results of scientific research on seamounts. Activities will involve:

- Public website. The programme website will have a section targeting outreach, including public-level descriptions of the programme and seamount ecology, and video and still imagery from seamounts. It will be accessed through the CoML portal, with linkages to the CenSeam web pages.

- Broad publications. CenSeam will use publications in multiple venues to raise awareness of seamount science and CenSeam programme outcomes.

- Supporting the CoML education and outreach effort. CenSeam will provide materials to the CoML outreach office.

- Museum exhibitions or displays are also a possibility.

As with all CoML Field Programmes, CenSeam will extend until 2010. By then, we expect to have created a strong, united seamount research community that has made (1) significant progress towards globally representative sampling of seamount types and locations (2) significant progress on the science questions outlined above; and (3) a comprehensive new understanding of seamount ecology to contribute to the CoML's final report.

How does the proposed CenSeam relate to crustal mining and the International Seabed Authority?

A key issue in any consideration of crusts mining is the potential impact on the fauna associated with the seamount substrate. There can be direct removal of the hard substrate community in areas that are mined. Disturbance of the substrate, and suspension of sediment that can settle and smother animals, needs to be considered also. Seamount communities can be dominated by slow-growing long-lived species (e.g., deep-sea corals and sponges), and these can provide a complex and structured habitat for the community. Recovery from disturbance can be slow.

There is a clear need to establish environmental baselines in any areas where mining could be of interest. CenSeam can have an important function in regions of seamounts, and other CoML programmes can be relevant when considering other specific habitat types (e.g. hydrothermal vents and seeps (ChEss), deep ocean seafloor (CeDaMar)), or geographical regions (e.g. Mid-Atlantic Ridge (MAR-ECO), Gulf of Maine (GoMA)). CenSeam will be involved in coordination of research activities, and promotion of a broader ecological base to seamount research. This will include physical structure and processes, and although CoML has a focus on biodiversity, an understanding of this requires information on the habitat. The geological structure and composition of the seafloor on seamounts is clearly critical to determining species distributions. The expansion of databases such as SeamountsOnLine (and Ocean Biogeographic In formation System (OBIS)) will be important in providing a summary of available information on a habitat or region. Available data in the short-medium term will in many cases be inadequate to avoid further study to define and describe baseline environmental conditions of seamount features which have cobalt rich ferromanganese crusts, but they provide the mechanism whereby global patterns in physical and ecological characteristics can be derived.

There is often little overlap in the scientific disciplines associated, on the one hand with geological investigation and mining, and on the other animal resource management (whether fisheries or biodiversity). There can also be lack of communication between government agencies charged with exploitation, and those responsible for conservation. However, the need to integrate the scientific disciplines, and the management objectives, are rarely disputed, and forums such as the 2004 workshop hosted by the International Seabed Authority is a clear step forward with its wide-ranging topics and diverse attendance. CenSeam, and other CoML programmes, will willingly work with the Authority in order to maximize data collection and collation, and ultimately improve our knowledge base and understanding of seamount ecosystems, and hence the impacts of mining.

ACKNOWLEDGEMENTS

The support of the International Seabed Authority in preparing this paper is acknowledged. Although the CenSeam programme is still at the proposal stage, CoML was willing to have it presented at the workshop, in order to gain wider feedback.

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SUMMARY OF THE PRESENTATION

Dr. Clark stated that his presentation would consist of a review of seamounts, remarks about the Census of Marine Life (CoML), and remarks about its programme and activities relating to seamounts (CenSeam). He said that he would also provide information on Seamounts Online, and inform participants about how CenSeam could help the International Seabed Authority with the evaluation of impacts of mining cobalt-rich ferromanganese crusts deposits in the Area.

Dr. Clark informed participants that CoML is a major international programme established to explain the diversity, distribution and abundance of marine life. Its lifespan is until 2010. Dr Clark said that Cen Seam is concerned with where organisms lived within the Oceans, and why their living conditions are suitable. He stressed that CenSeam's work is not just about biodiversity, because the broad goal is to understand the processes, dynamics and functions of the ecosystems. CenSeam's work therefore, covered biology, and included the physical, geological and chemical components of these ecosystems. He said that many institutions use the results of CoML programmes. He mentioned that there are no hard and fast boundaries between different habitats, and stated that without the ability to compare fauna in adjacent seamount habitats, knowledge of the fauna of specific seamounts is of limited use.

Dr. Clark noted that CoML projects are not discrete and merely subject oriented, but overlap, as components attempting to provide an overall picture of the oceans. He said that the word "biodiversity" conjures images of charismatic fauna, such as sponges, corals and crabs. He also said, however, that even when restricted to the productivity of the benthic environment and diversity, most of the picture is missing in this image. He said that organisms found in the top layers of the sediment are as important to biology as they are to the issue of mining crusts.

According to Dr. Clark, in New Zealand there have been discussions about the definition of seamounts in the fishing industry because the industry is sensitive to accusations of it as a destroyer of seamounts. He said that if an elevation of 1,000 metres defines a seamount; most of the fishing industry is exempt because it is fishing on topographic peaks below this elevation. Recalling a previous presentation, Dr. Clark said that recently, the use of the term seamount is not only with regard to topographic peaks on the seafloor, but to describe peaks of volcanic origin. Dr. Clark stated that "Seamounts" do not have to be volcanic in origin, as there are two large seamounts off New Zealand that are rifted continental blocks. Dr. Clark felt that the definition was quite important, and informed participants that the classic seamount definition separates topographic peaks on the seafloor into seamounts, knolls and the smaller pinnacles, depending on size.

He said that based on ecology, scientists do not know the effect of elevation on biodiversity, or how the benthos or fisheries systems associated with these features function. He said that in the waters around New Zealand, some of the most spectacular big water fauna are on relatively small features. He noted the differences in the faunal composition from shallow to deep water. He also said that although elevation might affect faunal composition, it does not appear to have a direct effect on the productivity of the system.

According to Dr. Clark, seamounts are widespread and prominent features of global topography. He said that seamounts could be a source of speciation and species radiation if there is localized distribution of species. He stated that there are significant differences in fauna on seamounts in close proximity.

Dr. Clark suggested that another reason why diversity could be high on seamounts in a biogeographical context is the complexity of the habitat types that occurred on them.

Dr. Clark informed participants that a CenSeam Seamount Planning Meeting in Oregon in 2003 concluded that there is a compelling need coordinate existing seamount efforts, synthesize existing knowledge and promote future field efforts. He said that the meeting set as overall objectives, an examination of the functioning of seamounts in both a global and individual seamount context, and the investigation of the productivity and evolution of seamounts. An additional objective was the interrelation of seamounts with the surrounding water column and seafloor.

Dr. Clark said that CenSeam is focussing on three major themes: a description of organisms found on seamounts, and the processes and functions occurring on them. He suggested an approach that determines the factors that drive community structure, diversity, productivity, and endemism, both at the scale of individual seamounts and habitats within the seamount.

Dr. Clark noted that because seamounts are highly variable, it is not possible to generalize about their structure, function and composition. He said that since there are millions of these features in the world's oceans, a serious and coordinated research effort is required to try to piece enough parts of the jigsaw puzzle for valid conclusions to be drawn about seamount biodiversity. He emphasized that to examine the biodiversity of seamounts it is necessary to incorporate the data on the physical environment associated with them. In this regard, he informed participants that CenSeam, as part of its examination of the factors that affect community composition, would incorporate data on the physical environment (geological origin, substrate type, etc.) in its analysis of the biodiversity of seamounts.

According to Dr. Clark, the second will be a change in scale of elements such as isolation, dispersal, and recruitment during investigations of how seamounts affected the wider ecosystem, and the third, the impact of the exploitation of fish and mineral resources on the benthic habitat. Among the unknowns identified by Dr Clark are how many seamounts are fished globally or had been fished; to what extent fisheries in the high seas depend on seamounts, and to what extent human activity could be managed to allow for both exploitation and conservation.

Dr. Clark said that the CenSeam Programme is looking at four areas for its key activities:

- *Coordination of existing research efforts and their expansion as required*.

  He said that one of the aims from the CenSeam workshop is to standardize methods and data reporting among the seamount programmes. In this regard, he said that there is active seamount research going on around the world and CenSeam wants to coordinate as much of the data collection as possible. He also said that while it might not be possible to standardize all methods, it should be possible to standardize methods for some components.

- *Fostering new field expeditions in the next few years.*

  Dr. Clark informed participants that fostering new expeditions would be an outgrowth of community workshops. He suggested bringing the seamount community together and focussing it on knowledge gaps in the global coverage to initiate new research in areas, which without international umbrella programmes like CenSeam, might not get off the ground.

- *Managing existing and future data, and synthesizing such data.*

  Dr. Clark said that data management would be crucial to progress in the next few years. He said that part of the effort would be to update CenSeam's database, expand it to include physical data, and to convert available analogue data into digitalized data to create a globally accessible database.

- *Public education and outreach.*

  Dr. Clark stated that in addition to CenSeam's enthusiasm for publications and outreach, these activities are important to obtain acceptance of CenSeam's work. He suggested a role for public and museum displays in demonstrating the high quality research CenSeam scientists carry out.

Dr. Clark said that while CoML might not have been able to offer much in terms of the hard outcomes for crust mining at the workshop, CenSeam would assist the Authority by providing a good understanding of biodiversity in seamount faunal communities. He said that through the standardization of sampling and improved sampling technologies, a better understanding of the biodiversity in seamounts should become available to the Authority. He noted that with the addition of data and information on the physical environment, CenSeam would enable people to learn about the linkages between the biology and the geology of seamounts. With regard to environmental baselines, Dr. Clark said that coordination of scientific interest would be important, particularly for determining what is required for baseline descriptions and for analysing the results. He suggested that the analysis of results should not be on an ad hoc basis, and emphasized the need for a global perspective.

Dr. Clark concluded his presentation informing participants that CoML would consider a revised CenSeam proposal in October 2004 that he hoped would begin in January 2005.

SUMMARY OF THE DISCUSSIONS

A participant pointed out that, although mining of cobalt-rich ferromanganese crusts is yet to take place, commercial fishing on seamounts has destroyed many habitats on seamounts. The participant wished to know what actions international organisations have taken to redress this matter. In response, Dr. Clark said that a proposal was submitted to the United Nations General Assembly in June 2004, requesting a total moratorium on deepwater fishing in the high seas. He informed participants of the recommendations that by the United Nations Informal Consultative Process on Law of the Sea (UNICPLOS) that dealt with the matter. Another participant pointed out that while the recommendations of UNICPLOS did not mention the moratorium on deep-sea trawling, the consensus reached was to defer the matter to Regional Fisheries Management Organizations and see whether they could implement the moratoriums at the regional level.

Dr. Clark pointed out that by definition, the areas affected would be seamounts. He stated that in the short term, the UNICPLOS recommendation would force countries to look at regional organizations more seriously. He said that following 15 years of debates about fisheries in the Matasmic Sea, New Zealand and Australia are in serious discussions about forming a joint regional management organization, although this was not fisheries specific. He said that even if the moratorium did not progress as quickly as hoped, it would create some movement on a national basis, which would affect some part of the high seas. A participant noted that there has been a lot of discussion about protected areas in the high seas beyond national jurisdiction. The participant noted that most of the concern is with seamount fisheries. The participant said that if states declared marine-protected areas in the high seas, particularly on seamounts, they would be in conflict with the mandate of the Authority. According to the participant, this is because the Authority managed the deep seabed, which includes seamounts.

Another participant pointed out that it is very difficult to get samples with traditional rock-dredging techniques, as sledges did not sample crust, and suggested the use of videos.

Part IV

OTHER RELEVANT RESEARCH

Chapter 14 Other programmes of relevance to the establishment of baselines, to the development of appropriate databases and to an increased understanding of the natural variability of polymetallic sulphides ecosystems: studies carried out by Mexican Research Institutions

Professor Elva Escobar-Briones, Professor and Head, Biological Oceanography, Biodiversity, Deep-Sea, Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnologia, México City, Mexico

Chapter 15 Benthic Characteristics of the deep Indian Ocean

Dr. Baban Ingole, Biological Division, National Institute of Oceanography, Dona Paula, Goa, India.

Chapter 16 Amounts of megabenthic organisms in areas of manganese nodules, cobalt-rich crusts and polymetallic sulpides occurences

Dr. Tomohiko Fukushima, Researcher, Ship and Ocean Foundation, Tokyo, Japan

CHAPTER 14 OTHER PROGRAMMES OF RELEVANCE TO THE ESTABLISHMENT OF BASELINES, TO THE DEVELOPMENT OF APPROPRIATE DATABASES AND TO AN INCREASED UNDERSTANDING OF THE NATURAL VARIABILITY OF POLYMETALLIC SULPHIDES ECOSYSTEMS: STUDIES CARRIED OUT BY MEXICAN RESEARCH INSTITUTIONS

Professor Elva Escobar-Briones, Professor and Head, Biological Oceanography, Biodiversity, Deep-Sea, Universidad Nacional Autónoma de México, Instituto de Ciencias del Mar y Limnologia, México City, Mexico

Introduction

Mineral resources are an important part of natural resources, and an important material foundation for the development of Mexican society. The ocean seafloor contains vast deposits of sand and gravel, carbonates, sulphides, phosphorites and diverse minerals that are useful for public works and the industry. Industry in the world is looking to the ocean for critical building materials as land supplies of sand and gravel are depleted and marine aggregate is also used for capping contaminated soils and sediments in coastal habitats. The increasing demand for resources requires that policies are developed to ensure sound environmental practices during the exploration and exploitation processes.

Cost-effective recovery of ocean oil and gas resources in the continental shelf habitats is the main activity carried out in the oceans of the country, long-term development should be considered within a national energy policy plan for Mexico that balances both the concerns for the environment with the energy security for future generations. Several marine resource development and environmental protection issues and the related scientific research programmes remain to be discussed among the federal, state governments, industry, scientific institutions and the general public.

The deep-seafloor ecosystem, one of the largest on the planet, covers roughly 60% of the Earth's solid surface and has been considered to be both an unexplored wilderness and a resource frontier (Rona, 2003). The potential resources of the deep sea derive from sources on land and in ocean basins; our scientific understanding of the knowledge of their diversity and distribution is poor and many remains to be explored. The processes that involve microbial life in the deposited minerals are slowly emerging.

The current view of the deep-sea is that of an ecosystem relatively homogeneous in space and time, punctuated by biological pulses of disturbance and organic enrichment that expand scales ranging from centimetres to thousands of kilometres. Physical heterogeneity associated with the polymetallic sulphides occurs at scales ranging from nodules on the seafloor to seamounts and crusts and vents at mid-ocean ridges. Low amounts of productivity, of physical energy and of biological rates create an unusual suite of conservation challenges in the vastness of the soft-sediment deep sea relative to the shallow-water seafloor habitats. The deep-seafloor is characterized by slow currents and sediment accumulation rates in the absence of sunlight; however, they exhibit high local species diversity making the habitat more sensitive to human impacts. These deep-sea rocky, highly reducing, microbially-mediated substrates foster communities significant in total area.

Manganese nodule mining has been recognized to be the largest-scale human activity to directly impact the deep-seafloor. The mining over much of the abyssal seafloor can yield habitat loss and local extinction of the nodule fauna, which differs markedly from the fauna of surrounding soft sediments. Most of the research carried out into deep-sea mineral exploration and extraction in Mexican exclusive economic zone has concentrated on manganese nodules.

Polymetallic sulphides deposits constitute a minor percentage of the deep-seafloor and are considered among the rare habitats in the enormous expanses of the deep sea. These occur in crusts on seamounts, at venting deposits and nodules that occur in the abyssal plain. Seamounts and hydrothermal vents have been considered isolated habitats in the deep ocean that differ from typical deep-sea soft sediments in hard substrate and high levels of productivity. These structures are numerous, aggregated and between groups widely spaced. Many of these systems fuel their highly diverse microorganism consortia by reduced chemicals such as hydrogen or with a physically forced large organic-matter flux yielding high biomass communities.

Manganese and cobalt crusts found near ridges are formed through similar hydrogenetic processes that create manganese nodules. Polymetallic sulphides occur in the form of massive consolidated sulphides mostly precipitated at hydrothermal vents. Polymetallic sulphides are common at ocean ridges; limited research has been conducted in the exclusive economic zone of Mexico. The Mexican government foresees these massive consolidated structures among primary economic targets in inactive hydrothermal vents where unstudied bacterial consortia are known to occur and that may offer a biotechnological resource. Environmental impact studies are needed in the specific vent fields of commercial interest to predict and effectively manage the deleterious effects of the deep-sea mining of massive sulphides.

The cost of extraction and the market value of the minerals are still far away from a mining reality to the country. If offshore mining should take place in the Mexican exclusive economic zone, it is far more likely to be in the Pacific and the Gulf of

California than in the Gulf of Mexico and northern Caribbean sites because potential richer deposits are closer to land. Further studies are needed in different disciplines to evaluate the sites with potential marine offshore mineral resources. As in many other seafloor issues large efforts are still needed to have a better knowledge of Mexican deep-seafloor as well as a significant development in legal framework.

Mexico's exclusive economic zone, extension and percentage of depth zones distribution

The exclusive economic zone in Mexico covers 2,892,000km², or an area larger than the terrestrial territory of Mexico. The seas in Mexico include four major seas: The eastern tropical Pacific, the Gulf of California, the Gulf of Mexico and the northern Caribbean Sea which expand along 11,590 km of littoral line in which an area of 3,000,000 ha is encompassed by coastal lagoons, 375,00 km² are on continental shelves and 5,083 km² are oceanic islands (Arriaga Cabrera et al., 1998). The deep-sea ecosystems represent over 70% of the exclusive economic zone and host a variety of habitats including hydrothermal vents, methane seeps, soft sediment extensions with manganese covered hemipelagic seafloors, seamounts, salt domes, dorsals, bottoms with minimum oxygen zones, transverse fault mountain ranges, subduction trenches, borderline elevations, asphalt volcanoes and other habitats yet not described. Many of these habitats are of utmost relevance for Mexico due to the occurrence of biotic, mineral and energetic resources and a potential large biodiversity of organisms that may contribute in the near future as resources for the biotechnology and pharmaceutical industry. Our knowledge is currently limited and the research institutions are contributing through collaborative research efforts with basic science to the exploration and characterization of these habitats, their resources and biotic communities.

Manganese nodules: Geographic occurrence of manganese nodules, and studies in the Eastern Pacific exclusive economic zone of Mexico

Geology and geochemistry

The abundance, chemical composition and source of the metals have been evaluated in nodules from the EPR-Clarion-Clipperton-Revillagigedo Archipelago area and continental slope and abyssal plain by Carranza and colleagues (1986, 1987). The largest abundance, 11 $kg.m^{-2}$, occurred in the Mimar Depression. These nodules were smooth and granular. The chemical composition and ratio of occurrence, in surface and buried nodules, of major elements is a function of geographic position, it varies with the geographic location and suggests different chemical processes that originate the nodules. The highest nodule abundance has been correlated with the highest concentrations of Fe, Mn, Cu, Ni and Co in the sediment where the slowest currents were recorded and in the neighbourhood of hydrothermal processes. An unusual relationship between Fe and Mn was related to the volcanic activity at Clarion. Previous studies recorded that the abundance, size, structure and composition are determined by the nature of the sediments and supply of materials for their growth. The sedimentation rate in the region based on radiolarians varies from 1.09 to 2.72 cm per1000y^{-1} (Martinez Lopez, 1989).

The nodules have been classified according to their Mn/Fe ratios and based on the concentrations of Mn, Ni, Co, Fe and Cu; their relative concentrations ranged in the order of 13-34% of Mn, other elements occurring in concentrations of less than 14% (Carranza –Edwards et al., 1986, 1987). Nodules with higher concentrations were named type A nodules and occurred in the southernmost section of the area studied. Nodules with higher Fe and Co concentrations occurred in the northern section of the area studied and were named type B nodules. Nodules of type A originate from diagenetic reactions in the southern sector of the area of study in contrast with type B nodules that were generated from the sea water-sediment interface chemical reactions in the northern section of the area of study (Rosales Hoz & Carranza Edwards, 1990).

The occurrence of nodules abundance was correlated with the metal concentration in superficial and sub-superficial sediment. The metal content in the sediment cores correlated with the location of the different stations along transects from the EPR, through the continental slope and into the abyssal plain. The comparative analysis of Cu, Ni and Co concentrations in surface and subsurface sediments and nodules revealed differences between EPR and the other two areas. The higher concentrations of organic matter (0.05 to 1.6%) and Zinc occurred at EPR where the lowest Fe and Mn concentrations occurred (Rosales Hoz & Carranza Edwards, 2001). The carbonate content in the cores varied from 1.1 to 3.2%, silt being the major grain size component in the cores and varying with distance from the continent (Rosales Hoz & Carranza Edwards, 1993). A factor analysis of the metal composition of the sediment cores recognized four factors accounting for 74.3% of the sample variance where the main processes of growth were hydrogenetic and diagenetic (Rosales Hoz & Carranza Edwards, 2001). The microscopy observations of surface sediments in the Clarion area revealed materials from volcanic origin additional to hemipelagic components. The proportion of the different components varies between EPR, Mimar Depression and an intermediate location. These sediments are enriched in Ni and Co and their concentrations related to hydrothermal influence and the seafloor sediment chemical composition (Rosales-Hoz & Carranza Edwards, 1993). The sources of metals were recorded based on the Mn:Al ratio as a function of the relationship between the composition and the seafloor environment where the nodules were formed. The Mn deposition from hydrothermal plumes was recorded to generate anomalies, concentrations in areas with abundant nodules reached 0.6% Mn content. Trends with depth in the sediment and among EPR, the continental slope and the abyssal plain in the eastern tropical Pacific were recorded. The differences in both nodules and sediment chemistry and mineralogical composition correlate (Rosales Hoz & Carranza Edwards, 1990).

Studies in the Gulf of Mexico, exclusive economic zone of Mexico

Although the ferromanganese nodules are present in the Gulf of Mexico (McKelvey & Wang, 1970, Emery & Uchupi, 1984) where they occur widely distributed on the deep-seafloor, they are less densely concentrated in the soft sediments and have lower percentages of manganese and of the associated elements of economical importance. The Gulf of Mexico is best known for its widespread oil and gas resources to which dense chemosynthetic communities are associated. The oil and gas resources are a major contribution of the basin (Nehring, 1991).

Polymetallic sulphides: Geographic occurrence of polymetallic sulphides (hydrothermal vents, seamounts), and studies in the Eastern Pacific exclusive economic zone of Mexico

Massive polymetallic sulphides have been found in the Pacific EEZ both in the EPR and the Gulf of California. The deposits in the Pacific and Gulf of California rifts are rich in copper and zinc sulphides and other minerals that have been considered modern analogues to the Cyprus copper ores (Hekinian et al., 1980). At these locations the spreading rate is fast (6cm.yr-1), a relationship between magma flow and polymetallic sulphides has been recorded (Edmond et al., 1982). Crusts of iron and manganese oxides and sulphides have been recorded in the Guaymas Basin on venting sites of the rift trough (Lonsdale et al., 1980). Copper and other polymetallic sulphide deposits have been recorded on the abyssal seafloor in the EPR and seamounts nearby (Hekinian et al., 1983b).

Shallow hydrothermal vents

Geology and geochemistry

Submarine hydrothermal vents, related to the volcanic activity from the East Pacific Rise occur along the continental margin and are high-temperature, deep-sea systems associated with recent rifting activity in the Mexican exclusive economic zone. The shallow coastal hydrothermal activity has been recorded in Punta Banda (Vidal et al., 1978, 1981), Bahia Concepcion in Baja California (Prol-Ledesma et al., 2002, 2003a), and in Punta Mita off Jalisco in the Pacific coast of central Mexico. The occurrence of shallow hydrothermal vents in western Mexico, related to the recent tectonic regime and the hydrothermal activity, is restricted to regional faults that channel meteoric water deep into heat flow areas. Its occurrence related to the tectonic evolution of western Mexico has been partially explained by seismicity and heat flow results (Prol-Ledesma & Juárez, 1986; Ferrari et al., 1994; Ferrari et al., 1997). In the case of Bahía de Banderas area where these shallow water hydrothermal vents occur, strong crustal stress has been suggested as a result of the convergence direction of the Rivera Plate (Kostoglodov & Bandy, 1995).

Submarine discharge of geothermal fluids and gas occur in all three systems. The shallow water hydrothermal vent fluids reach temperatures of up to 87°C and produce hydrothermal deposition of minerals (Prol-Ledesma, 2003). The chemical composition of the vent water is similar among all three locations despite the distinct geological setting. The chemical composition of the thermal fluids discharged by these shallow submarine vents is controlled by the mixing of coastal seawater with meteoric water. Enrichment in Hg has been observed in the altered rocks of submarine hydrothermal systems and the presence of cinnabar has been confirmed in the Punta Mita submarine hydrothermal system. The interaction of the hot water with organic matter in the layers of sedimentary rocks produces nitrogen and methane, and mercury and other elements are leached from the volcanic and sedimentary rocks. Mercury remains in solution in the thermal fluid until it reaches the seafloor (Prol-Ledesma et al., 2002). These hydrothermal manifestations are distributed along a submarine fissure in basaltic rocks. The water discharged by the vents is more dilute than seawater and is depleted of precious and base metals. The vent gases are nitrogen (>80%) and methane (~12%). The carbon isotopes indicate a thermogenic origin of methane (Prol-Ledesma et al., 2003b).

The chemical composition of the precipitates is enriched in Sb, As, Ba and Hg. The isotopic composition resembles deep vent samples (Prol-Ledesma, 2003). In a first stage of the hydrothermal vents that occur in Bahia Banderas carbonates are deposited as calcite and dolomite followed by apatite and barite that occur as veins within layers of sequential deposition of sulphides. Sulphide and native copper deposition have been attributed to shallow hydrothermal activity with formation of some type of exhalative deposits (Núñez-Cornú et al., 2000). Vents are not well developed here, probably due to destruction by recurrent explosive events or by storm erosion.

The coastal hydrothermal submarine vents that occur near Punta Mita are partially covered by recent sediments. The hydrothermal venting produces calcareous tufa mounds, where pyrite is the most abundant sulphide mineral that precipitates around the submarine hot springs. The sulphur isotopic signature and composition of pyrite suggests that the source of sulphur is microbially-reduced sulphate seawater. Another potential source includes transport by the hydrothermal solution that may originate by thermochemical reduction of seawater sulphate or from the leaching of the underlying rocks (Alfonso et al., 2003).

The mounds in Punta Mita consist of travertine-like calcite aggregates that develop around the main submarine hot springs amidst a hydrothermally-altered basaltic rock. Two main calcite generations are texturally recognizable. Microbial communities may have induced precipitation of calcite through microbial methane oxidation. Barite, sulphides form by direct precipitation from the hydrothermal fluid. The Punta Mita hydrothermal carbonate mounds form under high temperatures in microbially-induced carbonate mineralization similar to cold seep carbonate formation (Canet et al., 2003).

Shallow water surficial sediments off Vizcaino Bay, Baja California suggest different lithologies and sources of the detrital components deposited. The geochemical partition analyses, the organic carbon concentrations, total carbonates support that the association with organic matter in areas under influence of upwelled waters and in the organic-rich deeper areas controls regional distribution of non-lithogenic elements. Different precipitation processes act in waters above continental margins and affect the presence and concentrations of specific elements. Detrital Mn and Fe, Cu, Cr, Ni and Zn are associated with peninsular mainland sediments and lithogenic detritus respectively (Daessle et al., 2000).

Deep hydrothermal vents

The vent environments are metal-rich due to the presence of extensive sulphide deposits and precipitation of metal sulphides, in addition of the discharge of vent waters. The Guaymas basin is located inside the Gulf of California and represents one of the segments of a spreading centre of the oceanic floor located along the mid-ocean mountain ridge of the eastern Pacific, extending from north to south following the eastern edge of the Pacific tectonic plate. The Guaymas basin is characterized by sedimentary inputs essentially derived from terrigenous detritus (Calvert, 1966; Shraeder, 1982) and supports a complex deep-sea sulphur-based chemosynthetic ecosystem.

Geophysics and geology

<u>East Pacific Rise, 21^{0}N</u>

Rock and sediment polymetallic sulphide samples from the 21° EPR hydrothermal vent systems were collected during the RISE mission and analyzed using x-ray fluorescence and diffraction, electronic microscopy and atomic absorption strategies to determine the origin of massive sulphides and evaluate the zinc, copper and iron concentrations amongst other metals. The study concluded that sulphides originate from hydrothermal activity and are formed by sphalerite, pyrite, pyrrhotite and chalcopyrite amongst others. Zn, Fe and Co occurred in largest amounts, Zn and Fe has values of 42.7 and 31.4% and is associated to pyrite. Cu occurs associated to chalcopyrite. Ag and Pb coexist and increase in similar ratios. Ni occurs in low amounts and in variable ratios and is associated with Co. Mn occurs associated with Fe with larger amounts in venting fluids. Cr occurs in ultra-basic rocks in deeper layers. Cd is the next element after Ag and may occur associated to sphalerite. Ba, Sr and Ca are associated to chalks and sulphites covering the vent structures. A large faunal assemblage occurs associated to the active and non active venting structures and includes chemoautotrophic bacteria in large densities and giant invertebrates that include polychaete worms, clams and crustacean (CYANAMEX, 1980.).

Guaymas Basin

The Gulf of California is characterized mineralogically by primary polymetallic sulphides and secondary minerals e.g. gypsum, barite, etc. A geochemical study of superficial sediment from the Guaymas Basin from the San Andreas transform fault system was carried out using x-ray analysis, SEM. The results recognized the presence of metals from hydrothermal vent origin and the presence of light and heavy oils generated from the hydrothermal activity in the central Gulf of California. The presence of sediments rich in organic matter displayed high variability over short distances due to the active tectonic and seismic activity with a high rate biogenic carbon export (Carranza et al., 1990). The northern section of the Gulf is a younger basin lacking shallow hydrothermal fluids that would favour polymetallic sulphides, the dominant components include Li, K, Ca and Ba in contrast with deeper venting sites. Hydrothermal fluids are saltier (Carranza et al., 1990).

Geochemistry

The study by Inzunza et al., (2003) provides data on the concentration and distribution of the heavy-metals Cd, Cu, Fe, Hg, Mn, Pb, and Zn in tissues of adult clams of an approximate age of 11 -14 years. The heavy-metal concentrations showed a decreasing order Zn>Fe>Cd>Cu>Mn>Pb>Hg in the different tissues studied of the clam. The gills accumulated higher amounts of Cd, Fe, Hg, Mn and Zn, the mantle presented the highest concentrations of Cu and Pb. The concentrations of Hg in gonads and the Pb in gills showed an increasing pattern with size and age (Ruelas Izunza et al., 2003).

Biology

The diverse expeditions carried out in the Guaymas basin have provided an estimate of megafaunal species biodiversity of approximately 14 species (Soto and Grassle, 1988). Diverse studies have been carried out on vent microbiological consortia describing the use of natural occurring substrates in the seafloor habitat (Romero Jarero et al., 1996), the food sources of the mega faunal components based on the stable isotopic signatures of tissues, materials and gut contents (Soto & Escobar, 1996; Escobar et al., 1996, 2002). The studies could recognize the endemicity of the faunal components as well as their associations with different symbiotic bacteria and chemosynthetic processes.

Seamounts

East Pacific Rise

Seismic reflection data from two segments of the East Pacific Rise (EPR) at latitude 16°N north of the Orozco Fracture Zone have described a prominent seamount chain with depths as shallow as 1300 m that extends within ~20 km of the ridge with axial depths that rise to 2200 m within a flat, plateau-like summit that broadens from approximately 3 to 4 km wide to 10 km at its widest point (Carbotte et al., 1998). Seismic reflection data have been obtained from ridge-crest seismic lines in the EPR recognizing the depths of the axial magma chamber the fracture and transition zones associated to the hydrothermal activity at the seafloor (Singh et al., 1999). Different axial morphology and crustal magma chambers depths are described for the two ridge segments suggesting accumulation of extrusive rocks (Carbotte et al., 1998).

Baja California Margin

Swath bathymetry and seismic profiles have been recorded along the Baja California margin from 23° to 27°N and have recognized active faulting of recent sediments along the Tosco-Abreojos fault system (TAFS) in the upper-slope of the margin suggesting that it belongs to the western active boundary of a Baja California Block and probably connects with active normal faults across the Baja California tip. The swath bathymetry and seismic data suggest that modern PA-NA plate motion is partitioned between the Gulf of California and the TAFS along the Pacific margin of Baja California (Michaud et al., 2004).

Jalisco Subduction Zone

The area at the northern end of the Middle America Trench, where the Rivera plate subducts beneath the North American plate between the Rivera and North American plates, has been termed the Jalisco subduction zone (e.g., Bandy et al., 1999). This zone consists of a 22-kilometre-wide zone of intense tectonic deformation bounded by undisrupted sedimentary units that has undergone over 500 metres of subsidence. The time of initiation of the tectonism is unknown; its details remain poorly constrained, but are associated with a NW movement of a forearc sliver, result of oblique convergence as recorded from multichannel, seismic reflection profile data from the offshore area of the Jalisco block near Manzanillo (Bandy et al., 2004).

Biology

Biological studies in seamounts in the Eastern Tropical Pacific are restricted to the pelagic and benthic fauna in Volcano 7, a 2.3-km high seamount where their distribution patterns were examined in relation to the lower boundary of the oxygen minimum zone (OMZ). The abundance of fauna is higher and size of the benthic and pelagic components is larger (Wishner et al., 1995). The zonation observed is a result from biological interactions and environmental control with the chemical and organic matter gradients of the OMZ with steep gradients in oxygen and organic-matter availability (Levin et al., 1991).

Exceedingly low concentrations (< 0.1 ml.l-1) encountered on the upper summit of the seamount exert control over abundance, composition and diversity of macrofauna. Large, agglutinating Xenophyophorea protozoans are the dominant epifaunal components on soft and hard substrates of the bathyal seamounts studied by Levin and Thomas (1988) in the eastern Pacific Ocean off Mexico. The occurrence of over ten distinct xenophyophore test morphologies built with sand-size pelagic foraminiferan tests represent previously undescribed species where abundances increase with decreasing latitude. Highest concentrations of Xenophyophorea protozoans are observed on caldera floors at depths between 1700 and 2500 m and play a role in maintenance of infaunal diversity and enhancing the abundance of peracaridea and other invertebrates providing habitat for 16 major macrofaunal taxa and three meiofaunal taxa and represent a functionally important component of deep-sea benthic communities (Levin & Thomas, 1988). Under normal dissolved oxygen concentrations food availability in sediments correlates with meiofaunal and macrofaunal abundance (Levin et al., 1991). The food chain at OMZ interfaces is short (bacteria to zooplankton or benthos) suggesting the intense utilization of organic material exported to the deep-seafloor (Wishner et al., 1995).

Studies in the Gulf of Mexico and the Caribbean exclusive economic zone of Mexico

Other important resources occur (small deposits of uranium, phosphate, sulphur, etc.), of interest are the polymetallic sulphides concentrations reported from salt-dome caprocks that originate from the interaction of metalliferous formation waters with the reduced sulphur produced or trapped in the caprock (Riggs et al., 1991). Deep-ocean metal deposits may occur in the northern Caribbean in the northernmost edge of the Cayman Trough.

Strategic resources and industry development

Marine mining of strategic mineral resources such as manganese, cobalt, polymetallic sulphides, gold, titanium, and other metals is not economically viable in the

Mexican exclusive economic zone and in the Area. Mineral extraction in marine areas of the Mexican exclusive economic zone is expected to begin a few decades from now once the technology to extract these minerals economically is developed, the deposits on land become exhausted, and when environmental considerations limit the extraction in land. Access to minerals in the continental shelf is an attribute of the federal government only. The Direction of Mining within the Secretary of Economy is the regulatory governmental body for managing mineral resources in Mexico, it requires environmentally-sound operations during the drilling and exploitation activities to protect the ocean.

During the last decades, Mexico balanced its industrial expansion with the protection of the environmental through the amendment of existing laws that currently emphasise the sustainable development of the renewable and non-renewable resources including mineral extraction. The environmental law in Mexico is the main body of authority in the Constitution, the laws that include the Federal Law of the Sea and Mining Law for the specific case of this text, regulations, executive orders or resolutions, decrees, agreements and standards or Normas Oficiales that have the force of law.

The Federal Law for the Protection of the Environment was enacted by the Congress in 1982 and included provisions for the protection and preservation of the ecosystem. A new legal framework to protect flora, fauna, soil and water was herewith initiated and included environmental principles with mechanisms for socioeconomic development. New federal environmental laws, such as LGEEPA, still in effect today rose from the enactment of environmental laws by the Congress after the amendment of the Constitution in 1987. LGEEPA and its amendment of 1996 address a wide range of environmental issues including protection of the environment; exploitation of natural elements, both in land and waters within the concept of sustainable development setting forth control and safety measures, penalties for non-compliance, guidelines for environmental impact statements and risk assessment. Elements such as preservation of biodiversity; establishment of protected natural preserves; sustainable use of resources are part of this law with mechanisms for cooperation among authorities, the public and private sector. In particular articles 134 and 170 focus on metal and derivates.

Article 5 of the amended LGEEPA provides that the assessment of the environmental impact of industries such as mining is exclusively of federal jurisdiction. Jurisdiction is based on the territory in which the activity takes place (i.e. underground, bodies of water, mines, seafloor, etc.), the type of activity (i.e. oil, mining, etc.), and the source of pollution (i.e. fixed or mobile, industrial, commercial or for services).

National conservation strategies

Despite the common occurrence of bottoms with manganese nodules, hydrothermal vent systems and seamounts in the Mexican Pacific exclusive economic zone, our knowledge of these three deep-sea ecosystems is poor relative to other marine coastal ecosystems, and future human threats are therefore difficult to predict. These habitats are known, from records in other geographic locations to support highly diverse microorganism and faunal associations and may respond differently to anthropogenic impacts due to the significant geological, physico-chemical and biogeochemical conditions that characterize them. Marine mineral extraction of manganese nodules, polymetallic sulphide ores and crusts occurring on seamounts, represent one of the most significant conservation challenges in the deep sea despite the current limited technology developed. The most valuable ores have been reported to lie in seafloor regions with very local biodiversity and complex interactions processes, lying both within and outside national jurisdictions.

The number of species currently known in Mexican marine habitats and ecosystems where polymetallic sulphide deposits occur is small and is limited to qualitative sampling and records of direct observations in the locations studied. The best-known taxa are crustacean, bivalves and annelids that occur as dominant components aggregated in the major sulphide structures and venting-affected area.

The national strategy includes actions focused in the evaluation of the diversity involve the sectors of both the Mexican government and the society. The main objective of these actions is to preserve the biological diversity of the country focused in the protection and conservation, the valuation of the biodiversity, the acquisition of knowledge and management of the information as well as diverse uses. The above is accomplished through a national information system of the biological diversity which is sustained in the scientific knowledge gathered. The information system is of relevance to the country's decision making, use and conservation of the biological diversity. The information system is based in primary data and metadata where the unit is "specimen-scientific name-geo-reference-date" and allows analyzing the information at different scales in databases. The programmes and this plan are being coordinated by the National Conservation Agency (CONABIO).

The country's initiative to preserve marine life

Mexico's strategy for the conservation of Biological Diversity. The programmes include a set of actions, objectives and strategic lines that represent the different sectors of the Mexican society and are focused to achieve the preservation of the biological diversity of the country. Different strategic directives of protection and conservation, the valuation of the biodiversity, the acquisition of knowledge and management of the information and the diverse ways of their use have been considered.

Country study of the Biological Diversity in Mexico. This programme describes, in a general scope, the biological diversity taking into account, among other reference issues, the degree of knowledge at the genetic, species and ecosystem levels, the processes and forms of use of the biological resources, the elements related to their conservation and the institutional capacity for conservation and sustainable use.

The country study provides a current image of the country's status in the biodiversity issues. It is the baseline for a general multisectorial diagnosis of the current conditions of the biological diversity. This study is being renewed and updated continuously and it includes all actions, projects and programmes being developed in a time span of two to five years.

The National System for Biological Diversity Information in Mexico (SNIB). The objective of SNIB is the recording, management, analysis and transfer of information of the biological diversity in Mexico. This information is of major relevance in the decision making of the use and conservation of the biological diversity sustained in scientific knowledge. SNIB is of strategic importance in a country like Mexico, second country in the world with largest diversity of ecosystems and fourth in species richness with over 500 species of fishery importance; almost 4,000 species with recorded healing properties, hundreds of exotic, invasive species and tens of thousands with biotechnology potential. Law protects almost 2,500 species and hundreds are being used in different purposes by the society.

SNIB is supported by the work of diverse institutions including national and international experts devoted to the study of biodiversity. The creation of this system dates back to the mid 80s where as a mandate to the National Commission for the knowledge and use of biodiversity in Mexico (Comisión Nacional para el conocimiento y Uso de la Biodiversidad, CONABIO) the Law of Environmental protection (LGEEPA) Art. 80 fraction V, established a national information system on the biological diversity and their sustainable use.

CONABIO adopted as an initial model a structure based in primary data in which specimens from scientific collections constituted the main structure of the system that evolved in the integrating concept and unit "specimen-scientific name-geo-reference-date" that allows to analyze the information at different scales when dealing with a large number of records. The SNIB considers three main components: data, analyses and modelling-and-transfer of the information recorded from both national collections and other located in other countries with Mexican specimens. The main products obtained include databases of homogeneous data distributed through the World Web on Biodiversity Information; electronic catalogues of species found in Mexico; digital geographic coverage and metadata; information of remote AVHRR and MODIS sensors with over 4,000 rectified and geo-referred satellite images and over 1500 aerial photographs.

Decision making, management of resources, legislation, law enforcement, permits and creation of natural protected areas are among some of the activities that are carried out with the SNIB information system. Some examples of relevance include the evaluation of invasion routes of exotic species; risk studies of wildlife as threatened by genetically-modified living species or exotic, invasive species; establishing priority areas for conservation of biodiversity; and the support of the position of Mexico in international treaties.

Collections. The effort to document collections started in 1995 through the inventory and diagnostic of the taxonomical activities carried out in Mexican major research institutions, curators, technicians, students and scientists. Databases and directories are the resulting products and geological and biological specimens and materials are deposited in major research institutions including CICESE, UABC, CIBNOR, UNISON and the different campuses of UNAM.

Marine priority regions (MPR). A total of 70 coastal and ocean areas were identified and characterized by their high biological diversity, the use of resources and the lack of biological diversity knowledge. Threats to the marine environment with highest incidence or with significant impact to the coastal zone and seas have been identified for each MPR and suggestions provided to prevent, mitigate, control and cancel the effects of impact. A technical card with general information on their geography, climate, geology, oceanographic conditions, biological information, resource use, economical issues and major concerns for conservation and use is available for each MPR.

The environmental criteria used to define the MPRs include ecological integrity, endemism, species richness, and hydrographic conditions, among others. The economy criteria include species of economical relevance, fishing grounds, major tourist sites, and strategic resources. The major threats recognized so far include pollution, environmental change by resource exploitation and by indirect anthropogenic activities, effects at distance, introduced species.

From the 70 coastal and ocean areas a total of 58 MPR were recognized as areas of high biodiversity, of which 41 were threatened in their biological diversity status and 38 were areas that had a specific use for welfare or development. Eleven areas were highlighted by their lack of knowledge both on biological diversity or their environmental conditions. The MPR form a part of the strategies instrumented by CONABIO that help promote the knowledge and conservation of the biological diversity in Mexico. In the case of the MPR located within areas that have polymetallic sulphide deposits in the Gulf of California and the eastern tropical Pacific Mexican exclusive economic zone a total of 6 MPR were considered that encompass a total of 685,143 km^2. These MPR include hydrothermal vents, bottoms with manganese nodules and seamounts within the OMZ. In the case of the deep-sea MPR located within areas that may have mineral ores and energetic deposits in the Gulf of Mexico 2 MPR have been considered and encompass a total of 137,561 km^2. These two MPR include salt domes, asphalt volcanoes and deep oil and gas reserves. In the case of the MPR located in the northern Caribbean Sea 3 MPR were considered that encompass a total of 2,522 km². These three MPR include seamounts (Arriaga Cabrera et al., 1998).

Natural protected areas. Marine protected areas represent an important mechanism in the conservation strategies of the country. These include coastal zone areas as well as open ocean areas. Both initiatives help to manage the habitats and resources in a wide spectrum of management formats and have been issued into the following categories: Biosphere Reserve, Special biosphere reserve, National parks, Areas for protection for flora and fauna, Areas of protection for natural resources, and other national protected areas at the state level.

Major threats to marine biodiversity

With the exception of those species that have economical importance in the region; shrimp, lobster, abalone and offshore fishes, the knowledge of the biology of other species has been poorly documented. Among the main activities that could place the species in threat are: oil spill, mining, deep-sea fishing, disposal of wastewater and dumping of materials, unsustainable scientific activities.

Policy-regulation-protection

Ecosystem and habitat destruction represents a major loss of ecological as well as economic value to the marine systems. Consequences of the habitat loss are the associated functions and services in the deep sea. Key actions ensure the effective conservation of ecosystems in the eastern tropical Pacific that include the development of a long term environmental monitoring programme, quantitative models that help predict the responses to disturbance, and education programs to public to understand the benefits of sustainable use. The total number of species that have been recorded or studied by scientists in hydrothermal vents is 14 (Grassle and Soto, 198) and although this knowledge is limited it represents almost 90% of the total marine diversity known for these type of marine ecosystems. Records of the different taxa at diverse taxonomic levels have been published in limited sources; a larger amount of the information is to be found in reports, bulletins and local references.

Suggested measurements. Biological diversity is central to ecosystem productivity and sustainability, especially when faced with extreme fluctuations engendered by anthropogenic activities. The loss of biodiversity and of their functional role in the ecosystem coupled with the ecosystem disturbances caused by the extraction of manganese nodules, polymetallic sulphides and crusts enhances the likelihood of unstable trajectories in ecosystem structure and function. Cryptic reorganization of marine communities leads to a new equilibrium driven by the need to adapt to multiple disturbances. The limited knowledge of the taxonomy, community structure and function, biogeography and basic natural history of deep-sea animals in the water column and seafloor and of the microbiological consortia prevents accurate assessment of the risk to the ecosystems from testing and large-scale mining.

In general there is a need for scientific data that will enhance understanding and predictability, and involvement in the processes of management and conservation for habitats with manganese nodules, in seamounts and in the OMZ, in cobalt crusts and sulphide mounds in hydrothermal vent and subduction zones.

Quantitative information on species and microbial occurrence, their abundance, biomass and geographical ranges should be gathered. The habitats should be described from the geological, physical and chemical points of view. Additional information on sensitivity to sediment burial and the time and spatial scale dependence of recolonization should be determined for dominant components in the three ecosystems.

No experimental studies have been conducted in Mexico's exclusive economic zone on mining manganese nodule, polymetallic sulphides and cobalt-rich ferromanganese crusts deposits. However, it is foreseen that, with time, these may acquire economic importance for the country's development and that there would be environmental consequences. The expected impacts will focus on the water-column life and the sessile benthic assemblages both from the extraction activities as from the indirect impacts from the processing platforms. It has been suggested that realistic assessments of the environmental consequences require a baseline database to establish scenarios with modelling exercises of the potential extraction activities. The baseline information will help to establish both the time and space scale of the environmental consequences and effects on the ecosystems and their processes. In addition to a preliminary evaluation of status and trends relating to conservation of the abyssal ecosystems associated with polymetallic sulphide deposits the re-evaluation of the paradigms of ecosystem control will be helpful to predict changes caused by extraction and will help recommend relevant management strategies.

Institutions, scientists and collaboration initiatives with other countries

The Mexican marine scientific research community in ocean science contributes to promote public awareness and understanding of the value of the ocean, its resources, and the marine activities to the Mexican society welfare. The marine geology and geophysics studies have highlighted, in part, the importance of domestic ocean energy and mineral resources to the national economy. The efforts made by the research institutions in Mexico are focused on basic science as well as to provide the relevant information to ensure the sustainable use and conservation of the ocean as a national heritage to future Mexican generations.

The research institutes (Institute of Marine Sciences and Limnology, ICML; Institute of Geology; Institute of Geophysics) and centres (Center of Geosciences) and schools (Engineering) of the National Autonomous University of Mexico (UNAM), CICESE and UABC are the main research institutions that have carried out studies related with polymetallic sulphides, manganese nodules and cobalt crusts in Mexico. The deep-sea studies in hydrothermal vents have been carried out in collaboration with US institutions (WHOI, SCRIPPS, MBARI, OSU, and Rutgers) and with IFREMER from France using both ROVs and submersibles that have provided direct observations and long term documentation of the structures and their communities. These studies have been carried out attending all regulations established for scientific research in Mexican EEZ. Governmental institutions such as the Mexican navy, the Mexican institute of oil and the environmental ministry have collaborated in many of these international research efforts.

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SUMMARY OF THE PRESENTATION

Professor Escobar said that her presentation would provide an overview of research related to polymetallic sulphides and manganese nodules conducted by her colleagues at the University of Mexico and other Mexican institutions. She said that most of the research was in the areas of geology, physics and geochemistry.

Professor Escobar said that manganese nodules occur in Mexican waters in the Pacific Ocean, where the Mexican exclusive economic zone is almost adjacent to the Clarion-Clipperton Zone. She said that reports in the literature suggest that there are manganese nodules in the southern Gulf of Mexico and the northern Caribbean Sea. Professor Escobar said it is her opinion that manganese nodules also occur in the southern area in the Caribbean Sea.

Professor Escobar said that studies started in the late 1980s in the Pacific area to characterize what types of nodules occurred in that area. She said that the first research cruise assisted scientists to describe the distribution, abundance and size of nodules, as well the chemical composition based on the different ratios of metals. She said that most of the studies indicated a relationship between the chemistry of the nodules and the sediment composition of the Mexican exclusive economic zone.

According to Professor Escobar, in this regard, a comparative geochemical analysis has shown that, based on the nickel and copper composition of the nodules, there is a correlation between the surface sediment, the subsurface sediment and the nodules. She said that it is possible to distinguish nodules from the East Pacific Rise, the continental slope and the Abyssal plain.

She noted that, in the case of polymetallic sulphides, while it is known that they might occur on seamounts, Mexican seamount research is quite limited. She said that Mexican scientists have mapped most of the seamounts and determined that they occur in the oxygen minimum zone. Professor Escobar noted that of interest in the area near Mexico there are hydrothermal vents, tectonic activity, seamounts and a high deposition of organisms.

Professor Escobar outlined the distribution of deep sea hydrothermal vents along the Continental Margin, in the dispersal zone and within the Gulf of California. In Mexico, she said that scientists have identified three coastal shallow vents sites. She said that one site is off Encinada, another within the Gulf of California, and the third and the most studied is off Jalisco. Occurring in water depths of 10 to 18 metres, Professor Escobar said that at all three locations, the vents are inactive, and continuously producing warm water in the temperature range of 80 to 90°C. She said that they contain vertical structures and had chemosynthetic communities. She also said that sulphates, sulphides and phosphates are associated with the structures, and the associated fauna comprise sponges and other organisms.

According to Professor Escobar, in the deeper area, the geophysical survey is among the best conducted in Mexico. She said that mapping of the area started with Peter Lonsdale and continued through collaborations with different countries such as the France (BART and FAMEX) in the Guaymas Basin, and with the United States on the East Pacific Rise. Professor Escobar said that the results from FAMEX were descriptions of the different basins and the fractures along the Baja California Peninsula, and a description of the tectonics in the area. She said that BART yielded descriptions of the West Coast of Central Mexico. Professor Escobar said that the most comprehensive study has been on the East Pacific Rise. She said that different programmes have cored this area extensively, including the Ocean Drilling Project. She also said that studies undertaken have been for different purposes such as geology and chemistry. Professor Escobar told participants that since many of the areas contain a thin layer of sediment, it was difficult to obtain samples of fauna.

Professor Escobar stated that, with regard to the fauna, their community structures have been the subject of studies by American and Mexican scientists. She said that the areas are highly complex because many of the vents are opening and closing continuously and the faunal communities seem to grow at a very fast rate. She described species diversity in the area as high. She also said that the Guaymas Basin is the best known.

Professor Escobar noted that the study of sulphides by Carranza and his group (1990) included the composition of rock samples using atomic absorption techniques and that he worked with the sediments, rock and some of the venting structures. In addition, she said the group obtained water samples to determine the water composition of both the small and large venting structures.

Professor Escobar said that temperature was one of the factors that regulated the variability in the area. There was a large variability of temperatures and, hence, micro habitats were formed. There was a border effect between the Abyssal and the venting area and it was along these that the highest diversities had been documented. Some of the studies had focused on heavy metal bioaccumulation. Many of the elements concentrated in high quantity in the gonads, mantle and gills, but also in other tissues.

Professor Escobar informed the participants that in collaboration with IFREMER, transects along the abyssal plain into the venting sites are available. She said that specimens of communities in the inactive structures have been collected and that they indicate that bacteria colonize the residual minerals. She also said that components of the inactive venting structures and invertebrates, such as shrimp, feed on the bacteria.

According to Professor Escobar, the implementation of Mexico's national conservation strategy is by its conservation agency called CONABIO. With the support of a foundation, Professor Escobar said that a designated priority mining area has been identified. Professor Escobar said that the conservation strategies for hydrothermal vents areas, nodules and seeps involved different sectors of the Mexican Government. She said these included different ministries, as well as public agencies. She also said that the purpose of the conservation agency is to preserve biological diversity in the different environments of both terrestrial and aquatic habitats.

Professor Escobar noted that the role of CONABIO was to protect and conserve the different resources in order to evaluate diversity, to acquire knowledge and provide information to managers in the government or in the different institutions. CONABIO, she said, has created a national system for information on biological diversity, which it maintains in a database. She said that this data and information is for decision-making and conservation. According to Professor Escobar, the database includes information on specimens, their scientific names, locations where they were collected, the geo-economic zone and a date. She said that from this information, the creation of several types of interactive tables is made possible. She also said that the database allowed for the analysis of the information at different scales.

The participants were informed by Professor Escobar that the conservation strategies included, in addition to the database, a country study of the biological diversity in Mexico, which was reviewed and updated every three to five years. It had last been reviewed in 2004. In addition, there is a national system for biological diversity information in Mexico, which is based on the 1990 Mexican Law of Environmental Protection.

Professor Escobar stated that the databases were electronic catalogues available online which also included digital coverage of the geographical conditions in Mexico, such as remote information from satellites and updated aerial photographs. Information was also available on all the curators and specialists in Mexico and their institutions. She added that Mexican scientists and collections were located at research institutions, not in museums.

Professor Escobar said that one programme had assigned 70 coastal and offshore areas as Priority Marine Regions in Mexico, based on different criteria. The areas had been chosen either for their high biological diversity, because of scant knowledge of that area, because it was recognised that some of the resources were potentially being overused, or because there were significant impacts on the environment and it allowed for the prevention and control of such impacts.

In conclusion, Professor Escobar said that in considering environmental baselines for exploration and mining of polymetallic sulphides deposits, activities that may harm habitats as well as actions to ensure the preservation of the associated ecosystems need to be taken into account. With regard to the development of long-term environmental monitoring programmes, she pointed out the need for information on models that would help to predict responses to disturbance. She said that because of the value of these ecosystems, it is essential to promote them and educate the public on their uses, management and conservation.

Professor Escobar ended her presentation with a slide show on a discovery made by Mexican scientists in collaboration with the GEOMAR and the TAMUCC projects in October 2003, courtesy of her co-authors.

SUMMARY OF THE DISCUSSIONS

Asked how the Asphalt volcano had been formed, Professor Escobar said that it was believed to have resulted from seepage of oil and eventually asphalt.

In response to a question regarding fisheries associated with seamounts in Mexico, Professor Escobar stated that the seamounts were too far from the coast for local fishermen to economically fish them.

Based on Professor Escobar's remarks about the discovery of heavy metals in the gonads, gills and mantle of clams, a participant asked her about the levels of heavy metals that are toxic to vent animals. Professor Escobar did not give specific values, but stated that there are varying tolerances for different organisms.

CHAPTER 15 BENTHIC CHARACTERISTICS OF THE DEEP INDIAN OCEAN

Dr. Baban Ingole, Scientist, Biological Division, National Institute of Oceanography, Dona Paula, Goa, India

The recent discovery of an active hydrothermal field near the Rodriguez triple Junction suggests that the mid-ocean ridge systems in the Indian Ocean are potential sites for hydrothermal mineralization. In addition, 20 vent-specific species, and over 300 benthic species belonging to major faunal groups, such as shrimps; ophiuroids, asteroids, holothurians, fishes, polychaetes and bivalves are known to be associated with these mineral deposits in the Indian Ocean. Similarly, microscopic communities, such as foraminiferans, crustacean nauplii, nematodes, turbellarians, as well as megabenthic forms, such as crinoids and ophiuroids, have been found to be associated with cobalt-rich crusts on the seamounts. The density of the benthic macrofauna in the deep Indian Ocean varied from 30 to 1430 no.m^{-2} (mean 376±346 sd, n=56). The abundance and distribution of deep-sea megafauna were assessed quantitatively from bottom photography and video records. Their density varied from three to eight individuals per $100m^2$ and it included invertebrate groups viz, xenophyophores, sponges, hydroids, sea pens, sea anemones, bryozoans, shrimps, sea cucumbers, sea urchins, starfishes and brittle stars and one vertebrate, viz, fish.

Deep-sea mining of ferromanganese deposits may not be economically feasible at present, due to quite a significant availability of relevant metals (e.g. Mn, Fe, Ni, Cu, Zn, etc) on land and expensive mining technology. However, it could be a reality in the future because of the strategic metals, which are quite scare on land. Deep-sea mining activities are expected to introduce a new set of environmental conditions to the benthic communities of the oceanic basin. An Indian deep-sea experimental study (INDEX) conducted in the abyssal plain of the Central Indian Basin (polymetallic nodule deposit site) using a benthic disturber indicated significant changes in the seafloor characteristics, geochemistry, sedimentology, geotechnical properties of the sediment and faunal diversity and biomass on the seafloor. Monitoring of the experiments conducted over five years revealed that recovery of environmental conditions at the deep-sea level was very slow. Hence, in order to understand the diversity and ecology of the hydrothermal sulphides and other potential sites in the Indian Ocean, one needs to explore numerous seamounts and vast mid-ocean ridges that would give considerable insight into the benthic environmental conditions associated with these deposits.

Morphology

The morphological features of the Indian Ocean include mid-ocean ridges, abyssal plains, a few deep-sea trenches, relatively few seamounts and islands, and numerous submarine plateaus and rises (Figure 1). The continental rises are gradually sloping plains of terrigenous sediment several kilometres thick, mainly from the Indus and Ganges Rivers.[9-11] The abyssal plain south of the Bay of Bengal is the flattest large area of the earth's surface.[12] Much of this plain has arisen from a turbidity flow down the northern slopes, extending 3,000 kilometres southwards into the deep sea.

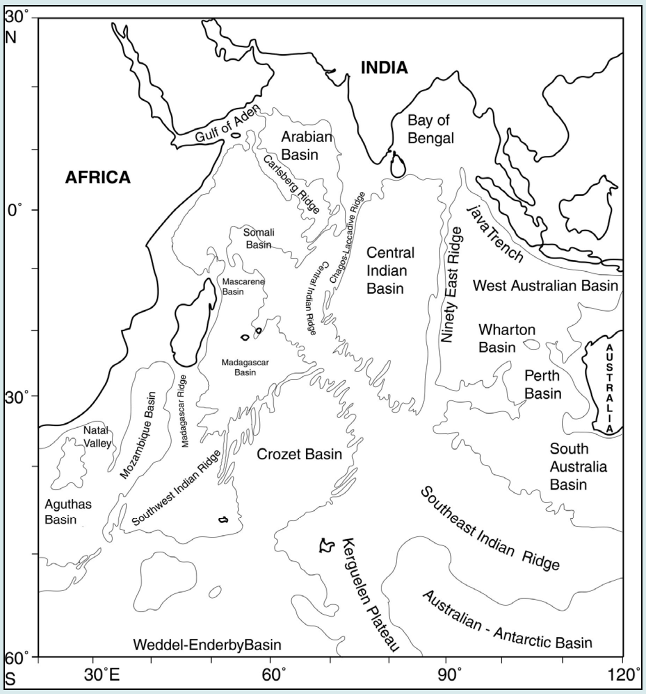

Figure 1: Topography of the Indian Ocean region.

Topography

The Indian Ocean is divided into a number of major basins by long sections of mid-ocean ridge (Figures 1-2). Some of these ridges such as the Ninety-East Ridge, the Mascarene Ridge and the Chagos-Laccadive Ridge are aseismic and do not appear to be sites of active seafloor spreading. Active ridges include the Carlsberg Ridge and the Mid- Southwest and the Southeast Indian Ridges, the last two of which extend beyond the limits of the Indian Ocean, connecting with the global mid-ocean ridge system.

Antarctic Bottom Water occupies depths below 3,800 metres and flows across the Madagascar continental slope as a deep western boundary current.[13] Oxygen concentrations follow the flow pattern, decreasing towards the north in the Arabian Sea and Bay of Bengal. The Indian Deep Water, formed from North Atlantic Deep Water carried into the Indian Ocean, occupies depths between 1,500 and 3,800 metres and spreads north in the western boundary current.

Substratum type

Most of the Indian Ocean seafloor, particularly those areas that are remote from land, is covered with calcareous ooze.[14] Thick terrigenous sediments, having high concentrations (2–5% by wt) of organic carbon, and composed mostly of terrestrial plant material, phytodetritus, and mineral grains transported by rivers,[10, 15] occur in the northern and western parts of the Indian Ocean, especially the Arabian Sea and the Bay of Bengal. In the Bay of Bengal, terrigenous sedimentation from the Ganges is particularly extensive, reaching depths of 5,000m. In the Arabian Sea, there is an organic carbon maximum (4.9%) at 400m, owing apparently to preferential preservation and accumulation of organic matter under low-oxygen conditions in the bottom water. Sediments are very thin on the crests of mid-ocean ridges, and essentially absent on the ridge axes. Because of the oligotrophic nature of the equatorial Indian Ocean, siliceous sediments are rare in low latitudes of the Indian Ocean. Red clay is present mostly in the eastern and southern Indian Ocean, near the equator and high latitudes. It is composed of fine-grained, organic-poor sediments resulting from volcanic activity at ridges.[10,14,16] The topographic highs, which are in the proximity of three major fracture zones, are composed of hard, massive basalts occurring at the crests, along the slopes and on the foothills as talus deposits.[17] Owing to strong geostrophic currents and consequent scouring of the sediments, the Wharton Basin, the southern Mascarene Basin, and parts of the Southwest Indian and Australian–Antarctic Basins have little or no sediment.[10] Sediment in these areas, when present, is mostly brown clay. In the southeast and southwest Indian Ocean, and in the Mozambique Basin, there are extensive pavements of manganese nodules at depths of about 4,000 m. [18]

Since 1982, India has conducted considerable research on the ferromanganese nodule deposits in the Central Indian Ocean and is presently conducting an environmental impact assessment to evaluate the possible impact of future nodule mining on the marine environment.[19] It has been suggested that the presence of nodules at the sediment–water interface is a result of benthic biological activity and strong bottom currents. Benthic organisms may move the nodules upward, maintaining them near the sediment–water interface[20] ,while strong currents may limit the deposition of sediment, allowing the nodules to grow.[10, 14, 21]

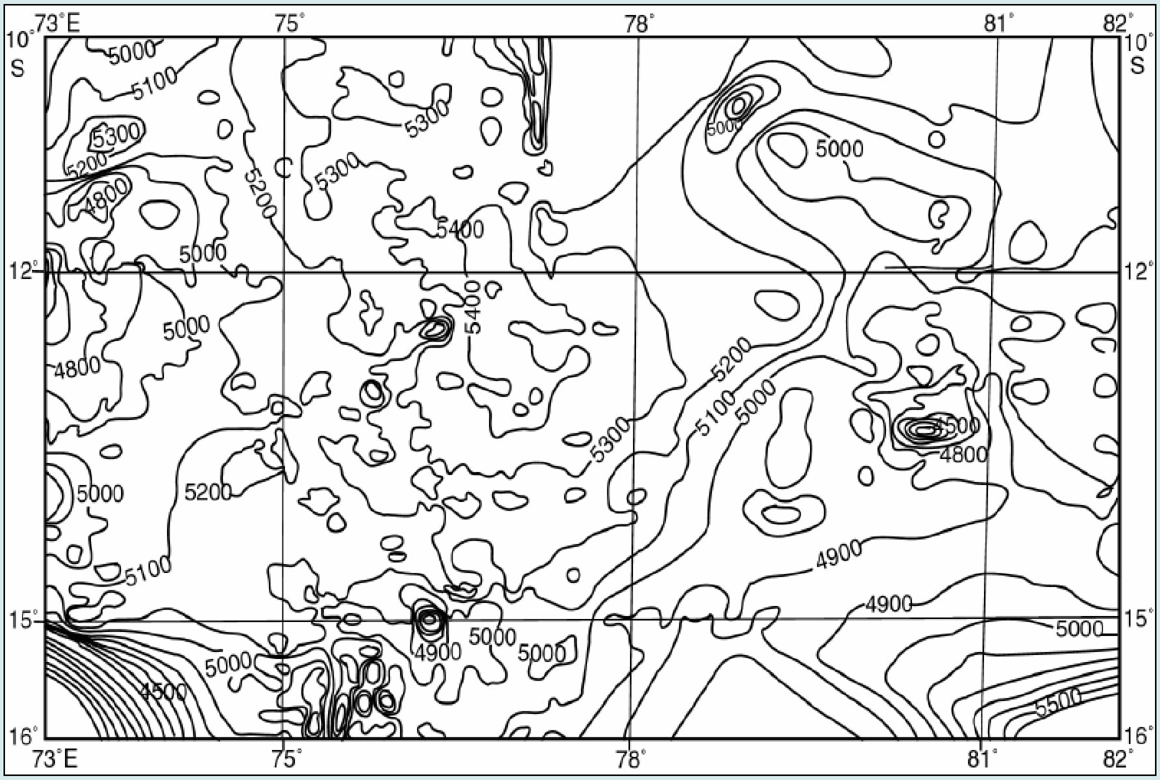

Figure 2: Bathymetry and morphology of the central Indian Ocean[22]

Benthic faunal composition, distribution and abundance

Recent biological studies conducted in the Central Indian Basin (CIB) suggested remarkably rich and diverse micro-, meio-, macro-and megabenthic communities on the deep-seafloor [20, 23-30]. However, the majority of the above studies were conducted in a limited area, with a specific objective (assessing the impact of deep-sea mining) and hence the inferences from Central Indian Basin data may not necessarily reflect the patterns of benthic standing stock for the entire Central Indian Ocean.

Composition and abundance of meiofauna

The meiobenthic assemblages of the abyssal plains of the Indian Ocean are made up of 18 metazoan groups. The depth integrated average abundance varied between 21 and 52 meiofauna (<0.5 mm size) per 10 cm^2 (mean=33.1 ± 0.63 SD; n=7; Figure.3). Nematodes were numerically the most abundant taxon with 37% of the total number collected, followed by nemertines, turbellarians, gastrotriches, polychaetes and harpacticoid copepods with relative abundances of 35, 11, 9, 4 and 1%, respectively.

According to Parulekar et al.[31] and Ingole et al.,[23] the contribution of meiofauna to the total standing crop is insignificant. The biomass values ranged from 0.02 to 0.41 $g.m^{-2}$ with a mean value of 0.08 $g.m,^{-2}$ in the deeper regions of the Indian Ocean. Although the meiofaunal biomass tended to decrease with increasing depth, no statistically significant correlation was found. According to Ingole[28] the meiofaunal abundance in the Central Indian Ocean basin falls within the reported range from similar depths in Pacific Ocean.[32, 33.] The macrofaunal biomass decreased away from the shore, suggesting a distance-dependent inverse relationship between macrofaunal biomass and distance from shore.[31.] Overall, the contribution of macro- and meiofauna biomass to the benthic standing crop was in the ratio of 31 to 1. [23]

Vertical distribution

Deep-water meiofauna is generally concentrated on a relatively thin surface layer of the bottom deposits because of the availability of food and oxygen. The vertical profile of meiofauna in the sediment column differed considerably between stations in the Indian Ocean, [23, 28] especially in the top 2 cm layers. Meiofauna was present down to a sediment depth of 30 cm (Figure 3) but ≥ 70% of the specimens were found between the surface and 6 cm depth with the bulk (45%) confined to the top 2 cm. While discussing the impact of physical disturbance on the deep-sea meiofauna, Ingole et al.[24, 28] demonstrated that nematodes and turbellarians are capable of penetrating deeper into the anoxic sediment layer. This may be the result of feeding pressure and predation by macrobenthos. Bioturbation activity of larger macro- and megabenthic organisms appears to be higher in the Central Indian Basin area, which may also help the burrowing of meiofauna in deeper sediment depths.

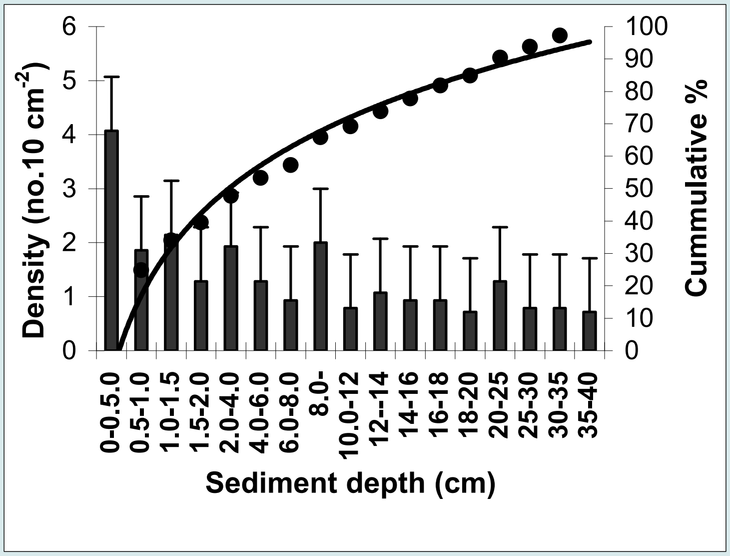

Figure 3: Vertical distribution of meiofauna in the Cental Indian Basin area[28]

Macrobenthic fauna

The macrofauna of the Central Indian Ocean comprises 24 major groups belonging to 15 phyla, predominantly Protozoa, Porifera, Mollusca, Annelida, Arthropoda and Echinodermata. Polychaeta was the dominant group in terms of number of individuals, contributing over 33% to the total macrofaunal population. Their density varied from 20 to 649m^{-2} with a mean value of 124.2 ± 40.3m^{-2}. Crustacea (23%) was the most diverse group and dominated the fauna in number of taxa (10 taxa). Amphipods (7.1%), isopods (5.3%), ostracods (4.0%) were major groups with higher percent prevalence. Paracaridean shrimps (0.8%), thalassinoid decapods (0.8%), cumaceans (0.6%), brachyuran crabs (0.3%), pagurid crabs (0.2%) and Tanaidacea (0.1%) were the other crustaceans. Gastropods and bivalves were the main constituents of molluscs and together formed over 15% of macrofaunal density. Protozoa (5%) was represented by foraminiferans (3.5%) and radiolarians (1.1%). Echinoids (1.7%), ophiuroids (1.2%) and holothurians (0.6%) represented Echinodermata (4%). Bryozoea (2%), Nemertinea (1%), Echiurida (1%) and Brachiopoda (1%) were the other faunal groups contributing over 1% to the macrofauna. Miscellaneous forms such as turbellarians, hydrozoans, sponges, sipunculid worms, siphonophores and fish larvae contributed about 7% to the faunal composition.

Distribution of density and biomass of macrofauna

Macrobenthic density in the Central Indian Ocean varied from 30 to 1430.m^{-2} (mean = 376 ± 346 n = 56), and biomass (wet wt) varied from 0.11 to 12.75 g m^{-2} (mean = 1.0 ± 1.9; n = 55). A particularly high density (7085 no.m^{-2}) was observed at a single station in the western region (08°42’644’’S;59°50’207’’E) but as it was relatively shallow (500 m), it was not included for the calculation of the mean. In general, macrobenthos density gradually increased from east to west. Maximum mean values were observed between 8–9°S and 57–62°E (Figure 4). High faunal density occurred in brown, oozy, silty sand and clayey, silty bottom. The western region has relatively shallower depths compared to the east. As assessed from the regression coefficients, abundance (density) of macrofauna decreased steadily with increasing water depth (Figure 5).

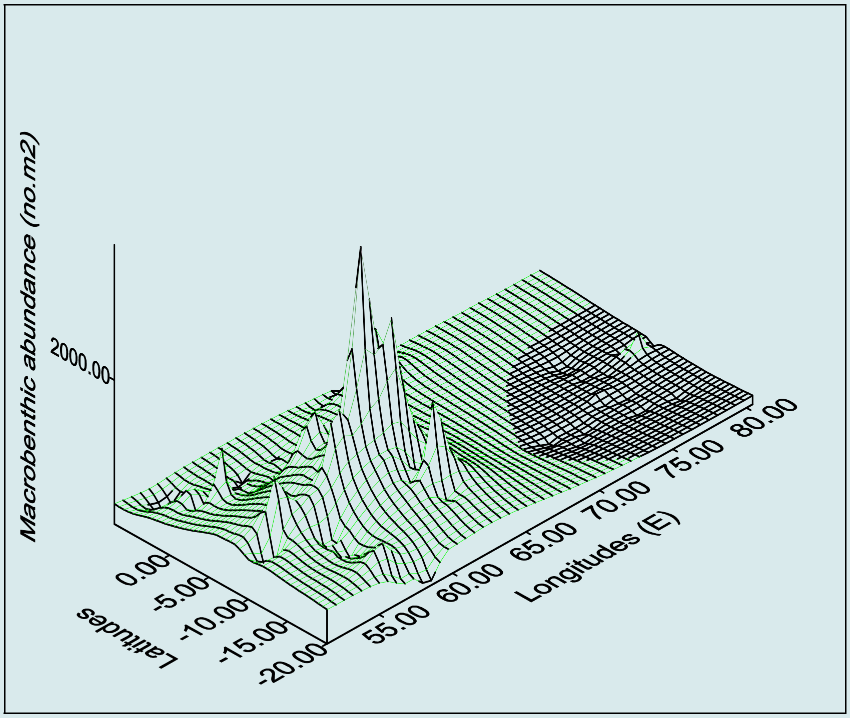

Figure 4: *Geographical distribution of macrobenthic population (no./m²) in the Indian Ocean.*[20]

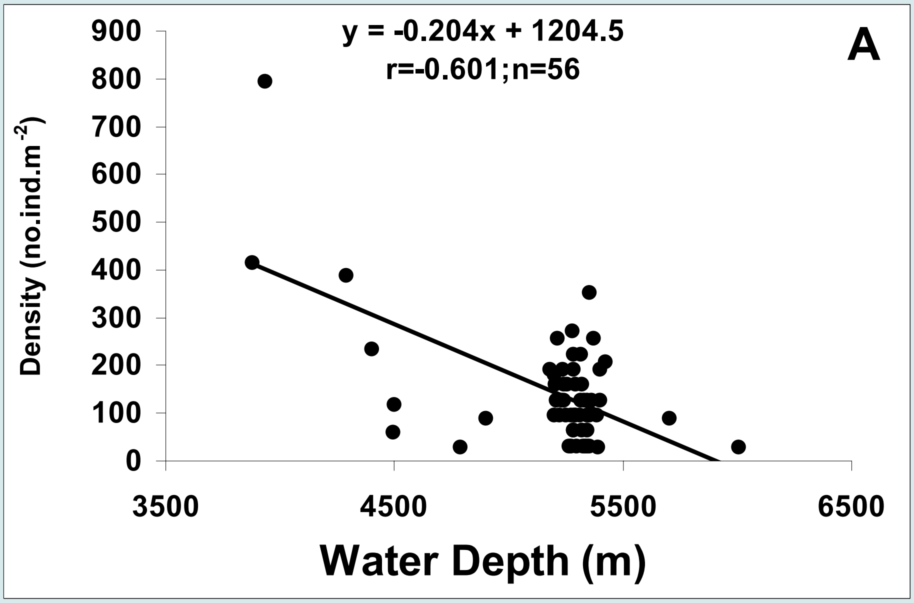

Figure 5: *Relationship between the abundance (density) of macrofauna and water depth* [20]

Megafaunal communities

The megafaunal assemblage of the Central Indian Basin has high biomass but low diversity.[29] The density and diversity enumerated from video recordings and still photographs varied between three and eight individuals per 100 m^2 (mean: 5.9 ± 2.1; n=5). Length of the deep tow profiles varied from 3.26 to 4.58 km (mean: 4.3 ±0.9), covering a surface area of 10,003 to 14,045 m^2 (mean: 11,702 ±1541 m^2). The fauna comprised 13 invertebrate groups, viz. xenophyophores, sponges, hydroids, sea pens, sea anemones, bryozoans, shrimps, sea cucumbers (Mesothuria murrayi., Molpadia sp., Pseudostichopus sp), sea urchins, starfishes (Hymenaster violaceus), and brittle stars (Ophiura sp.). A total of 3,311 individuals were observed on five profiles.[30]

The xenophyophores were either embedded or rooted firmly in the sediment and were numerically the most important, representing ≈ 64% (2,111 individuals) of the total megafaunal composition, followed by sea cucumbers (14%), sponges (13%), shrimps (3%), sea anemones (2%), sea urchins (1%), and starfish (1%). Fish (0.7%), bryozoans (0.7%), hydroids (0.6%), brittle stars (0.6%), and crinoids (0.2%) were relatively scarce (<1%).

Of the two identified sponge species, Hyalonema sp. was more common than Euplectella sp. Fish belonging to the genera Typhlonus and Bathysaurus were also observed in the area. A total of 15 different types of sea cucumbers were observed, Mesothuria murrayi being the dominant type. Starfish (Hymenaster violaceus) were frequently seen on the sediment surface associated with large mounds.

Hydrothermal systems

Most hydrothermal systems studied to date are located either in the Pacific or in the north central Atlantic Ocean. The Central Indian Ridge is important biogeographically and evolutionarily, since it is the main link between the Atlantic and the Pacific vent faunas. This makes the Central Indian Ridge system an attractive target for mid-ocean ridge studies.[20] However to date, only 20 species of vent-specific organisms are known from the Indian Ocean[20] out of the >500 known hydrothermal species.

The recent discovery of hydrothermal vents in the Indian Ocean[34] strongly suggests the possibility of more such activity in the region. As suggested by Lonsadale,[35] searching for local clusters of filter feeding animals might be one of the simplest methods for locating the precise sites of active hydrothermal vent. With this in mind, Ingole[20] reanalysed data on the distribution and abundance of macrofauna in the Central Indian Ocean Basin. Physical, chemical, biological and geophysical studies conducted along the

Central Indian Ridge indicated the possibility of many active vent sites with potential hydrothermal sulphide deposits.

Hydrogen sulphide (H_2S) has been identified as the most important potential energy source for microbial growth around hydrothermal vents, and microorganisms are inferred to be the principal dietary item of hydrothermal vent-associated invertebrates. These vents are oases for unique life forms based on chemosynthesis where organisms derive energy by mediating chemical reactions within the hydrothermal fluids. The macrofaunal abundance and biomass measured from the vent environment could be 500 to 1,000 times higher than that of the surrounding deep-sea environment. The high abundance and biomass of macrofauna recorded at a few locations in the western area of the Central Indian Ocean Basin (Figure 4), may be related to the very recent finding of hydrothermal vents over the Central Indian Ridge System. The discovery of the "Kairei" hydrothermal field, near Rodriguez Triple Junction, and Edmond field, near 23°52''S, suggests that mid-ocean ridge systems in the Indian Ocean are potential sites for hydrothermal mineralization and contain active vent fields. The high abundance of macrobenthos around Carlsberg Ridge [20, 36] and the Central Indian Ridge observed by Ingole et al.[20, 25] points towards the possibility of more unexplored hydrothermal vent sites in this region. However, no investigation on the microbes or any other sulphide-related benthic organism has been reported thus far from the Central Indian Ridge. Animal assemblages at abyssal depths may also depend on chemoautotrophic production associated with continental margin "seeps". As suggested by Gage and Tyler,[37] seeped fluids exhibit a fauna taxonomically similar to that of hydrothermal vents such as tubeworms, vesicomid and mytilid bivalves, which can use the carbon from dissolved methane through symbiotic bacteria. Future studies, therefore, need to be directed towards finding the chemoautotrophic production with close grid seabed sampling that could give substantial clues for possible hydrothermal activities.

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SUMMARY OF THE PRESENTATION

Dr. Ingole expressed his appreciation for participating in the workshop and said it was an opportunity to discuss a neglected subject matter. He said that for studies of global biodiversity, discussions are required to enable a comparison between locations. He said that global diversity is an area for international collaboration.

Dr. Ingole stated that with regard to environmental baselines for cobalt-rich ferromanganese crusts and polymetallic sulphides deposits in the Indian Ocean, Indian scientists had carried out a considerable amount of work that may have relevance. In this regard, he said that Indian scientists had mapped seamounts, the mid-ocean ridge system and the abyssal plains. He said during the past 20 years, the scientists had studied areas in the abyssal plains (polymetallic nodules), but that research on the ridges is relatively recent and sampling of the seamounts is in the planning stage.

Dr. Ingole noted that, in the abyssal plains, scientists found 300 species of fauna, of which 50 per cent are new to science. He said that these species were potentially at risk from commercial activity, which included commercial fishing and not just mining.

Dr. Ingole said that geological studies in the Central Indian Ocean Basin had mapped over 100 seamounts, and sampled some of them. He said that the scientists are also aware of crusts deposits in the basin.

He said that the Spade box corer, the Veen grab and the Peterson grab were the tools used to sample 250 stations. He said another device is the multiple corer, even though it had limitations. For interdisciplinary work, Dr Ingole described the Spade box corer as the most suitable because it facilitates sharing samples for geological and biological analysis. Dr Ingole said that the study on the macrobenthos included an assessment of their diversity and distribution. He also said that while other species had been recovered, the taxonomic expertise was not always available to identify them. Dr. Ingole agreed with a previous presenter that there is a serious global problem with regard to the availability of taxonomic specialists.

Dr. Ingole noted that, in the deep sea, diversity is high but density is low. He gave an example that during sampling, within a specific area, some species are only found in a single box core. While stressing the difficulty of obtaining good samples of many of the species, Dr Ingole stated that with regard to macrofauna, polychaetes dominated followed by crustaceans.

Dr. Ingole informed the participants of experiments conducted in select areas of the Central Indian Basin to investigate the vertical distribution of organisms, particularly with reference to the polymetallic nodule deposits. He said scientists wished to know what the impact of future exploitation of polymetallic nodules would be on the benthic environment. According to Dr. Ingole, during mining the benthos is an important indicator of impacts and could be a component of the assessment effort. He said that the purpose of studying the vertical distribution of organisms was to find out to the extent of mining's impact in this regard.

Dr. Ingole stated that the disturbance study had three components; a pre-disturbance, a post-disturbance and a monitoring component. He described pre-disturbance as typical of any habitat, in that biological activity, and therefore density, was maximum at the surface, gradually decreasing with depth into the sediment. Three weeks after the disturbance (the post-disturbance component), Dr Ingole said that the top layer, where the sediment was disturbed, suffered an almost 40 per cent of the reduction in organisms. Subsequent monitoring of the area that is scheduled very 45 months revealed that in terms of diversity, the environment was approaching a recovery phase.

According to Dr. Ingole, as far as the megabenthic study is concerned, most of it had been photograph-related although some samples had been collected in the dredge and box corer, and used for taxonomic identification. Xenophyophores were the dominant megafauna, followed by sponges, starfish, crustaceans, shrimps and fishes. He said that the density of the megabenthos from the photographic studies varied, but generally, it was slightly lower than in the Pacific Ocean, although diversity was quite high.

Dr. Ingole gave some examples of the megabenthos such as sea cucumbers, sponges and starfish. He said that there was a reduction in the megabenthos immediately after the disturbance, but that during the monitoring component there was recovery. He informed participants that since a majority of the megafauna were motile organisms, they could avoid the disturbance. He pointed out that because the disturbance brought some of the burrowing macrobenthos to the top layer, exposing them as a food source for the megabenthos, recovery was fast. He said that the relationship between nodule abundance and faunal density is not strong. He said this was the conclusion, even though the density of the macrobenthos decreased as the abundance of nodules increased. Dr. Ingole believed that, since the abundance of nodules was 6-7 kg/m^2, mobile forms probably did not have enough area, so the lack of available space could be the reason for the reduced abundance.

Dr. Ingole noted that 10 families were recovered from box core samples, but only five in other sampling devices. He said that this was why the sampling methodology needs to be standardized. Dr. Ingole told participants that most of the studies relating to the meiobenthos went down to 10 centimetres' sediment depth because this work is tedious and time consuming

Dr. Ingole informed participants that, with regard to ridges, Indian scientists had started a new programme to identify hydrothermal sulphides. He described the programme as multi-disciplinary and designed to investigate the physical, chemical, biological and geological processes along the Indian Ridge, the Carlsberg Ridge, the Central Indian Ridge and the Triple Junction. He said that because of the sulphides potential along the back-arc basins, these are parts of the study. Dr. Ingole announced that data from these studies would be presented at an InterRidge workshop in Goa scheduled for January 2006.

Dr. Ingole said that some zooplankton sampling had been carried out in the water column with some interesting results. Scientists had not been able to conclude anything, but had gotten some interesting data. Some of the areas in the Indian Ridge had very high biomass. There was some sort of infection in one of the species which occurred most at deeper depths. It was a tumour-type infection, maybe due to a parasite. It could also be due to the heavy metal concentration in the area, because the skin was susceptible to infection or perhaps due to carcinogenic substances at the hydrothermal vent.

It was noted by Dr. Ingole that sampling was conducted to determine which organisms occurred in the area, particularly on the surface, rock surfaces or within the crevices. This was carried out by scraping the surfaces of the rocks which were exposed along the Rift Valley. Scientists were looking for meiofauna and had found turbellarians and nematodes.

According to Dr. Ingole, under the InterRidge Programme, Indian scientists invited collaboration with anybody who wanted to participate in their research cruises. They had ship facilities, lab equipment, a multi-disciplinary group working on environmental studies and ongoing investigations related to seamounts, as well as the ridge programme. The main interests of the programme are conventional taxonomy, molecular taxonomy and bio-medical potentials. In conclusion, Dr. Ingole said that he was most interested in reproduction because this needed to be known when investigating recolonization.

SUMMARY OF THE DISCUSSIONS

A participant asked Dr. Ingole whether he knew what type of carcinogenic substance was causing the tumours in the images that he had shown in his presentation. He replied that he was unsure, but thought that it might be heavy metals.

One participant noted that there seemed to be a large variation in the abundance of organisms within sites and that more samples may be required to ensure accurate results. Geologists used statistics to determine the number of samples that were required for patchy distributions and it was suggested that these could also be applied to biological surveys.

In response to a question regarding the seamounts sampled by Indian scientists, Dr. Ingole replied that Indian geologists were working on cobalt-rich crusts and that there is an independent programme for cobalt crust research funded by the Indian Government.

A participant said that for impact assessment work in the deep sea, it is important to have more than one reference area, and to include geologists and geophysicists, because it would be very hard to distinguish anthropogenic impacts from natural variability. Dr. Ingole responded that the reference site was geologically, and maybe geochemically, almost identical, to the test site.

CHAPTER 16 AMOUNTS OF MEGABENTHIC ORGANISMS IN AREAS OF MANGANESE NODULES, COBALT-RICH CRUSTS AND PLOYMETALLIC SULPHIDES OCCURENCES

Dr. Tomohiko Fukushima, Researcher, Ship and Ocean Foundation, Tokyo, Japan

Introduction

As environmental conservation of the ocean becomes increasingly important, the deep-sea environment is no exception. However, our knowledge is so little that it is fair to call the deep sea areas an "unknown world", particularly, with regard to fauna living at depths of more than 600 m, the existence of which was only confirmed a century ago (Murray and Renard, 1891).

When we consider the balance between deep-sea development and environmental protection, because of this "unknown world", careful study is needed by those who are concerned with deep-sea development and environment protection. However, the different conditions being obtained in the deep sea preclude the use of existing assessment manuals, originally devised for coastal zones, concerning survey instruments, abilities and equipment of research vessels, skills of technical staff, etc. (Fukushima et al., 2003).

In environmental studies, it is important to quantify the abundance and biomass of the community being studied. It is necessary to evaluate those data objectively and compare them with similar data from other sites. In this case, the data to be compared should be treated in the same manner. However, even at present, information of biomass, abundance, faunal composition and diversity are much less than that of shallower water (Fukushima et al., 2003).

Given to those backgrounds, abundances of megabenthic organisms in areas of manganese nodules, cobalt-rich crust and polymetallic sulphide in the Pacific Ocean were estimated. Data were obtained from 1987 to 1999 by the Metal Mining Agency of Japan (currently the Japan Oil, Gas and Metals National Corporation (JOGMEC) under the technical corporation agreement between the South Pacific Applied Geoscience Commission (SOPAC) and the Government of Japan.

Materials and methods

Materials

Still photographs, which were taken by the continuous deep-sea camera system (CDC), were used to estimate abundances, faunal composition, feeding habitat, etc. Since, originally, researches were conducted to explore deep-sea mineral resources; observed areas are not similar to those conducted as an ordinary scientific research. In the polymetallic sulphide site, in particular, observation covered not only the surroundings of hydrothermal vent sites, but also the wider areas. The photographs were collected within the exclusive economic zone of Kiribati, Cook Islands, Tuvalu, Papua New Guinea, Vanuatu, Solomon Islands, Tonga, Samoa, the Marshall Islands and the Federated States of Micronesia in the South Pacific Ocean. The number of photographs and the areas covered are described in Table 1.

TABLE 1: NUMBER OF PHOTOGRAPHS AND COVERED AREA

	MN		CRC		PS	
Country	No. of Photo	(ha)	No. of Photo	(ha)	No. of Photo	(ha)
Kiribati	950	0.57	1,773	1.06		
Cook	794	0.48				
Tuvalu	73	0.04	753	0.45		
PNG					1,073	0.64
Vanuatu					2,560	1.54
Solomon					1,524	0.91
Tonga					1,736	1.04
Samoa			589	0.35		
RMI			3,428	2.06		
FSM			3,311	1.99		
Covered Area (ha) = (3m * 2m) / 10000 * No. of Photograph						

Abbreviations: MN= manganese nodules ; CRC=cobalt-rich crusts; PS =polymetallic sulphides; PNG= Papua New Guinea; RMI= Republic of the Marshall Islands; FSM = Federated States of Micronesia

Identification

In this particular study, megabenthos was defined as the fauna, which was large enough to be recognized in the photograph. Although, when possible, observed animals were classified as lower taxon, phylum or at class levels, classification was applied to data analysis for the sake of precision. Large motile animals, such as shrimps or fishes, may occasionally avoid the camera vehicle (Christiansen and Thiel, 1992). Since all shrimps recognized in the study were nektonic, shrimps and fishes were excluded from the quantitative data. Xenophyophorea were widely distributed in the deep seafloor of clay and ooze. However, its high fluctuation in size and shape, and dark brownish colour made it difficult to recognize quantitatively (Levin and Goody, 1992). Other exceptional cases are described in Table 2.

TABLE 2: RULES OF CLASSIFICATION

Visible Parts	Treatment
Partially body	In the case that unique characters of its own were confirmed, it was treated as be appeared. In other cases, the obstacles were treated as indeterminate animals
Out of focus	In the case that unique characters of its own were confirmed, it was treated as be appeared. In other cases, the obstacles were treated as indeterminate animals
Uncertain Animals	The organism classified as possible lower taxon. However the case which difficult to determine of its phylum, the animals were treated as indeterminate animals. Furthermore, in the case that difficult to determined either living organisms or not, such as obstacles were treated as no appearance.

It is not unusual to have difficulty in determining whether or not the object in the photograph is a living organism. For example, small sponges or ophiuroids were sometimes over reflected against the flashlight from the deep-sea camera and resembled "white spots" (Figure 1). Those objects were treated as indeterminate.

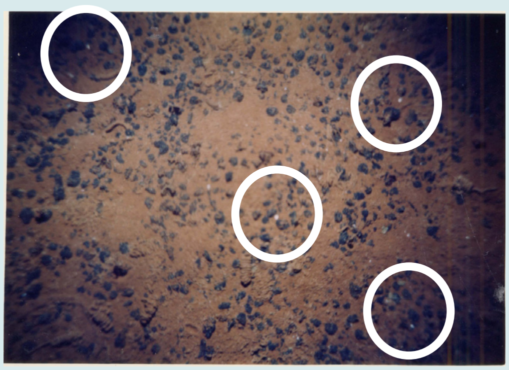

Figure 1: White spots

Feeding types

Some of the deep-sea organisms have a particular feeding strategy, which is different from fauna living in shallower water. Therefore, the classification of feeding types based on the coastal fauna's ecology is not always applicable to that of deep-sea fauna. However, given the limited knowledge of their ecologies, in the present study, for convenience, feeding types were divided into as the follows.

(a) Suspension feeder: Porifera, Cnidaria, Crinoidea, Ascidiacea
(b) Deposit feeder: Holothuroidea, Echinoidea, Hemichordata
(c) Others: Annelida, Mollusca, Asteroidea, Ohiuroidea,

Sediment types

In order to understand a diversity of habitat of megabenthos, seafloor properties were classified into the following five types (Figures 2-6).

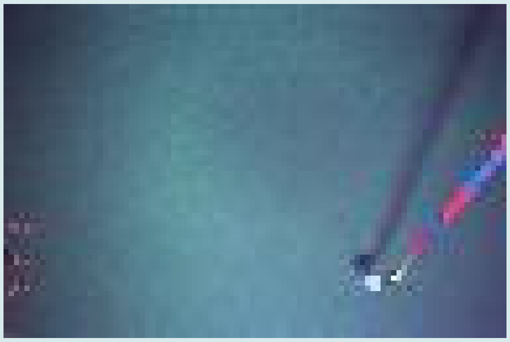

Figure 2: Clay or ooze: Most of the part of seabed was covered by clay or ooze.

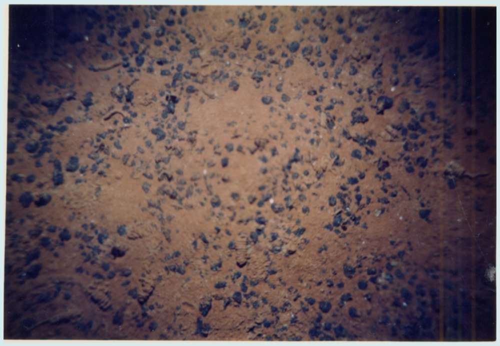

Figure 3: *Poor manganese nodules area: less than 30% of manganese nodules.*

Figure 4: *Rich manganese nodules area: more than 30% of manganese nodules.*

Figure 5: *Rocky or cobble area: Rocks or cobbles are lying on the seafloor.*

Figure 6: Crust area: covered by crust.

Results

Seafloor conditions

Percentages of clay or ooze, poor manganese nodules, rich manganese nodules, rocky or cobble area and crust area in the manganese area were shown in Figure 7. In the Cook Islands, rich manganese nodules occupied more than 65% of the area. Similarly, in Kiribati, 90% of the area was rich in manganese nodules, while in Tuvalu, over 85% of the area was occupied by clay or ooze. In all cases in the manganese area, although different categories were recorded, a monotonous seabed condition was estimated. On the other hand, diverse conditions were observed in both cobalt-rich crust and polymetallic sulphide areas (Figures 8-9).

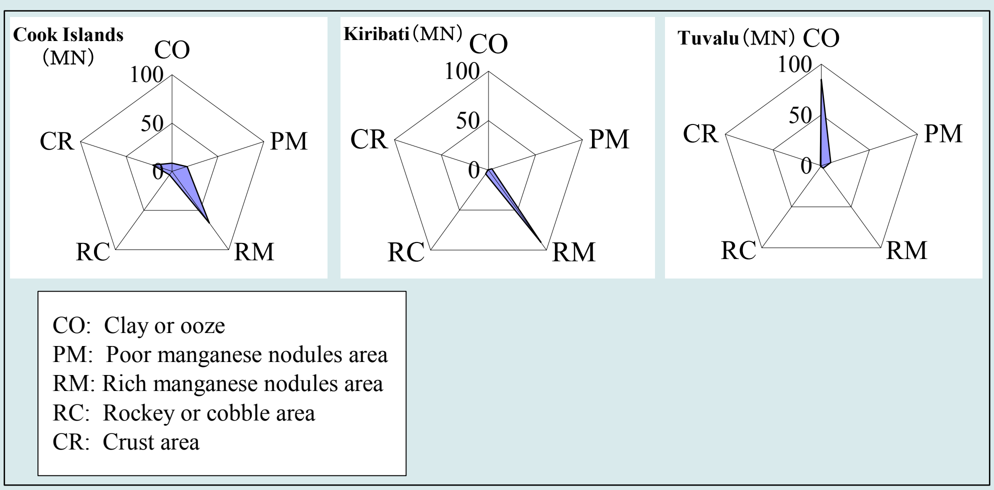

Figure 7: Seafloor conditions in manganese nodule areas

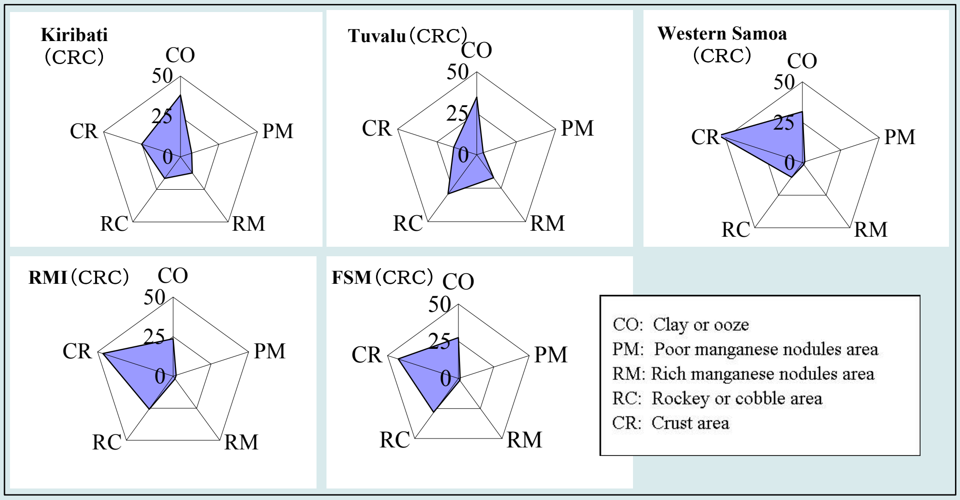

Figure 8: Seafloor conditions in cobalt-rich crust areas.

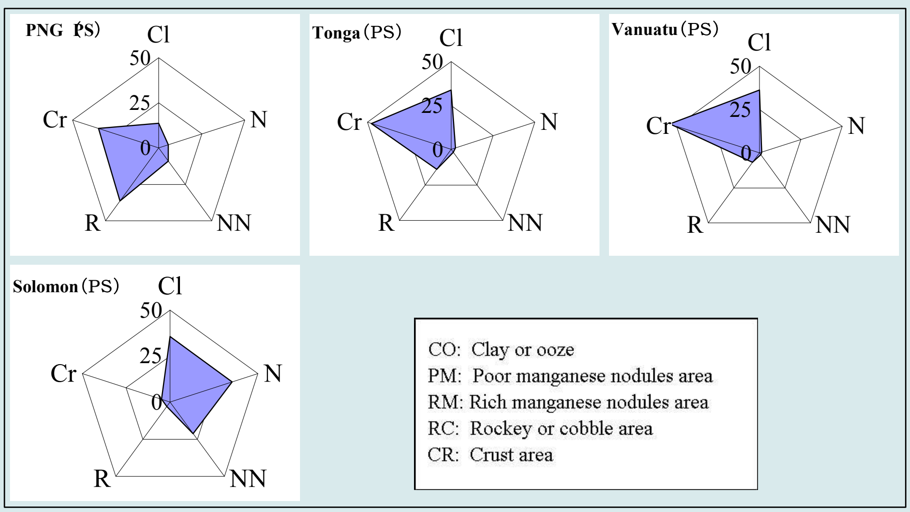

Figure 9: Seafloor conditions in polymetallic sulphide areas.

Fauna

Observed fauna are shown in Table 3. A total of 23 faunal groups were recognized in the manganese nodules, the cobalt-rich crust and polymetallic sulphide areas. All fauna were recognized in the polymetallic sulphide area, all but one in the cobalt-rich crust area, and only 10 in the manganese nodules area.

TABLE 3: APPEARANCE FAUNA OF MEGABENTHOS

	Phylum	Class	Order	MN	CRC	PS
1	Protozoa	Rhizopodia	Xenophyophores	○	○	○
2	Porifera	hexactinellida		○	○	○
3				-	○	○
4	Cnidaria	Anthozoa	Actinaria	○	○	○
5		Anthozoa	Gorgonacea	-	○	○
6		Anthozoa	Pennatulacea	○	○	○
7		Bryozoa		-	○	○
8	Annelida	Polychaeta		-	-	○
9	Mollusca	Decapoda		-	○	○
10	Echinodermata	Crinoidea	Comatulida	-	○	○
11		Crinoidea		○	○	○
12		Asteroidea		○	○	○
13		Echinoidea		-	○	○
14		Holothuroidea		○	○	○
15		Ophiuroidea		○	○	○
16	Arthropoda	Crustacea	Macrura	-	○	○
17		Crustacea	Anomura	-	○	○
18		Crustacea	Brachyura	-	○	○
19		Crustacea		-	○	○
20	Prochordata	Ascidiacea		○	○	○
21	Hemichordata	Enteropneusta		-	○	○
22	Vertebrata	Chondrichthyes		-	○	○
23		Osteichthyes		○	○	○

Abundance

Abundances of megabenthos in areas of the manganese nodules, the cobalt-rich crust and the polymetallic sulphides are shown in Figure 10. The lowest density was observed in the manganese nodules area (31±23 inds / ha: mean ±SD), which was 6 times less than that of the cobalt-rich crust area (193±329 inds / ha) and 13 times less than the polymetallic sulphide area (426±418 inds / ha). However, in the case of cobalt-rich crust and polymetallic sulphide areas, the ratios between means and suspension feeders were higher than that of the manganese nodules area, which suggests higher fluctuations of megabenthos abundance. In a particular case in the polymetallic sulphide area, over 90 individuals appeared in a photograph.

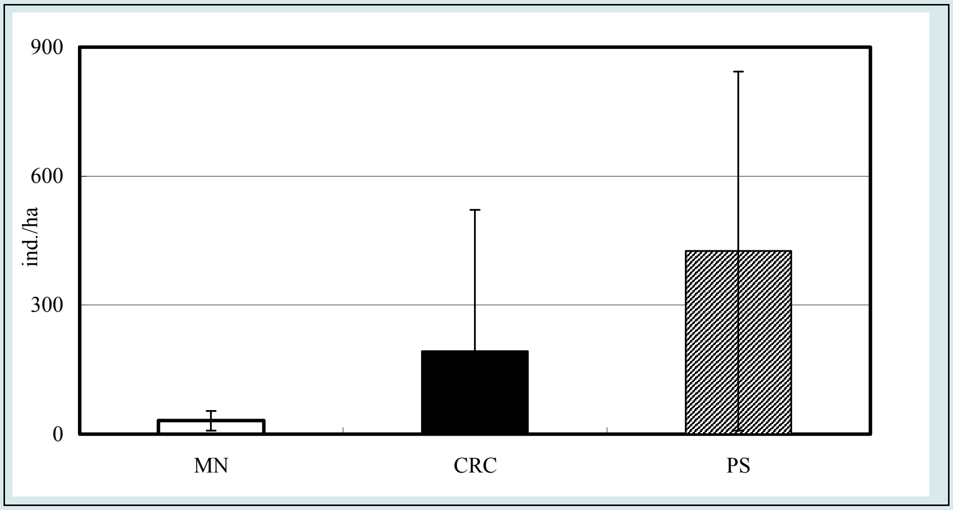

Figure 10: Amounts of megabenthic organisms in the areas of manganese nodules, cobalt-rich crust and polymetallic sulphide.

Feeding habitat

The percentages of suspension feeders found in the manganese nodules area were smaller than that found in the cobalt-rich crust and polymetallic sulphide areas. In contrast, smaller percentages of deposit feeders were recognized in the cobalt-rich crust and polymetallic sulphide areas (Figure 11). Dense distribution of suspension feeders were observed along edges of crusts. The dominant suspension feeders in the cobalt-rich crust area are Crinoidea and Pennatulacea, on the other hand, in the polymetallic sulphide area, Actinaria and Porifera were the most abundant.

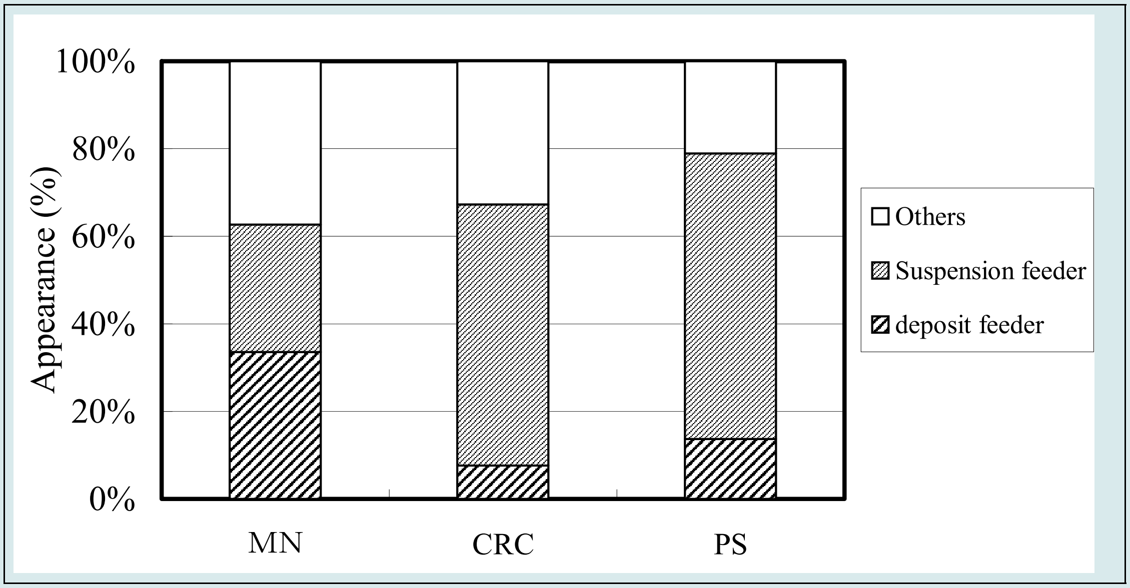

Figure 11: Ratios of feeding types of megabenthos

Discussion

Summary of results was shown in Table 4. Although data materials collected for the purpose of exploration research in the manganese nodules, cobalt-rich crust and polymetallic sulphide areas, ecological characteristics of megabenthos were understood to some extent. The reason why the faunal diversity was the lower in the manganese nodules area could be explained by the monotonous environment of their habitats, which were suggested by the data of seafloor properties.

Megabenthos distributions were abundant in the following order: in the polymetallic sulphides area, the cobalt-rich crust area, and the manganese nodules area. The fact that over 90 individuals are recognized in a photograph taken at the polymetallic sulphides area, led to speculation of the existence of chemosynthetic communities. In the cobalt-rich crust area, strong currents, which transport organic materials, were inferred, because the highest density of suspension feeders was observed along to edges of crusts. In general, megafauna distributed in manganese nodule areas were supported by a small amount of organic materials supplied from the upper layer (Shirayama, 1984). Those estimations emphasize the importance of food supply for deep-sea megabenthos.

It is reasonable that the higher percentages of deposit feeders were recognized in the manganese nodules area which was occupied by clay or ooze or poor manganese nodules. In the cobalt-rich crusts or polymetallic sulphides areas, crusts or cobbles were distributed on the surface of the seafloor, which suggests that many substrates for suspension feeders are available.

TABLE 4: SUMMARY OF RESULTS

parameters	MN	CRC	PS
habitat condition	monotonous	diverse	diverse
faunal diversity	lower	higher	higher
abundance	poor	midium	rich
S/D ratio	small	large	large

habitat condition was determined by conditions of seafloors
faunal diversity was determined by the number of faunal group
S/D ratio: Ssuspension feeders / Deposit feeders

Although interesting facts regarding characteristics of megabenthos ecology were addressed by the present study, problems remain. In the environmental guideline for manganese nodules development prepared by the International Seabed Authority, the camera tow system (photographic transects) is recommended for megabenthos research (ISA, 2001). However, we must keep in mind the fact that only epifaunal and metazoan species were counted by this method. In other words, infaunal species, which are considered to play an important part in the deep-sea benthic ecosystem, were ignored. In addition, Xenophyophorea, which are protozoa and supposed to be the largest biomass in the deep seabed, were uncounted.

When we estimate megabenthos amounts for purposes of an environmental impact assessment study for manganese nodules development, survey areas should be selected at random within the area planned for future development. In the case of cobalt-rich crusts and polymetallic sulphides areas with large fluctuations of environmental characteristics of the seafloor, estimations of megabenthos abundances change, depending on the selection of the survey site.

Taking those problems into consideration, research methods for an assessment of the development of cobalt-rich crust and polymetallic sulphide areas preclude the use of the environmental guidelines prepared for a development for manganese nodules area. This strongly demonstrates the need for adequate discussion and consideration of environmental assessment methods in those areas.

ACKNOWLEDGEMENTS

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SUMMARY OF THE PRESENTATION

Dr. Fukushima stated that human activities in the deep-sea area were likely to increase as a result of the disposal of carbon dioxide utilisation of gas hydrate and, of course, mining of mineral resources, such as manganese nodules, cobalt-rich crust and polymetallic sulphides. Since the 1960s, deep-sea mineral resources had been paid considerable commercial and industrial attention. However, the environmental protection movement had grown in the same period and this had led to the mining code and environmental guidelines prepared by the International Seabed Authority. However, there was so little knowledge, that it was fair to call the deep-sea areas an "unknown world". Even the information available on biomass, abundance faunal composition and diversity was much less than that on shallower water.

According to Dr. Fukushima, in environmental studies, it was important to quantify the abundance of the community being studied. It would be necessary to compare results with similar data from other sites and both sets of data should be treated in the same manner.

The participants were informed by Dr. Fukushima that Japan had been conducting a basic survey for deep-sea mineral resources in the economic zone as part of the Japanese International Technical Cooperation Project. The survey had been initiated in 1985 and was ongoing at the time of the workshop. It had produced various results related to manganese nodules, cobalt-rich crusts and polymetallic sulphides. Deep-sea camera observations had been conducted in the study for the purpose of exploring mineral resources. After completion of the analyses of the exploration, still photographs and video recordings would remain and could be used for other purposes, such as megabenthos observation.

Dr. Fukushima noted that the photo transect method had been recommended in the environmental guidelines prepared for the Authority by the Metal Mining Agency of Japan and SOPAC. He had not participated in the survey, but he had obtained still photographs that had been taken by the continuous deep-sea camera system (CDC). Surveys in the areas of manganese nodules had been conducted in Kiribati, the Cook Islands and Tuvalu areas. Cobalt-rich crusts were near Kiribati, Tuvalu, Samoa, the Marshall Islands and Fiji. Polymetallic sulphides were near Papua New Guinea, Vanuatu, Solomon Islands and Tonga. The photographs showed an area of 3 metres by 2 metres and the total covered area varied from 0.45-1.00 hectares.

Dr. Fukushima said that, in the study, megabenthos had been defined as fauna that was large enough to be identified by photograph. Observed animals had been classified to the lowest possible taxa level. Animals, the identity of which was uncertain for whatever reason (including out-of-focus photographs), were treated as an "indeterminate animal". Cases in which it was difficult to determine whether the object was living or dead were treated as "no appearance".

According to Dr. Fukushima, large water animals, such as shrimp or fish, occasionally avoided the path of the camera. All shrimps recognized in the study had been nektonic and, therefore, shrimp and fish had been excluded from the quantitative data. Xenophyophorea were widely distributed in the clay and ooze. However, there was a high fluctuation in size and shape and the brownish colour made it difficult to recognize them quantitatively.

Dr. Fukushima noted that it was not unusual to experience difficulty in determining whether objects in the photographs were living or non-living organisms. For example, small sponges or ophiuroids were sometimes over reflected, so that, against the flashlight, they looked like "white spots". Those objects were treated as indeterminate.

Dr. Fukushima stated that there were three feeding types: suspension feeder; deposit feeder; and others. The suspension feeders were Porifera, Cnidaria, Crinoidea and Ascidiacea. Deposit feeders were Holothuroidea, Echinoidea and hemichordate. Others were Annelida, Mollusca, Asteroidea and Ohiuroidea.

Dr. Fukushima then presented the results and discussion, as follows: In the Cook Islands, more than 65% of the area was occupied by rich manganese nodules; in Kiribati, more than 90% was occupied by rich manganese nodules; and near Tuvalu, 85% of the area was occupied by clay or ooze. In all cases, in the manganese nodule areas, although different categories had been recorded, a monotonous seabed condition had been estimated. However, various conditions had been observed in both cobalt-rich crust areas and polymetallic sulphide areas. A total of 23 faunal groups had been recognized in the manganese nodule areas, all of which had also been recognized in polymetallic sulphide areas, and all but one had been recognized in the cobalt-rich crust areas.

Dr. Fukushima informed the participants that many types of Porifera had been recognized. The Hyalonema was very abundant in the manganese nodule areas and many Actinaria were observed in the areas of polymetallic sulphides. Dr. Fukushima showed a video highlighting the abundance of megabenthos in areas of manganese nodules, cobalt-rich crust and polymetallic sulphide. The lowest density had been observed in the manganese nodule area, with 31 individuals per hectare, and the cobalt-rich crust and polymetallic sulphide areas had 193 individuals per hectare and 426 individuals per hectare, respectively. Abundance in cobalt-rich crust areas was six times that in the manganese nodule area, and abundance in the polymetallic sulphide areas was 13 times higher than in the manganese nodule areaa. The standard deviations in the mean abundance in cobalt-rich crust and polymetallic sulphide areas were higher than that in the manganese nodules area, which suggested a higher variation of megabenthos abundance. In an extreme case, in the polymetallic sulphide area, over 90 individuals appeared in a single photograph.

Dr. Fukushima noted that a smaller percentage of suspension feeders had been found in manganese nodule areas, in contrast to a smaller percentage of deposit feeders observed in cobalt-rich crust and polymetallic sulphide areas. Dense distributions of suspension feeders had been observed around each of the crusts. The two dominant suspension feeders found in the cobalt-rich crusts were Echinoidea and Pennatulcea, whereas in the polymetallic sulphides area, Actinara was most abundant.

Dr. Fukushima explained that the reasons why faunal diversity was lower in the manganese nodule area could be the monotonous environment of the habitat suggested by the data on the seafloor properties.

According to Dr. Fukushima, the distribution of megabenthos was most abundant near polymetallic sulphides, intermediate in cobalt-rich crusts and lowest in the manganese nodule areas. The recognition of over 90 individuals in a photograph of polymetallic sulphides had led to speculation about the existence of chemosynthetic communities. In the cobalt-rich crusts, Dr. Fukushima said there are strong currents, which transport organic matter, resulting in the observation of a high density of suspension feeders along the edge of the crusts. He said that these estimates emphasize the importance of deep-sea megabenthos. He reiterated the findings as the higher percentage of deposit feeders observed in manganese nodule areas. In areas of cobalt-rich crusts and polymetallic sulphides, he said that there were many substrates for suspension feeders.

However, Dr. Fukushima indicated there were problems. In the environmental guidelines for manganese nodule exploration, the recommendation is for the use of a camera-towed system. He acknowledged that estimates of megabenthos abundance are possible using random photographs in nodule areas, but said that there was more variation in abundance in cobalt-rich crusts and polymetallic sulphides areas. He concluded that the selection of sites was, therefore, more important.

Dr. Fukushima said that the contractor should submit a report on environmental baseline data and predict the environmental impact resulting from mining. In addition, these results should be reviewed by the Legal and Technical Commission. Dr. Fukushima wanted to know if the contractor would constantly maintain the accuracy of its megabenthos data by following the environmental guidelines. He also wanted to know if the Commission would evaluate the accuracy of the data submitted by contractors using the recommended method.

Dr. Fukushima informed participants that the determination of the distribution of megabenthos in areas of manganese nodules, cobalt-rich crusts and polymetallic sulphides has been accomplished using the photo transect method. He described the photo transect method as the method recommended in the environmental guidelines prepared for manganese nodule development. He said that although certain characteristics of megabenthos distribution in each site were determined, problems remained, particularly regarding the accuracy of quantitative data sets. Dr. Fukushima said that according to the mining code, contractors must submit reports on environmental baseline data and predict potential environmental impacts of mining. In addition, the Legal and Technical Commission must review these results. He said that if megabenthos data were required in the guidelines for cobalt-rich crusts and polymetallic sulphides development, intercallibration methods would be required for both contractors and the Commission.

Dr. Fukushima stated that Japanese manganese nodule research had been carried out between 1975 and 1999 and environmental research from 1990 to 1997. That research had been very intensive. Research on the cobalt-rich crusts was underway at the time of the workshop and, while polymetallic sulphides exploration research has been ongoing since 1985, the environmental research is incomplete.

SUMMARY OF THE DISCUSSIONS

A participant asked Dr. Fukushima whether there were more benthic animals in the clay or ooze than in the areas rich in manganese nodules, but he said he could not respond to the question since he did not know the relationship between the manganese nodule area and the ooze area.

Part V

WORKING GROUP DELIBERATIONS

Chapter 17 Guidelines for acquiring the physico-chemical environmental data required for establishing environmental baselines at polymetallic sulphides and cobalt-rich ferromanganese crust deposits, and the data-collection requirements for a monitoring programme

Chapter 18 Guidelines for acquiring biological data required for establishing environmental baselines at polymetallic sulphide deposits and the data-collection requirements for a monitoring programme

Chapter 19 Guidelines for acquiring biological data required for establishing environmental baselines at cobalt-rich ferromanganese crust deposits, and data-collection requirements for a monitoring programme

Background

After all the presentations had been made, the participants divided themselves into the three working groups to consider the main aim of the workshop which was to prepare suggestions for the Legal and Technical Commission regarding the information and data to be gathered by contractors for environmental baselines and an ongoing monitoring programme. The three working groups were (i) Chemical and physical considerations at cobalt-rich ferromanganese crusts deposits (Chairperson – Dr Andres Thurnherr), (ii) Biological considerations at polymetallic sulphides deposits (Chairperson – Dr Cindy-Lee Van Dover), and (iii) Biological considerations at cobalt-rich crusts deposits (Chairperson – Dr Julian Anthony Koslow).

Following a few hours of discussions within each working group, all the participants met again in plenary so that each working group could present the results of its deliberations and obtain feedback from the other working groups. As some participants had already left because of the impending hurricane, the planned fifth day of the workshop was cancelled, and it was decided that the working groups would carry out the remainder of their work via email and present their final recommendations to the Commission through the Secretariat. An advantage of that process was that participants with expertise appropriate to more than one working group would not be restricted to participating in only one working group. A list of the participants in each working group is contained in the table below.

Participants in each working group

Name	*Chemical and physical considerations at both resources*	*Biological considerations at polymetallic sulphides*	*Biological considerations at cobalt-rich crusts*
Prof. Aike Beckmann	✓		
Mr. Mayumy A. Cabrera-Ramírez	✓		
Dr. Lúcia de Siqueira Campos		✓	✓
Dr. Malcolm Clark		✓	✓
Dr. Adam Cook	✓	✓	✓
Prof. Colin Devey		✓	
Ms. Shannon Dionne		✓	✓
Mr. Anton Eisenhauer	✓		✓
Prof. Elva Escobar-Briones		✓	✓
Mr. Luíz Gamboa	✓		
Ms. Valentina Germani		✓	✓
Prof. Peter Herzig	✓	✓	
Mr. Albert J. Hoffmann	✓		
Dr. Baban Ingole			✓
Dr. Woong-Seo Kim		✓	
Dr. Julian Anthony Koslow	✓	✓	**Chair**
Dr. José Hipolito Monteiro	✓	✓	✓
Prof. Jorge Nieto-Obregon	✓		
Dr. Lindsay Parson	✓	✓	✓
Dr. Francisco Querol-Suñe	✓		
Prof. Peter A. Rona	✓		
Prof. Steven Scott	✓		
Dr. Rahul Sharma	✓		
Dr. Andreas Thurnherr	**Chair**	✓	✓
Professor Cindy-Lee Van Dover	✓	**Chair**	✓
Dr. Michael Wiedicke-Hombach	✓		
Professor Huaiyang Zhou	✓	✓	✓

Upon completion of each of the working group reports, the Chairpersons of each group together with the Secretariat and Mr Heydon of Nautilus Minerals, met to finalize the main report containing a synthesis of the workshops recommendations. Mr Heydon who was to participate in the workshop was unable to do so because of the impending hurricane. He did however submit two presentations entitled "Exploration for and pre-feasibility of mining seafloor polymetallic sulphides" and "Mining on land vs the seafloor - a case study" that are reproduced in full in Annexes 1 and 2. His input was considered invaluable as his company is the first to attempt to commercially exploit polymetallic sulphides in the territorial waters of Papua New Guinea.

The results and recommendations from the three working groups are contained in Chapters 17, 18 and 19. The format for these reports follows that for "Guidelines for assessment of environmental impacts from the exploration for polymetallic nodules in the Area" (1999). That report included the following chapters to which the working groups, as appropriate, made modifications.

1. Introduction
2. Definitions
3. Activities not expected to cause serious harm
4. Activities with potential for causing harm
5. Monitoring of activities, collection of baseline data, mitigation of effects
6. Reporting requirements
7. Regional baseline data
8. Recommended cooperative research
9. Future needs in environmental monitoring

The composite document arising from the three sets of recommendations for consideration by the Legal and Technical Commission for cobalt-rich ferromanganese crusts deposits and polymetallic sulphides deposits are contained in Part VI of the proceedings.

CHAPTER 17 GUIDELINES FOR ACQUIRING THE PHYSICO-CHEMICAL ENVIRONMENTAL DATA REQUIRED FOR ESTABLISHING ENVIRONMENTAL BASELINES AT POLYMETALLIC SULPHIDES AND COBALT-RICH FERROMANGANESE CRUST DEPOSITS, AND THE DATA-COLLECTION REQUIREMENTS FOR A MONITORING PROGRAMME

1. General notes

The present document describes the recommendations agreed to by the physical/chemical working group during and after the International Seabed Authority meeting that was held in September 2004. It is intended to complement the two sets of recommendations agreed to by the biological working groups on mining of polymetallic sulphides and of cobalt crusts. (Unless otherwise noted, the recommendations in this document apply to both types of deposits.) The recommendations will be submitted to the Legal and Technical Commission for establishing environmental baselines and for subsequent environmental monitoring during exploration (including test mining). At some sites it may not be reasonably feasible to implement some of the specific recommendations. For example, it may not be possible to measure heat flow at a site that is entirely sediment-free. In this case, the contractor should provide arguments to this effect when submitting a work programme to the Commission, which can then exempt the contractor from the specific requirement.

In December 2004 D. Heydon (Nautilus Minerals) joined our discussion and provided valuable criticism of some aspects of the draft report. Several of the issues he raised are related to the fact that our recommendations and baseline requirements are not restricted to the impacts that Nautilus Minerals anticipates to be associated with the mining technology that they are currently developing. Since our mandate is not restricted to evaluating a particular mining plan of a particular company, we have chosen to keep the draft recommendations general. Perhaps the most significant difficulty in preparing this report is the lack of knowledge of potential future mining techniques. The only concrete plans that we are aware of consist in the mechanical break-up of the deposits on the seafloor, transport to the surface and processing there. However, both blasting and chemical dissolution were mentioned during the workshop and the subsequent discussions. Based on current information, blasting and chemical dissolution are considered unlikely. Nevertheless, the potential severity of their environmental impacts has prevented us from omitting mention of those techniques from this report. The potential impacts of blasting techniques, in particular, are not discussed here. Of course, it is likely that future mining operations will employ additional techniques that we have not considered in our discussions. Therefore, the International Seabed

Authority should revisit the physical considerations as technologies are developed and the proposed mining technology is identified to ensure that assumptions and considerations described here continue to be relevant.

Regardless of the mining techniques to be employed, it is expected that some amount of particulate and/or dissolved mining by-products are released into the water column in the vicinity of the mined deposits, the transport conduits and the processing sites. With the currently proposed exploration and mining techniques, the primary anticipated mining by-products are particles created by the mechanical break-up of the mined minerals. (While it is expected that mining operators will minimize the loss of economically valuable minerals, it does not seem realistic to assume zero loss.) Since the particle-size range is not known, it is assumed that the by-products of mining include very small particles, which can remain in suspension for months. The possibility of the introduction of toxic substances cannot be excluded either. While bound metals are not biologically available, dissolution of metals and consequent metal toxicity may take place under particular environmental conditions (e.g., low pH in the guts of marine invertebrates, oxygen minimum zones in the water column). Other possible examples include accidental or intended release of chemicals used during exploration and test mining. Therefore, the primary goal of the physical baseline data collection consists of assessing the dispersal potential both for particles and for dissolved substances. Knowledge of the dispersal potential is also required for monitoring and mitigating the effects of accidental spills related to the mining operations. We therefore recommend that the dispersal potential near future mining sites be assessed, even if the design target of the mining technology includes avoidance of the release of any mining by-products into the environment.

According to available information provided by the Authority, the exploration area initially covers up to 100 contiguous blocks, each measuring 10km x 10 km. This area will be progressively decreased towards the eventual (test-) mining target, the size of which is of the order of a deposit. In the case of polymetallic sulphides, the deposit scale is expected to be in the order of 1 km^2 or less (a typical deposit scale of 200 m x 200 m was mentioned during the discussions); in the case of cobalt crusts, the deposits can potentially encompass an entire seamount. Away from topography, spatial scales in the ocean are usually set by the combined effects of stratification and rotation (e.g. Rossby radius of deformation, Burger number, etc). Topography adds strong constraints on these scales and, in practice, topographic scales often dominate. Therefore, it is not possible to explicitly specify the scales required for baseline data collection near topography. In this document, an attempt has been made to specify the considerations that should be taken into account by the Legal and Technical Commission when commenting on the work programme proposed by a contractor. When in doubt, the Commission should request advice from scientific experts to determine the suitability of the survey plan to resolve the required scales.

2. Physical and chemical baseline data

Physical and chemical baseline data should be collected over the entire exploration area, including the perimeter. The recommended sampling resolution is loosely based on World Ocean Circulation Experiment (WOCE) and CLIVAR (www.clivar.org) standards, with station spacing not exceeding 50 km. In regions of large lateral gradients (e.g. in boundary currents and near major topographic structures), the horizontal sampling spacing should be decreased in order to allow resolution of the gradients. As an example, in order to sample a 100 km x 100 km square of flat seabed, a minimum grid consisting of 3 x 3 stations is required. If a 100-km-long section of ridge crest, extending 5 km off the axis on either side of the crest is to be explored, this will most likely also require at least nine stations, because of the fact that the flow on either side of the ridge crest cannot be expected to be the same, even several hundred metres above the topography. In the vertical, there should be at least five samples each in the top and bottom 200 m of the water column. In the interior, the vertical sample spacing should be no more than 100 m. Here too, the resolution should be increased in high-gradient regions (e.g. to locate and quantify any oxygen minimum).

Water-column sampling must include all "standard" parameters (temperature, salinity, oxygen, chlorophyll in the euphotic zone, particle load), as well as the chemical parameters listed in Table 3 on page 517 of the report of the International Seabed Authority on "Standardization of Environmental Data and Information - Development of Guidelines'' (Phosphate, Nitrate, Nitrite, Silicate, Carbonate alkalinity, Zn, Cd, Pb, Cu, Hg, TOC). In addition, relevant physical and geochemical parameters (including pore-water chemistry) of the sediment should be determined, again with the same ISA guidelines serving as a reference for the list of chemical parameters to be reported (Table 2, p. 516: Phosphate, Nitrate, Silicate, Nitrite, Carbonate alkalinity, Eh, PH, Fe, Mn, Zn, Cd, Pb, Cu, Hg). Once details of the proposed mining-techniques are known, the parameter lists should be extended to include any potentially hazardous substances that may be released into the water column during mining. All measurements must be accurate to accepted scientific standards (e.g. CLIVAR). In order to allow for later analysis of additional parameters water samples suitable for analysis of dissolved and particulate matter should be collected and archived in a repository accessible for scientific study.

Once a target mining site has been identified, a high-resolution characterization of the base line will be required. The same parameters as before must be measured. As indicated above, it is not possible to specify concrete sampling requirements without detailed knowledge of the setting of the target site. However, the sampling resolution must be sufficient to characterize the distribution of the measured parameters across the entire target region. For parameters without significant horizontal gradients, the determination of base-line ranges (e.g. means and standard deviations) is considered adequate. For parameters with significant spatial structure (gradients, extrema) the sampling resolution must allow the structure to be characterized. Because of the strong influence of topography on the spatial scales of oceanic features it is expected that this will require a survey plan with station spacing depending on topographic scales, for example, with finer resolution on steep slopes.

Hydrothermal vent fields on spreading axes or volcanic centres are episodic, with a dormant phase for most of the time, alternating with active venting for some fraction of the time. From a geological point of view, there is a difference between dormant sites, which are still under the potential influence of a heat source, although there is no current venting of hydrothermal fluids under way, and extinct sites, which have been carried away from their heat sources, or the heat sources of which have been extinguished. However, from an ecological point of view, these two scenarios can be considered to be largely equivalent. What is important biologically, however, is whether there is active hydrothermal venting occurring at the site (case i), whether the planned mining operations will restart hydrothermal venting at an otherwise inactive site (case ii), or whether a site is hydrothermally inactive, even when disturbed by mining (case iii). It is therefore important that the baseline assessment includes a determination of whether the target site is case i, ii or iii. If the Legal and Technical Commission deems it important to know whether a site is truly extinct, that is to say, no longer associated with a heat source, heat-flow measurement can be used. (There was no consensus as to the importance of this distinction in our group, although more members were of the view that the distinction was not important on timescales relevant for mining.)

As part of the high-resolution baseline survey, a suite of representative pre-mining cores of the deposit, as well as a suite of representative pre-mining cores of seafloor sediment around the target area (including the top few cm, which can be lost when standard corers are used) are to be collected and stored in a suitable repository available for scientific study. (Here too, there was no full consensus in our group and the view was expressed that the Legal and Technical Commission should decide whether to include this recommendation in the final guidelines.) It is suggested that a reasonable sampling strategy would consist of sediment cores taken at 1-km intervals, starting at the margin of the deposit and extending at least 10 km along the four cardinal points.

In addition to the physical and chemical parameters, high-resolution (at least 200 m horizontal, 10 m vertical) high-quality (accuracy of 1% of water depth or better) bathymetric data should be collected over the area where the dispersal of mining by-products is expected to significantly impact the environment. The extent of the area will depend on the mining techniques to be used, as well as on the dispersal potential at the target site (see below). Furthermore, water-column vertical particle flux time series at the target site near the surface, at mid-depth and near the seabed must be determined. The temporal resolution of the particle-flux measurements must be one month or better and nephelometry time series should be recorded on the sediment traps.

It is expected that contractors will collect additional data (e.g. required for the physical characterization of the deposit) at higher resolutions than required in these recommendations. Full data sets of all potentially useful parameters should be made available to the International Seabed Authority to aid in the assessment of possible environmental impacts. (For reasons of transparency, it is recommended that commercially non-sensitive data be made publicly available.) The data to be released should include size, shape, tonnage, and grade of the deposit. This is important because it will indicate the magnitude of the disturbance caused by mining.

3. Assessing dispersal potential

Before mining is to begin, the dispersal potential for mining by-products (and potential accidental spills) from the target site must be determined. Designing a strategy again requires detailed knowledge of the proposed mining techniques and the topographic and oceanographic setting of the target site. In particular it is noted that specific topographic structures, such as seamounts, are often associated with dynamical features that strongly affect the regional dispersal potential. The dispersal assessment must be sufficiently detailed to resolve those features.

For each mining by-product, the timescale over which it causes significant environmental impact must be determined. (Of course, these timescales may depend on dilution, in which case determination of vertical and horizontal mixing rates near the target site must be included in the dispersal assessment.) Dispersal potential must be assessed over timescales that range from the tidal frequencies to the largest of these “environmental-impact” timescales. Both advective and eddy-diffusive contributions to the dispersal potential must be assessed. It is noted that an assessment of the dispersal potential in the deep ocean generally requires long-term monitoring efforts. Even the determination of mean-flow directions and speeds at depth can require several years' worth of current-meter data. Assessing eddy-diffusive dispersal is even harder and generally requires the application of Lagrangian techniques, such as neutrally buoyant floats or dye-release experiments. For these reasons, it is recommended that an assessment of the regional dispersal potential at several levels in the water column begin early during exploration. It may be possible to assess dispersal near the surface and near 1000m from available data - surface drifters and ARGO floats, respectively - and at the time of mining, additional data sets may have become available.

Before mining is to begin, the dispersal potential must be assessed at all levels where environmentally significant mining by-products are to be released into the water column and where accidental spills are considered most likely. The required vertical resolution will depend on the regional dynamical regime (vertical shear of the horizontal currents), but it is anticipated that at least three levels need to be sampled (near-surface, mid-depth, near-bottom). The flow near the seabed in particular must be temporally and spatially well resolved, for example, using bottom-mounted ADCP measurements with sufficient sampling to resolve the dominant tidal flows. In regions of topographic relief near the mining site, both the horizontal and vertical resolutions must be increased to allow the dominant dynamical structures that are usually associated with deep-sea topography (boundary currents, trapped eddies, overflows, etc.) to be resolved. Near active vent fields, it is often possible to gain useful first-order dispersal information at the level of neutrally buoyant plumes from hydrographic, chemical and optical observations. Interpreting plume-dispersal observations in terms of dispersal potential for mining by-products is complicated by a variety of factors, including the generally poor knowledge of the temporal and spatial characteristics of hydrothermal sources, the fact that hydrothermal plumes disperse at their equilibrium level, which depends both on the source and environmental background characteristics, and by the fact that the particle composition (and, thus, the settling velocity) of hydrothermal plumes cannot be controlled. Nevertheless, it is expected that hydrothermal-plume dispersal observations will be useful, in particular for designing controlled follow-up dispersal studies.

In order to complete an assessment of the dispersal potential, a 3D hydrodynamic numerical model that covers the temporal and spatial scales important for dispersal must be constructed and applied in a series of experiments. The contractor should use a model that is accepted by the ocean modelling community as well-suited for dispersal studies near the seabed; simple box models or z-coordinate models with coarse vertical resolution at depth are not expected to be adequate. The details of this model will be dependent on the topographic and oceanographic settings of the target site. Resolution should be in accordance with the scales described above (i.e., gradients should be resolved by several points) and the model needs to be validated by comparison with the observational data. After validation, the numerical model should be used to investigate "what if" scenarios, for example, to estimate the potential impact of accidental spills, or for certain extreme cases (atmospheric storms).

4. Monitoring during test mining

Before commercial mining is to begin, it is advisable to carry out test mining accompanied by environmental monitoring, in order to validate the assumptions, for example, as to the release of mining by-products, etc. The purpose of environmental monitoring during test mining is to determine if effects are consistent with those predicted in the existing environmental assessments and to ensure the detection of any unanticipated effects. Most importantly, monitoring results will be the primary basis for mining-impact assessments. Prior to, during, and after test mining, the baseline parameters listed above should be collected.

CHAPTER 18 GUIDELINES FOR ACQUIRING BIOLOGICAL DATA REQUIRED FOR ESTABLISHING ENVIRONMENTAL BASELINES AT POLYMETALLIC SULPHIDE DEPOSITS AND THE DATA- COLLECTION REQUIREMENTS FOR A MONITORING PROGRAMME

Explanation of approach

Excerpts from the International Seabed Authority report entitled "Guidelines for assessment of environmental impacts from the exploration for polymetallic nodules in the Area" (1999) were used as a template for the initial working group discussion that took place in Kingston, Jamaica, on 9 September 2004. The report included the following chapters:

1. Introduction
2. Definitions
3. Activities not expected to cause serious harm
4. Activities with potential for causing harm
5. Monitoring of activities, collection of baseline data, mitigation of effects
6. Reporting requirements
7. Regional baseline data
8. Recommended cooperative research
9. Future needs in environmental monitoring

Highlighted in bold are chapters with important sections for biological consideration, which were discussed in detail by the working group members. Chapters 1, 5, 6 and 9 are largely ISA boilerplate; working group members reviewed these chapters and suggest no changes.

1. Assumptions

We assume that licenses for extraction of polymetallic sulphides from the seafloor will not be granted until demonstrable technology and economics are in place (i.e., that mining the seabed is economically attractive in the Area compared to mining on land). The nature of the biological considerations associated with test mining of polymetallic sulphides depends on the type of mining technology used to extract the minerals, and on the scale of the operation (i.e., number of tons extracted per annum per region). The mining technology and scale of operation in turn likely depend on the water depth and the metal grade. For very rich metal grades, small mines can be economical, while a low-grade mine will require a much higher throughput.

Three methods – mechanical removal with or without initial processing on the seabed, blasting, and chemical dissolution – were identified at the International Seabed Authority Meeting in September 2004. Strip mining and open-cast mining were identified as methods in an International Seabed Authority technology brochure (ISA, 2000). Of the methods identified, mechanical removal without initial processing at the seabed was deemed the most likely technology to be used and is the method of mineral extraction assumed in this report. Deep-sea mining is assumed to be more mobile than that of terrestrial mining operations and thus may be more wide-spread (Halfar and Fujita, 2002).

We assume that the International Seabed Authority will monitor test-mining activities, will report activities to an advisory body that includes biologists with expertise in chemoautotrophic ecosystems, will inspect off-shore facilities as appropriate to ensure compliance, and will have the authority to intervene immediately should unsupportable risk to the biological communities be identified. The Authority should assume that deep-sea test mining will have adverse ecological impacts on organisms associated with deep-sea sulphides until evidence is presented to the contrary.

The Authority should revisit the biological considerations and requirements as technologies are developed and the proposed test mining technology is identified to ensure that assumptions and considerations described here continue to be relevant. We note that blasting has important implications for acoustic impacts on marine mammals, and that chemical dissolution raises important issues relating to toxicity affects in the environment. Risk assessment for any method of extraction of minerals from the seabed needs to be undertaken.

2. Definitions

Relevant terms defined in "Guidelines for assessment of environmental impacts from the exploration for polymetallic nodules in the Area" include the following:

> ***Exploitation*** means the recovery for commercial purposes of polymetallic sulphides or cobalt crusts in the Area and the extraction of minerals there from, including the construction and operation of mining, processing and transportation systems, for the production and marketing of metals.
>
> ***Exploration*** means searching for deposits of polymetallic sulphides or cobalt crusts in the Area with exclusive rights, the analysis of such deposits, the use and testing of recovery 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.

Marine environment includes the physical, chemical, geological and biological components, conditions and factors which interact and determine the productivity, state, condition and quality of the marine ecosystem, the waters of the seas and oceans and the airspace above those waters, as well as the seabed and ocean floor and subsoil thereof.

Polymetallic sulphides means hydrothermally-formed deposits of sulphide minerals which contain concentrations of metals including, inter alia, copper, lead, zinc, gold and silver.

Prospecting means the search for deposits of polymetallic sulphides or cobalt crusts in the Area, including estimation of the composition, sizes and distributions of deposits of polymetallic sulphides or cobalt crusts and their economic values, without any exclusive rights.

Serious harm to the marine environment means any effect from activities in the Area on the marine environment that represents a significant adverse change in the marine environment determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally-recognized standards and practices.

Additional definitions to clarify the intent of terms used in this report include:

active sulphides**:** polymetallic sulphides through which warm water is flowing. Active sulphides (also called hydrothermal vents) deliver reduced compounds (e.g., sulphide) to the seafloor-seawater interface where they can be oxidized or otherwise autotrophically metabolized by free-living or symbiotic microorganisms.

chemosynthesis**:** process by which microorganisms metabolically transform inorganic carbon to organic carbon (cells) using energy derived from oxidation of reduced compounds. Chemosynthesis is the basis for the food web associated with deep-sea hydrothermal vents. Chemoautotrophy is a more descriptive and precise term for the general phenomenon of chemosynthesis; the two words are often used interchangeably.

cumulative impacts**:** impacts resulting from incremental changes caused by other past, present or foreseeable actions.

direct impacts**:** impacts caused as a direct result of an action, such as loss of habitat and populations due to removal of sulphides or other materials.

endemism**:** refers to the degree to which a species is restricted to a particular geographic region; endemism usually occurs in areas that are isolated in some way. Biologists also use the term 'endemic' to refer to an organism that might be geographically widespread, but is restricted to a specific habitat, e.g., hydrothermal vents.

***fauna*:** the term fauna includes invertebrates and vertebrates

habitat area: polymetallic sulphides

***hard substrata*:** outcrops in the form of carbonate concretions, solid material, crustal rocks or deposits of precipitated materials, metals and minerals discharged from the subsurface by hydrothermal systems.

***hyperthermophiles*:** Archaea and Bacteria that grow optimally at temperatures in the range of 95 to 110°C and can survive to temperatures close to 120°C.

***impact zone*:** zone where impacts (direct, indirect, cumulative, and/or interactive) result from the activity.

impact interactions: the reactions between different kinds of impacts (e.g., physical disturbance of substratum and deposition of particulates). Impact interactions may be between impacts caused by just one action in the Area and/or between the impacts of other actions in the Area).

impact reference zones: areas used to assess the effect of activities in the Area on the marine environment; these impact reference zones must be representative of the environmental characteristics (physical, chemical, biological) of the area to be mined.

inactive (or dormant) sulphides: polymetallic sulphides through which warm water is no longer flowing into the overlying seawater (i.e., they are "cold"). Disturbance of these sulphides may result in renewal of hydrothermal fluxes into the water column, turning inactive sulphides into active sulphides (hence the concept of "dormant" sulphides).

indirect impacts: impacts on the environment that are not a direct result of the activity, often produced away from or as a result of a complex pathway (physical, chemical, biological). Often referred to as secondary (or even tertiary) impacts.

microorganisms: include Bacteria, archaea, and microscopic eukarya

***organisms*:** the term organisms includes bacteria, archaea, eukarya

***plankton**:* includes larval stages of benthic and pelagic organisms, phytoplankton (in surface waters), zooplankton, jellies, and other drifting or weakly swimming organisms

***polymetallic sulphides*:** hydrothermally-formed deposits of sulphide minerals which contain concentrations of metals including, inter alia, copper, lead, zinc, gold and silver (ISA Draft Regulations). These deposits include sulphides associated with active as well as inactive hydrothermal vent settings. These sulphides may occur as buried deposits or they may be exposed on the seafloor. They may occur on seamounts, mid-ocean ridges, and back-arc ridges.

preservation reference zones: areas representative of the mining site, but in which no mining shall occur; used to assess changes in the biological status of the environment caused by mining activities

***serious harm to the marine environment*:** any effect from activities in the Area on the living or non-living components of the marine environment and associated ecosystems which represent a significant adverse change in the marine environment, **or threat of** *serious or irreversible damage*, as determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally-recognized standards and practices.

sub-habitat: refers to a visually recognizable component of a larger habitat, e.g., tubeworm and mussel beds may be sub-habitats of a specific active polymetallic sulphide field; an operational term that facilitates an understanding of the habitat as a whole

***symbioses (chemosynthetic)*:** associations between bacteria (=symbionts) and invertebrates or vertebrates (= hosts), in which the symbionts are chemosynthetic and provide nourishment to the host. The bacteria may be either endosymbiotic (living within the host tissues; e.g. tubeworms, clams, mussels) or episymbiotic (living on the outside of the host; e.g. bresiliid shrimp, alvinellid polychaetes).

3. Activities not expected to cause serious environmental harm

Based on available information, a variety of technologies currently used in exploration are not considered to have the potential to provoke serious harm to the marine environment. These include:

(1) Positioning systems, including bottom transponders and surface, subsurface buoys filed in Notices to Mariners;

(2) Meteorological observations and measurements, including instrument deployment;

(3) Satellite monitoring e.g., AVHRR for plumes in surface waters;

(4) Oceanographic observations, including hydrographic observations and measurements, including instrument deployment;

(5) Gravity and magnetic observations;

(6) Towed plume-sensor measurements (chemical analysis, nephelometers, fluorometers, etc);

(7) Bottom or sub-bottom acoustic profiling (without use of explosives), electromagnetic profiling, profiling of resistivity, self potential, or induced polarization;

(8) Mineral sampling of limited nature such as those using grab or bucket samplers;

(9) Shipboard mineral assay and analysis;

(10) Sampling by box core, small diameter core, reamed reverse-circulation drill cutting samples, or grab sample to determine seabed geological, geochemical, or microbiological properties;

(11) Video/film and still photographic observation and measurements;

(12) Sampling of small quantities of water, sediment, and biota using precision sampling;

(13) Sampling with epibenthic sled, dredge, or trawl, so long as the sampling area does not exceed 5% of the habitat area;

(14) Metabolic measurements (e.g. dissolved oxygen consumption) at the sediment-water interface;

(15) DNA screening of samples from hard-substrate.

4. Exploratory phase activities (including test mining) with potential for causing environmental harm

4.1 Potential benthic impacts

(a) Direct impacts of sulphide recovery, where sediments and associated organisms will be crushed or dispersed in a plume and the sulphide removed;

(b) Smothering or entombment of benthic organisms away from the site of sulphide removal, where the sediment plume settles. This may be especially critical for sessile organisms attached to hard substrata and for epifaunal or infaunal organisms that cannot move quickly enough to adjust their position;

(c) Alteration of the nutritive quality of surfaces used by surface deposit-feeders or chemosynthetic associations;

(d) Clogging of feeding apparatus of suspension feeders; dilution of resources for deposit-feeders;

(e) Toxic effects associated with deposition of dissolved (from diluted mud discharges), fine and coarse metal sulphides in benthic habitats away from the site of sulphide removal. While particulate metal sulphides are not "bioavailable", it is conceivable that ingestion and digestive enzymes at low pH might render the sulphides and other discharged material bioactive;

(f) Loss of brood stocks for populations of species associated with polymetallic sulphides or other specialized and restricted habitats within the dispersal shadow of the test-mining mining-generated plume.

4.2 Potential water-column impacts (deriving from discharge of tailings, effluent at depth)

(a) Mortality of and changes in composition of plankton exposed to discharge plume, effluent (including larval stages of invertebrates colonizing sulphide deposits) caused by toxicity, interference with feeding mechanisms, alteration of trophic interactions.

(b) Effects on meso- and bathypelagic fish and other nekton caused directly by sediment plume or associated metallic species, or indirectly through the food web.

(c) Impacts on deep-diving mammals, such as through impacts on abundance of their prey.

(d) Depletion of oxygen by bacterial growth on suspended particles.

(e) Effects on fish behaviour and mortality caused by sediments or trace metals.

(f) Dissolution of heavy metals within the oxygen minimum zone and their potential incorporation into the food chain.

4.3 Potential Upper-Water-Column Impacts (if tailings, sediment, effluent are discharged near surface)

(a) Trace metal bioaccumulation in surface organisms;
(b) Reduction in primary productivity due to shading;
(c) Effects (positive or negative) of trace metals on surface productivity;
(d) Effects on behaviour of marine mammals and seabirds, due to reduced water clarity and/or reduction in abundance of prey.

5. Regional baseline data

Because the populations of fauna of sulphide deposits are subsets of metapopulations that interact through dispersal and colonization, it is important to know the degree of isolation of populations occupying the sulphide deposit that is removed and the likelihood that a given population serves as a critical brood stock for other populations. Regional baseline data thus include:

(a) Maps of size, distribution, and, as far as can be determined, age of sulphide deposits and other critical habitats (seeps, diffuse low temperature vents, whale skeletons);

(b) Regional hydrographic regimes.

What are the key biological parameters and what are the appropriate spatial and temporal scales required in order to evaluate the environmental impact of test mining? Before defining specific guideline recommendations, we identify here several points that should influence the guidelines. The Authority should:

(a) Advocate strategic selection of index parameters with robust statistical design wherever possible, rather than haphazard inventories with inadequate, inappropriate sampling;

(b) Take best advantage of data-collection methods that exploration requires (e.g., imaging, mapping);

(c) Recognize that quantitative sampling of hard substratum environments in the deep sea is a challenge that academic scientists do not routinely achieve. Small animals, or those hidden in crevices, amongst coral, etc, will require several types of sampling equipment.

(d) Recognize that exposed sulphide surfaces will be irregular, potentially steep-sloped, and difficult to image quantitatively without the use of an ROV or a new technology to be developed.

(e) Recognize that samples are required for taxonomic identifications, DNA sequencing, and voucher collections, and that a repository (or multiple repositories, as appropriate) should be designated for voucher collections.

(f) Recognize the value of digital photo- and genomic libraries of faunal vouchers and microbial assemblages; a financially, logistically, and scientifically rational program for the acquisition of these types of data should be a requisite part of the baseline requirements.

(g) Understand that taxonomy by numbers (e.g., species 1, species 2, etc), if consistent rules are used and vouchers are maintained, is a good basis for baseline studies, but that classical and molecular taxonomy must be supported, either directly by the mining companies or as part of Cooperative Research programmes.

(h) Anticipate that molecular methods will advance rapidly during the next decade, making biotic surveys at all levels, especially the level of microorganisms, much more rapid and economically feasible than they are today. Molecular sequences should be deposited in Genbank or equivalent internationally recognized sequence databases. The International Seabed Authority should monitor progress in these molecular technologies and revise baseline requirements as appropriate.

6. The seafloor community

A primary goal must be to determine whether the communities associated with sulphide deposits to be mined are robust or fragile and whether they are essentially permanent or ephemeral (Ahlfeld 2002). This goal can be accomplished through evaluation of physical factors that influence the distribution, abundance, and growth of the organisms associated with the sulphides and through studies of the age structure, growth rates, and patterns of senescence and death in the dominant organisms (Ahlfeld 2002).

The fundamental requirement for a baseline study that can be used to assess whether serious harm has occurred to a marine environment as a result of test mining of polymetallic sulphides is a species-abundance matrix for those areas likely to be impacted by the test mining. This is the basic information that biologists acquire to make an assessment of any community they encounter.

Appropriate methods for acquisition of quantitative species-abundance matrices for soft-sediment and pelagic environments likely to be impacted by test mining of sulphides are described in detail in the draft guidelines for manganese nodules and are not repeated here.

Hard substrata at or away from sulphide deposits, especially where the organisms are small, are recognized as challenging environments to sample quantitatively. Slurp sampling, grab samples of any larger organisms in the area, and video documentation or photo-transects may be the only means suitable for developing a species-abundance matrix. ROVs will be a better tool for documentation and sampling near or on vertical and hard substratum habitats than camera sleds. AUVs or hybrid ROVs-AUVs may ultimately prove to be an ideal survey/sampling platform.

7. Baseline requirements for sulphides deposits

The biotic survey of sulphide deposits should be of deposits that are biotically representative of the kind of deposit to be recovered or otherwise directly or indirectly impacted during the test mining programme. Analysis of organic carbon, nitrogen, and sulphur stable isotope compositions are useful preliminary screens for unusual trophic ecologies (i.e., reliance on chemoautotrophic or methanotrophic production rather than photosynthetic production). We recommend that isotopic analyses (C, N, S) be conducted on a statistically representative number of individuals for the one or more species that make up the bulk of the biomass within different sub-habitats.

Particular attention needs to be given to defining the baseline conditions of the affected environment. Data collection should be focused on determining the current and future status of the resource, and on the impacts of development plans and programmes. Attention also needs to be given to approaches suitable for active vs. inactive sulphides. The academic scientific community has paid scant attention to the ecology of inactive sulphides and is not yet in a position to provide much insight into potential impacts of test mining operations. We know that particulate metal sulphides can be used as substrates for autotrophic production by some microorganisms, but we do not know the rates of production or how or if this production is important as a trophic resource for heterotrophic organisms. We know little about the degree of endemicity of organisms associated with inactive sulphides. We know that some inactive sulphides are merely dormant, not cold, and can be reactivated by tectonic and volcanic processes or even by human intervention.

8. Minimum requirements

(a) Identify and qualitatively assess the distribution of all major sub-habitats of the proposed test mining site (e.g., mussel beds, tubeworm clumps, bacterial mats, and peripheral fauna); note that at inactive sulphides or hard substrata away from sulphides, there may not necessarily be easily recognized sub-habitats (in which case a random sampling strategy can be developed).

(b) Impact reference zones and preservation reference zones should be carefully selected and should be known (based on biotic surveys) to share the biotic characteristics of the polymetallic sulphide deposits and other habitats likely to be impacted. The selection of these zones should be reviewed by the ISA and an advisory board of scientists with an expertise in chemosynthetic ecosystems. Impact zones and preservation zones are likely to be extremely useful in evaluating environmental impacts (direct, indirect, cumulative and interactive). Impact and preservation reference zones allow one to understand natural variability in time and space associated with natural geological, hydrodynamic, and biological processes.

(c) For active sulphides, survey temperature-faunal relationships (e.g., 10-20 discrete, video-documented t-measures within each of sub-habitats).

(d) Bulk collection (slurp, grab, dredge) of invertebrates by sub-habitat in discrete sample boxes, 7 samples per sub-habitat, where possible, plus selective acquisition of individuals of representative fauna. This will enable determination of biomass, abundance or coverage dominants in a given sub-habitat. Collections should be photo-documented (and indexed to video imaging) *in situ* to provide an archive of context/setting information for each sample. GIS mapping tools are recommended as a means to place habitat and sample characteristics in spatial contexts.

(e) Standard practices for proper preservation of organisms should be followed, including discrete sampling of sub-habitats into separate sample containers with closed lids to prevent washing on recovery, recovery within 5-6 h of collection to obtain quality material, immediate processing and preservation of samples on deck or maintenance in cold rooms for durations of no more than 6 h before preservation (less where molecular assays are planned). Multiple preservation methods will be required, including, for example preservation in formalin for taxonomic studies, freezing or preservation in 100% ethanol for molecular studies, and drying of whole animals and/or selected tissues for stable isotope analyses.

(f) Collections sieved onto 63 μm and 250 μm sieves, 5 samples preserved 24 h in 10% buffered seawater formalin then into 70% EtOH for taxonomy. Two sub-samples frozen or preserved in EtOH using methods appropriate for molecular sequencing and archives. Megafaunal invertebrates should be preserved separately for subsequent taxonomic, molecular, and isotopic analyses.

(g) Subsequent sorting, identification (see 10 below), and enumeration of preserved samples in the laboratory, together with molecular and isotopic analyses as appropriate.

(h) Evaluate temporal variation for at least one sulphide deposit (ideally, annually over three years; minimally, twice – once at the beginning and once at the end of the year prior to the start of test mining activity). This evaluation must include a video/photo survey of sub-habitat distribution and associated temperatures and sampling of any new sub-habitats that appear. Strategies (including cooperative research) for determining growth rates, recruitment rates, and the trophic status of dominant taxa should be developed and executed as part of these time-series studies. The programme should also follow the sampling programme outlined in 1-6 above at each time interval.

(i) Evaluate spatial variation by sampling at least 3 sulphide deposits, if present, in the area, each separated by a distance greater than the projected deposition of 90% of the particles suspended by the test-mining operation.

(j) Exchange of identification codes, keys, drawings, sequences with major laboratories or collections that carry out taxonomic studies of vent fauna is required.

9. Traceability

Requiring the use of gene sequence databases, voucher collection repositories, and digital photo libraries, has the potential to lead to conflict with common heritage and bio-prospecting. The Working Group discussed this issue at some length and maintains that traceability is essential and must be achieved in a reasonable manner. Specimens must be archived for comparison with taxonomic identifications from other sites, and to verify the details of changes over time. If species composition does change, it might be subtle, and reference back to the original animals (where there might only have been a putative identification) is essential.

Impact assessment is the process of identifying the future consequences of an ongoing or proposed action (Arts et al., 2001). There has been much discussion in the impact assessment literature in recent years concerning the accuracy of impact predictions. There are often practical difficulties in verifying impact predictions in well-known ecosystems (such as coastal systems). A study by Sadler (1996) reports that 75% of the time, assessment is unsuccessful or marginally successful in providing confidence levels for data used in models predicting impacts. In the case of deep-sea habitats, this problem is exacerbated by limited available information. This problem is magnified as one moves from the simple activity that causes an impact (in this case the test mining), to strategic levels of decision-making (the test-mining of several sites), usually based on long-term actions (decades) and over a larger geographic area (The Area).

The guidelines suggested here will help to identify and predict the relevant effects of the test mining and to ensure that environmental considerations are explicitly addressed and incorporated into the decision making process. Available information on community structure and function of the sites where deep-sea test mining will take place is limited, therefore voucher collection repositories, a gene sequence database repository, and a photo-library of species/specimens will help to evaluate and to anticipate, avoid, minimize, or offset the adverse effects of the activities considered in test mining and mining of deep sea-floor sites. The goal of the impact assessment – to protect the productivity and capacity of natural systems and the ecological processes which maintain the functions of these natural systems – requires traceability.

Voucher collection repositories, a gene sequence database repository, stable isotope analysis and interpretation, and a photo library of species/specimens could be part of a partnership between scientific and corporate groups (see Cooperative Research, below). The basic scientific information acquired in partnership should result in cost-effective acquisition of information that will assist in development planning and decision-making, and the recognition of any significant environmental effects or key issues during test mining. This information can be used to find solutions with a minimum-conflict approach. By conducting the environmental impact process with impartial rigor, subject to verification, the forthcoming data can be used to evaluate the affected environment, to evaluate proposed alternatives and their impacts, and to identify measures necessary to monitor and investigate residual effects.

10. Cooperative research

Recent years have witnessed a revolution in the knowledge and technology development in deep-sea sciences. A number of research institutes around the world are carrying out extensive research programmes on seamount and ridge systems, including studies on hydrothermal vent habitats. These institutions have considerable biological and scientific expertise, and could be willing to join with the mining contractors in conducting some of the required environmental research. They could provide sampling equipment and expertise, and would likely be eager to join the contractor's vessel and to assist in sampling remote areas. Prospective test-mining contractors should be encouraged to contact appropriate scientific research institutes. The International Seabed Authority should continue to promote interactions between mining contractors and relevant international scientific programmes that might exist [such as the ChEss Program (part of the Census of Marine Life) and InterRidge].

- Cooperative research could involve interactions with multiple oceanographic disciplines and multiple institutions

- Cooperative research would likely facilitate establishment of baselines of natural variability from geologic and other environmental records in the selected areas. Cooperative Research programmes between mining contractors and academic or other institutions will likely facilitate studies of political, economical, social, and legal aspects.

- During the test-mining phase, mining contractors and cooperative research programmes may prove especially synergistic, bringing together the expertise, research facilities, logistic capability and common interests of the mining contractors and cooperative institutions and agencies. In this way, the mining contractors may make best use of expensive research facilities such as vessels, and the extensive expertise in geology, ecology, chemistry, and physical oceanography of academic colleagues.

- Cooperative research should establish a link between the scientific community and the commercial entrepreneurs in partnerships to develop full potential of the test-mining activities.

- The International Seabed Authority is encouraged to develop a training and preparation programme for biological sampling, preservation, and processing as part of a cooperative programme between mining contractors and the academic communities engaged in study of organisms associated with sulphide deposits. This will be especially important as deep-submergence technologies improve and as molecular methods evolve.

- The Authority should serve in an advisory capacity to mining contractors in terms of identification of cooperative research opportunities, but mining contractors should be free to seek their own links to academic and other professional expertise.

- The Authority and mining contractors should work together with cooperative research programs to maximize the assessment of environmental impacts while minimizing the cost of these assessments to the industry.

- Significant data on the fauna and sulphide deposits in "the Area" is held by a disparate range of parties, including marine scientists. Much of this data, including samples, is not readily available to the general public, and unpublished data and samples may be poorly archived after a group completes its work. To promote and market the Area as an attractive exploration target to mining contractors, the International Seabed Authority should consider options to secure subsets of these samples and copies of data as assets of the Area. Under the United Nations Convention on the Law of the Sea, Marine Scientific Researchers are obliged to provide coastal States with representative samples of minerals and fauna and to furnish it with copies of all data.

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CHAPTER 19 GUIDELINES FOR ACQUIRING BIOLOGICAL DATA REQUIRED FOR ESTABLISHING ENVIRONMENTAL BASELINES AT COBALT-RICH FERROMANGANESE CRUST DEPOSITS, AND DATA-COLLECTION REQUIREMENTS FOR A MONITORING PROGRAMME

1. Introduction

The 1982 United Nations Convention on the Law of the Sea ("the Convention") and the 1994 Agreement relating to the Implementation of part XI of the United Nations Convention on the Law of the Sea of 10 December 1982 ("the Agreement"), require the International Seabed Authority to develop the rules, regulations and procedures relating to prospecting, exploration and exploitation on the international seabed. At present, the Authority is in the process of adopting draft Regulations on Prospecting and Exploration for cobalt-enriched crusts on ridges and seamounts in the Area ("the draft Mining Code").' An important element of the draft Mining Code is the protection of the marine environment from activities relating to exploration.

Regulation 28(1) of the draft Mining Code provides that the Authority shall develop procedures for establishment of environmental baselines against which to assess the likely effects on the marine environment of activities in the Area. Regulation 28(2) provides that each contract shall require the contractor to establish environmental baselines against which to assess the likely effects of its programme of work on the marine environment and a programme to monitor and report on such effects.

These guidelines reflect the current state of scientific knowledge of the deep-sea environment. In accordance with the Convention, they have been developed taking into account the views of recognized experts in the field. It is recognized that certain activities that would be conducted during exploration, of a non-invasive nature, such as meteorological observations and measurements, and that have not been shown to cause environmental harm, can be separated from those that have to be monitored.

The guidelines stem from the acceptance of the international community's need to gain better understanding of the natural conditions at potential mining sites and to obtain additional scientific information on the potential impacts from mining.

2. Definitions

For the purposes of these guidelines, the following terms are to be read and interpreted in a manner consistent with the draft Mining Code:

"**Activities in the Area**" means all activities of exploration for, and exploitation of, the resources of the Area.

"**Area**" means the seabed and ocean floor and subsoil thereof, beyond the limits of national jurisdiction.

"**Authority**" means the International Seabed Authority.

"**Contractor**" means a State or entity which has entered into a contract with the Authority to carry out activities in the Area and includes the Enterprise when it has entered into such a contract with the Authority.

"**Exploration**" means searching for cobalt-enriched crusts on seamounts and ridges 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.

"**Marine environment**" means the physical, chemical and biological components, conditions and factors which interact and determine the productivity, state, condition and quality of the marine ecosystem, including the coastal area, the waters of the seas and oceans and the airspace above those waters, as well as the seabed and ocean floor and subsoil thereof.

"**Seamounts**" means isolated sub-surface features, usually of volcanic origin, of significant height above the seafloor.

"Cobalt-enriched crusts" means ferromanganese crusts with enriched cobalt content typically formed by precipitation and found on hard substrates in the deep sea on features with significant topographic relief, such as seamounts and ridges.

"**Resources**" means all solid, liquid or gaseous mineral resources in situ in the Area at or beneath the seabed, including polymetallic nodules and cobalt-enriched crusts.

"**Secretary-General**" means the Secretary-General of the Authority.

"**Serious harm to the marine environment**" means any effect from activities in the Area on the living or non-living components of the marine environment and associated ecosystems which represent a significant adverse change in the marine environment determined according to the rules, regulations and procedures adopted by the Authority on the basis of internationally recognized standards and practices.

3. Activities not expected to cause serious environmental harm

For the purposes of these guidelines, two phases can be distinguished during exploration. The first phase is the period during which baseline data are obtained. This period typically involves testing components of the mining system (engineering tests) and precedes testing of the integrated mining system.

The second phase occurs when the integrated mining system is tested, for example, for endurance and reliability (test mining); monitoring of the environmental impacts of test mining is required.

Based on available information, exploratory activities of the type listed below, whether carried out before or during the test mining phase, are not considered to have the potential for causing serious harm to the marine environment and will require no further environmental assessment:

(a) Gravity and magnetometric observations and measurements;

(b) Bottom and sub-bottom acoustic or electromagnetic profiling or imaging without the use of explosives;

(c) Mineral sampling of a limited nature such as those using either corer, grab or basket samplers;

(d) Sampling of water-column physical and chemical properties and its biota;

(e) Meteorological observations and measurements, including the setting of instruments;

(f) Oceanographic, including hydrographic, observations and measurements, including the setting of instruments;

(g) Sampling by box corer, small diameter corer or grab sampler, or dredge to determine seabed geological or geotechnical properties;

(h) Sampling with epibenthic sled, dredge, trawl, grab, box-corer or other gear used to sample the fauna on and around seamounts, so long as the area disturbed by sampling is a very small fraction (generally < 1%) of the habitat area, except for highly limited habitats, such as the summit of small seamounts, where the proportion of the area sampled may be somewhat greater;

(i) Use of imaging systems (e.g. video, camera);

(j) Shipboard mineral assaying and analysis;

(k) Positioning systems, including bottom transponders and surface and subsurface buoys filed in Notices to Mariners;

(l) Dye-release tracer studies.

4. Activities with potential for causing environmental harm

Current scientific information indicates that some environmental impacts may be caused by test mining during the exploration period, although the potential for serious environmental harm is not known. It is anticipated that the potential for serious environmental impact will be greatest at the seafloor and at the depth zone of discharge of mine tailings and effluent and below. Because of the potential for some environmental harm, it is strongly recommended that discharges be released below the bottom of the oxygen-minimum layer.

4.1 Potential benthic impacts

It is anticipated that the primary benthic impacts caused by test mining during the exploratory phase will be:

(a) Direct impacts along the track of the crust collector, where the crust and associated fauna will be removed or dispersed in a plume consisting of crust fines, sediment, trace chemical constituents, and living, dead and macerated fauna;

(b) Potential toxic effects associated with the deposition or dissolution of crust material on suspension and deposit feeders away from the mining site;

(c) Smothering or entombment of the benthic fauna away from the site of crust removal, where the plume settles; and

(d) Clogging of suspension feeders' feeding apparatus and dilution of their food resources.

4.2 Potential water-column impacts

Discharge of tailings and effluent below the oxygen-minimum zone during mining may cause some environmental harm to the pelagic fauna.

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

(b) Effects on meso- and bathypelagic fishes and other nekton caused directly by the sediment plume or associated metallic species or indirectly through impacts on their prey;

(c) Impacts on deep-diving marine mammals, such as through impacts on abundance of their prey;

(d) Impacts on bacterioplankton through the addition of fine sediment in meso- and bathypelagic zones;

(e) Depletion of oxygen by bacterial growth on suspended particles or by chemical oxidation of resuspended reduced metals;

(f) Effects on fish behaviour and mortality caused by the sediments or trace metals;

(g) Dissolution of heavy metals (e.g. copper and lead) within the oxygen-minimum zone and their potential incorporation into the food chain; and

(h) The possible clogging of zooplankton by filtering particles in the plume.

4.3 Potential upper-water column impacts

If tailings, sediment and effluent are discharged in near-surface waters (above the thermocline) then there are additional impacts to those listed in section 4.2 above.

(a) The potential for trace-metal bioaccumulation in surface waters;

(b) Reduction in primary productivity due to shading of phytoplankton by the surface discharges;

(c) Enhanced primary productivity and potential changes in community composition due to fertilization with nutrients or micro-nutrients (e.g. iron) from deep water;

(d) Potential deleterious effects on phytoplankton from trace metals; and

(e) Effects on behaviour of marine mammals and seabirds caused by the mining operation, reduced water clarity, lower abundance of prey and/or food web amplification of toxic trace metals from the surface discharge.

5. Monitoring of activities, collection of baseline data, and mitigation of effects

The activities in each exploration plan are expected to include general survey operations, such as those listed in section 3, and also engineering tests conducted to develop and demonstrate mining techniques. During the two phases, it is very important to obtain sufficient information from the potential mining sites (commonly termed "baseline data") to document clearly the natural conditions which exist prior to mining, and to gain insights into the natural processes such as dispersion and settling of particles, and benthic faunal succession, and to gather other data which will make it possible to acquire the necessary capability for accurate environmental impact prediction.

The impacts of naturally occurring periodic processes on the marine environment, such as tidal effects and seasonal effects, as well as episodic processes, such as the El Nino/Southern Oscillation and large tropical storms going through the area, are believed to be significant but are not well quantified. Thus it is very important to acquire as long a history as possible of the natural responses of surface and benthic communities to these processes.

Under the provisions of the draft Mining Code, contractors will be required, in cooperation with the Authority and the sponsoring State or States to establish environmental baselines against which to assess the likely effects of the programme of work on the marine environment and a programme to monitor and report on such effects. To maintain the credibility of the environmental impact assessment, it is critical that qualified independent scientists are contracted to establish the environmental baseline and to monitor and report on potential impacts.

Contractors will also be required to permit the Authority to send its inspectors on board vessels and installations used by the contractor to carry out activities in the exploration area to, inter alia, monitor the effects of such activities on the marine environment.

Collection of baseline data will be the primary concern during the engineering test, while monitoring of test mining will focus on acquiring a predictive capability for the impacts to be expected from the commercial or strategic system. Monitoring requirements for these two classes of activity are described in the following sections.

5.1 *General exploration survey monitoring*

In accordance with the draft Regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area (hereafter known as the 'draft Mining Code'), the contractor's programme of work during the exploration phase would be annexed as a schedule to the contract for exploration. Initially, the programme of work will consist of those elements specified by the contractor as part of its application for approval of a plan of work for exploration.

These would include, inter alia:

(a) A general description and a schedule of the proposed exploration programme, including the programme of work for the immediate five-year period, such as studies to be undertaken in respect of the environmental, technical, economic and other appropriate factors that must be taken into account in exploration;

(b) A preliminary assessment of the possible impact of the proposed exploration activities on the marine environment;

(c) 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;

(d) A description of a programme for oceanographic and environmental baseline studies in accordance with these regulations and any environmental regulations and procedures issued by the Authority that would enable an assessment of the potential environmental impact of the proposed exploration activities, taking into account any guidelines issued by the Authority.

If the contractor's plan of work for exploration is determined to be otherwise acceptable and is approved by the Council, the Secretary-General will specify an environmental field plan. The plan will be based on the plan proposed by the contractor and reviewed by the Legal and Technical Commission for completeness, accuracy and statistical reliability. It would then be incorporated into the programme of work under the contract.

The environmental field plan, among other things, will include monitoring environmental parameters relating to verification of the above findings concerning potential impacts (sect. 3), and will be devoted primarily to collection of data that address the three unresolved concerns with the potential for serious environmental harm, as identified in section 4, as well as to confirm the preliminary assessments of insignificant harm for all other potential impacts identified in published environmental assessments for deep-seabed mining. The Authority has developed technical guidelines (sect. 7), which include parameters pertaining to oceanographic data collection. These technical guidelines are intended to provide assistance in developing environmental field plans in consultation with contractors.

5.2 Monitoring of test mining

The contractor must provide the Authority with sufficient notice of planned test mining. The Authority views the mining system tests as an opportunity to examine, with industry, the environmental implications of mining.

Prior to conducting test mining, the contractor shall submit to the Authority a test mining plan. Preliminary descriptions of test mining, if they exist, should be submitted to the Authority with the application for approval of a plan of work for exploration; details shall be submitted at least two years before testing begins.

A test mining plan shall include provision for monitoring of those areas impacted by the contractor's mining activities where the proposed activities have the potential to cause serious environmental harm, even if such areas fall outside its mine site. The programme will include, to the maximum extent practicable, specification of those activities or events that could cause suspension or modification of the tests due to serious environmental harm if the specified activities or events cannot be adequately mitigated. The programme will also authorise refinement of the test mining plan prior to testing and at other appropriate times, if refinement is necessary to reflect proposed operations accurately or to incorporate recent research or monitoring results.

The test mining plan will include strategies to assure that sampling is based on sound statistical methods, that equipment and methods are scientifically accepted, that the personnel who are planning, collecting and analysing data are independent and scientifically well qualified, and that the resultant data are submitted to the Authority in accordance with specified formats. Technical guidelines for parameters to be included in the test mining plan are identified in section 7.2.

At the mining-test stage, delineation of the impact reference area and preservation reference area is recommended. The impact reference area should be selected based on it being representative of the environmental characteristics, including the biota, of the site to be mined. The preservation reference area should be carefully located and large enough so it is not affected by the natural variations of local environmental conditions. Its species composition should be comparable to that of the test-mining area, and it should be located upstream of test mining operations. The preservation reference area should be outside the test-mining area and areas influenced by any mining or processing plumes.

6. Reporting requirements

To enable the Authority to implement its responsibility for environmental protection as described in section 1, the contractor shall report regularly, and at least annually, on the environmental impacts of the activities proposed and undertaken and on the environmental baseline data obtained. Section 7 describes possible formats to use for submitting this information for general exploration surveying. The contractor must present physical, chemical and biological information for the exploration area. This information should include all relevant environmental information, if any, obtained during the reporting period. Specification of formats and data requirements will be developed through consultation between each contractor and the Authority. Planned activities in the exploration area, including the testing of integrated mining systems, which simulate commercial recovery, also must be described. If information submitted indicates that the integrated system tests are resulting in serious environmental harm, the Legal and Technical Commission may modify the terms and conditions under which the tests are conducted to address such problems. In all such modifications, the Commission shall take into account the state of the technology being developed, the processing system utilised, the value and potential use of any waste, the environmental effects of the activities, the economic and resource data, and the international need for the mineral resources.

7. Regional baseline data

Although the actual technology for exploiting cobalt-enriched crusts is not known today, the technical principles of mining are known and the environmental disturbances may be predicted to some extent. This premise justifies issuance by the Authority of guidelines for the collection of baseline data against which potential impacts may be assessed. The main impacts are expected to be at the seafloor, with minor impact expected at the tailings-discharge depth and in the water column below. The mining operation will remove the crust and associated fauna. The break-up of crust material will create a near-bottom plume, which may partly be transported to the ocean surface depending on the technology for lifting the crust material. The mining vehicle will also compress and damage the benthic fauna in adjacent areas where it operates.

The sediment and fine crust material transported to the surface with the crust may be discharged into the ocean together with the fines. Disposal in the surface waters would possibly:

(a) Interfere with primary productivity by increasing the nutrient levels and decreasing the light penetration into the ocean;

(b) Enter the food chain and disturb vertical and other migrations; and

(c) Lead to the reduction of manganese oxide and the solution of metal components in the oxygen-minimum zone;

(d) Therefore, the suggested tailing discharge should be well below the oxygen-minimum zone. Because the oxygen-minimum zone varies regionally and to some extent seasonally, environmental studies must;

(e) Determine the depth range of the oxygen-minimum layer at each mining area;

(f) Concentrate on the oceanographic properties around the discharge depth;

(g) Include oceanographic parameters in the upper water layer because of the potential for accidental discharge.

7.1 Baseline-data requirements

7.1.1 Physical and chemical oceanography

To assess the potential environmental impact of crust mining, baseline conditions and the potential dispersal of material must be assessed near the seabed, at any potential discharge depth, and near surface. As noted in the report of the Working Group on Physical and Chemical Considerations, the detailed sampling regime will depend on the underlying topography of the claim area. We refer the reader to that report for its detailed consideration of the vertical and horizontal spatial scales of sampling, the sampling programmme and types of measurements required, as the basis for an adequate baseline for the claim area and to develop physical models of dispersal potential and hence, environmental impact.

7.1.2 Seafloor community

Mining of cobalt-enriched crusts will have its greatest impact on the seamount or ridge benthic community. Because a large proportion of this community may have a highly-localized distribution, biological sampling should be carried out, so far as possible, on all seamount features of potential interest within each claim area, in order to build a picture of the distribution of the seamount community within the claim area. Seamount faunas typically vary in relation to local topography (e.g. summit, slope or base of the seamount), sediment cover, depth, seamount height and size, slope angle, oxygen content in the water, currents, regional productivity and potentially other factors. Habitat types should be assessed initially based on photographic/video transects, and by submersible or ROV, if possible. Imaging surveys carried out by the contractors to map sites of potential mining interest can serve several purposes, so long as there is adequate biological resolution (see below). Further biological sampling must be stratified by habitat type, which will be defined by seamount topography (e.g. summit, slope and base), hydrography, current regime, predominant megafauna (e.g., coral mounds), oxygen content of the water if the oxygen minimum layer intersects the seamount, and potentially by depth as well, with replicate biological samples obtained using appropriate sampling tools in each stratum. A minimum of five replicate epibenthic sled samples per stratum is recommended for collection of specimens and to assess species richness.

7.1.2.1 Macrofauna and megafauna

Data on habitat type, community structure, associations of megafauna with substrate, and the abundance, percent cover, and diversity of megafauna should be based initially on at least four photographic transects to cover the four quadrants and extending from the flat seafloor beyond the base of the seamount, along its slope and across its summit. (More limited sampling may be required on larger seamount features.) Further photographic transects should be carried out in crust areas of potential mining interest. To resolve the fauna, the camera system should be maintained no more than 3 m from the seafloor and be able to resolve features greater than 1 cm in diameter.

Photographic/video images provide extremely limited species resolution, so further biological sampling is required using appropriate samplers within each habitat and community type. Hard substrate habitats should be sampled with a dredge or epibenthic sled with an inner cod-end mesh of 25 mm (e.g. the CSIRO Seamount Epibenthic Sampler (Lewis 1999). A photographic reference collection of the fauna should be obtained, species being photographed under standard light conditions as soon as possible following retrieval to record natural colours. Abundance and, where possible, individual biomass should be recorded by taxon; however provisional taxonomic identifications (e.g. starfish sp.1, starfish sp.2, etc) may be required during the field work, based on photo identifications. The data can be revised following definite species identification in the laboratory. The bulk of specimens should be preserved in formalin, with replicate (up to 30) individuals of dominant fauna preserved in ethanol for possible genetic analysis. In soft bottom areas, such as at the base of the seamount and surrounding seafloor, at least 5 replicate box-core or 10 replicate multiple-core samples should be collected for quantitative sampling of the sediment biota. Macrofaunal and meiofaunal community structure (abundance, species structure, diversity) and bacterial biomass should be assessed using standard sampling protocols.

The macro- and megafauna should be identified to species so far as possible in the laboratory. The taxonomy of this fauna is highly specialized, so proper identification will require development and use of a collaborative network of taxonomic specialists. Due to the potentially high levels of endemism of the seamount fauna and its implications for conservation, it is essential to be able to rigorously compare the faunas from different areas surveyed by different investigators. Consistent taxonomy, conducted to international standards, is therefore critical.

7.1.2.2 *Crust fauna*

In addition to the macro- and megafauna, the meiofaunal and microbial community structure and biomass associated with the cobalt-enriched crust should be examined from rock dredge and rock drill samples, or obtained from ROV/submersible sampling, where possible. At least 10 samples should be taken, and species identified that live on the rock or in crevices and pits in the crust.

7.1.2.3 *Demersal fishes*

The demersal fishes and other nekton living over the seafloor should be assessed by trawling, so far as possible. At depths beyond trawl capabilities and on very rugged bottoms, this community will be assessed based upon towed photographic/video transects, with deployed cameras set up to record at different time periods, or with submersible/ROV observations and photographs. Seamounts can be important ecosystems with a variety of habitats for a number of fish species that form aggregations there for spawning or feeding. Therefore the impacts of mining operations could be significant for this fish behaviour, and needs to be evaluated.

7.1.2.4 *Trace metals in benthic and benthopelagic organisms*

Trace metals should be assessed in muscle and target organs of dominant benthic and benthopelagic fish and invertebrate species. This should be done at least four times before mining operations begin (to measure natural variability), and thereafter at least annually to monitor possible changes due to mining activity.

7.2 *Pelagic community*

7.2.1 Deep water

The pelagic community structure of deep zooplankton and fish around the depth of the plume and in the benthic boundary layer need to be assessed. It is recommended that the fish community be assessed in the upper 1,500 m based on depth-stratified sampling in at least three depth strata. Replicate sampling should be carried out on a diel basis and temporal variability examined.

7.2.3 Surface water

If there is potential for surface discharge, the plankton community in the upper 200 m of the water column is to be characterized. Measurements should be made of phytoplankton composition, biomass and production; zooplankton composition and biomass, and bacterial plankton biomass and productivity. Temporal variation of the plankton community in the upper surface waters on seasonal and interannual scales should be studied. Remote sensing can be used to augment field programmes. Calibration and validation of remote sensing results are essential.

7.2.4 Marine mammals and other pelagic megafauna

Observations on marine mammals and, so far as possible, other near-surface megafauna (e.g. turtles, fish schools) are required. Sightings of marine mammals and other pelagic megafauna should be recorded during the baseline study. It is recommended that marine mammal and megafaunal species and their behaviour be recorded on transects between stations. Temporal variability should be assessed.

7.3 Test mining

In addition to the information needs outlined in section 7.1, the contractor shall provide to the Authority a test mining plan (see section 5.2). This plan will include an early characterization of engineering tests and monitoring procedures proposed for the life of the exploration contract. The Authority recognizes that details of the tests are likely to be unique to the contractor. Therefore details, including possible mitigation measures, additional baseline studies etc., should be proposed by the contractor, reviewed by the Legal and Technical Commission on a case-by-case basis, and worked out through mutual consultation as activities evolve. Two categories of parameters are to be included in the test mining plan. The first category consists of parameters that can be studied properly using the techniques currently available. The second category consists of parameters that are difficult to measure or observe with existing technology. The parameters listed in section 7.3.3.1 to 7.3.3.5 must be included in the test mining plan and included in the contractor's data submissions to the Authority within two years after testing operations.

Impact assessment must be based on a properly designed BACI (Before-After Control-Impact) study with sufficient replication to detect impacts on the order of a 50% change in community structure in surrounding areas. Environmental monitoring during test mining must therefore be carried out at mining impact and comparable reference sites, to be selected based on an initial assessment of their faunal composition. The impact assessment must include impacts on both the benthic and pelagic environment.

7.3.1. Mining system characteristics

Each of the following characteristics of the system to be tested relates to crust-collector contact, benthic discharge or surface discharge. The reasons for the Authority's interest in these characteristics of the mining system are twofold:

(a) To evaluate the degree to which the proposed system falls within the existing impact analysis assumptions for first generation technology already covered in existing environmental assessment efforts; and

(b) To provide inputs for impact prediction modelling efforts.

The parameters of interest include:

(a) Crust removal technique

(b) Method for transporting the crust to the surface

(c) Mine-ship processing of crust, including washing and separation from sediment or rock

(d) Overflow discharge rate

(e) Estimated crust recovery rate from the seafloor and overall.

7.3.2 Test mining

The following data must be submitted by a contractor before planned test mining:

(a) Test site location and boundaries,

(b) Test plans

(c) Transportation corridors in the Area, and

(d) Estimated characteristics of surface and benthic discharges, including discharge point geometry flow rate and variations with time, composition and density, discharge temperature, and size distribution of suspended particles.

7.3.3. Environmental monitoring during test mining

The purpose of environmental monitoring during test mining is to determine if effects are consistent with those predicted in the existing environmental assessments and to ensure the detection of any unanticipated serious harm. Most importantly, monitoring results will be the primary basis for mining impact assessments. Prior to, during and after test mining, the baseline parameters outlined in section 7.1 should be collected. To obtain statistically defensible data, the period of monitoring should be determined in accordance with sound scientific principles. In addition, the parameters mentioned in section 7.2.3.1 to 7.2.3.5 should be measured during the test mining period. Those mentioned in section 7.2.3.6 to 7.2.3.7 are highly recommended for measurement during the test-mining period. Contractors working within a similar biogeographic region and using similar mining techniques may collaborate in designing a single impact assessment.

7.3.3.1 *Benthic impact and faunal succession*

Information from samples, photographs, videotapes or other means will assist in determining the impact on the benthos. Such information will help to resolve questions about the significance of the impact and will assist in developing any appropriate mitigation strategies for commercial recovery operations. Information on the faunal succession that follows the mining will help to determine the potential for the recovery of the benthic population from the effects of mining. Data should include samples in the immediate test area before and after test mining, at selected distances away from the mined area to determine the effect of the benthic plume, and at selected times after test mining (e.g., at 1, 5 and 10 years). These impact experiments can be conducted collaboratively among collaborators.

7.3.3.2 *Impacts on plankton and effects of trace metals*

A combination of monitoring and shipboard and laboratory experimentation may be necessary to resolve completely, prior to test mining, the issues of impacts on phytoplankton and zooplankton if there is surface discharge and the effects of trace metals.

7.3.3.3 *Observations of upper-water biota*

Information on other effects of the plume on the midwater biota can be gathered by making observations of unusual events such as fish kills from air embolism in the area of the test mining discharge zone, and unusually large concentrations of fish, marine mammals, turtles, and birds.

7.3.3.4 *Vertical light distribution*

The vertical distribution of light directly affects primary productivity in the euphotic zone. If there is surface discharge, vertical light-intensity profiles will show the effect of discharged particles on light attenuation and spectral bands (photosynthetically active radiation - 400-700 nm, and blue light - 475 nm) over time, depth and distance from the mining ship. These values will be used to detect any accumulation of the suspended particles at the pycnocline.

7.3.3.5 Particle dispersion in midwaters

Data on the dispersion of mining-solid discharges will refine existing dispersion models to make accurate predictions of plume behaviour and to assist in extrapolating from test mining to commercial-scale mining.

7.3.3.6 In situ settling velocity

Knowledge of in situ settling velocities for mining discharge particles, both in mid-water and near the seafloor, will help verify and improve the capacity of mathematical models for accurately predicting the dispersion of the midwater and benthic plumes. This information is relevant to the concerns expressed in section 7.2. regarding the midwater plume and to the primary concern of impacts from the benthic plume on the benthic biota.

7.4 Data collection, analysis and archival protocols

7.4.1 Data accessibility

The baseline, engineering test and test mining studies carried out on the parameters listed in sections 7.1 and 7.2 represent an important source of data and knowledge. The synthesis of such data and experience can work to the advantage of all contractors. As an example, synthesised data on bathymetry, currents, winds, salinity, temperature, and dissolved oxygen fields can form critical inputs for the modelling of regional-or basin-scale oceanographic processes. Models can be validated and fine-tuned by this sea-truth data and can then partially supplement costly data-collection exercises. Some claim areas lie adjacent to or in the vicinity of other claims providing a further justification for data accessibility and the joining of efforts in modelling, so that activities in neighbouring areas can be modelled and accounted for.

Mining may require real-time data on water-column conditions both for the safety of pipelines that carry crust material to the ship and for optimising the discharge depth of pipelines carrying the tailings. In such cases, increased data accessibility increases the likely accuracy of models and will assist:

(a) In the identification of best practices;

(b) In the development of a common approach to an acceptable database;

(c) In the multilateral exchange of views and data leading to international cooperation;

(d) In savings of time, effort and cost in alerting the community to failures;

(e) In savings through reduction of measurement of some parameters.

The workshop strongly recommended that all contractors make environmental data freely available within two years of data collection.

7.4.2 Data collection and analysis

The types of data to be collected, the frequency of collection and the methodology are outlined in these guidelines. 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 Organisation (UNESCO) and available at World Data Centres and Responsible National Oceanographic Data Centres, or those established or recommended by the Authority. Selected manuals and guides are listed in appendix A to the present document.

7.4.3 Data archival

It is recommended that data, data descriptors and inventories of the data be deposited with the Authority. Environmentally important data of the type listed in sections 7.1 and 7.2 should be freely available for scientific analysis and an inventory of the data holdings from each contractor should be accessible on the World Wide Web. Metadata that detail the analytical techniques, error analyses, descriptions of failures, techniques and technologies to avoid, comments on sufficiency of data and other relevant descriptors should also be included in addition to the actual data. Such a data archival and retrieval scheme could assist all contractors in the search for environmentally-significant indicator elements.

7.4.4 Reporting

Assessed and interpreted results of the monitoring shall be reported to the Authority together with the data according to regulation 28 and annex 4, section 5.4, of the draft Mining Code.

8 Recommended cooperative research

To answer certain questions on the environmental impacts from mining, specific experiments, observations and measurements must be conducted. However, all contractors need not execute the same studies because reactions in the affected ecosystems are likely to be similar. Repeating certain experiments or impact studies would not necessarily add to scientific knowledge or to impact assessments, while needlessly consuming financial, human and technological resources. Since all contractors will have access to experimental results, it would be unfair to burden the efforts on a single contractor. However, all contractors should be expected to collaborate in research to incrementally increase scientific understanding of the Co-crust and seamount ecosystems. Therefore, contractors are strongly urged to explore and find means to unite some of their efforts in international cooperative oceanographic studies.

On the other hand, the abundance and diversity of seamount fauna, its levels of endemism and hence susceptibility to extinction, will likely vary considerably from one site to another. Studies of faunal diversity and distribution will therefore need to be carried out at each potential mining area.

Taxonomic expertise is extremely limited, even for major groups within the fauna, for example, fish, molluscs, decapod crustaceans, corals, sponges, and the echinoderms. It will be important that at least these key groups—and as many others as possible—be assessed at each site. This can be accomplished most efficiently through development of cooperative taxonomic "centres" or groups of experts who will be responsible for the taxonomic identification of each major group.

The potential risk of extinction for a significant fraction of the seamount fauna within a potential mine site will depend largely on the distribution of the fauna, that is, how localized or widespread the species are distributed. Assessment will require syntheses of the biogeography of the seamount fauna. This will require collaboration among mining contractors and with the broader seamount research community.

The biology of dominant components of the seamount fauna is poorly known but of considerable importance to assess potential impacts and recovery rates. Critical parameters include rates of growth, longevity, age of maturity, modes of reproduction, dispersal and recruitment. Population genetic studies should be carried out to provide further insight into exchange processes between seamounts within and between chains/clusters. These studies can be carried out collaboratively and/or results shared among mining contractors, so these studies can be carried out most efficiently.

The dynamics of recruitment and of the recolonization of disturbed seamount habitat and the time-scale of the recovery process needs to be assessed, and this can be undertaken cooperatively.

Modelling studies should be undertaken collaboratively, closely linked to the field studies, to assess extinction risks under various management strategies, including various options for the design of protected areas. Overall conservation strategies need to take account of other impacts on the seamount fauna, such as of bottom trawling and coral harvesting.

8.1 Mining tests

The mining tests are to be conducted by all contractors, unless they use mining equipment which has already been tested by other contractors. In a mining test, all components of the mining system tested earlier in various engineering tests will be assembled and the whole process of mining, lifting crust to the ocean surface and discharge of tailings will be executed. This will be the first occasion on which all impacts will occur. As this mining test will be an endurance test for the engineering, it is assumed that it will last up to several months and may be done with a somewhat scaled down system. For environmental assessments, it is most important in the development of mining that this test phase be carefully monitored and investigated. However, the environmental impact assessment need not be repeated by all contractors. After in-depth evaluation of the first mining test, predictability of impacts for other mining systems will be available and in later tests environmental studies may be restricted to unresolved questions or to specific local environmental conditions or to changes of impacts due to different techniques. It seems reasonable to assume that a first mining test will extend our knowledge considerably, and all contractors will gain through this experience. Subsequent mining tests may be conducted with much less effort. For these reasons, it is expected that contractors will unite their efforts in the first and following mining test to achieve the maximum in knowledge increase with a minimum of effort on behalf of each contractor.

9. Future needs in environmental monitoring

Monitoring, baseline data collection and continued research on seamount communities may develop information on future needs for mitigating potential environmental harm. If such needs are identified, terms, conditions and restrictions may be modified appropriately.

As the environmental monitoring programmes of potential contractors develop, standardization of methodology and reporting of the results is envisioned as extremely important. The Authority should promote the unification and standardization of research and development methods and technologies. In this regard, it was noted that such standardization should include instruments and equipment, quality assurance in general, collection, treatment and preservation techniques of samples, determination methods and quality control on board vessels, analytical methods and quality control in laboratories, and data processing and reporting. Method standardization will allow for comparison of results across the seamount provinces and lead to selection of critical parameters for monitoring efforts. As seabed mining technology develops, sediment dynamic studies are required to provide an understanding of how particles in the layer above the seafloor are transported. Included in these studies should be the geochemical changes in sorption of metals. In future, recolonization of disturbed areas should be monitored to assess the likely timescale for post-mining environmental amelioration.

Part VI

RECOMMENDATION OF THE WORKSHOP AS SUBMITTED TO THE LEGAL AND TECHNICAL COMMISSION AT THE ELEVENTH SESSION OF THE INTERNATIONAL SEABED AUTHORITY AS DOCUMENT ISBA/11/LTC/2

1. Introduction

In respect of the protection and preservation of the marine environment during prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crust deposits, the draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area (ISBA/10/C/WP.1) would require the International Seabed Authority, inter alia, to establish and keep under periodic review environmental rules, regulations and procedures to ensure effective protection for the marine environment from harmful effects which may arise from activities in the Area, and together with sponsoring States, to apply a precautionary approach to such activities based on recommendations of the Legal and Technical Commission (see ibid., regulation 33, paras. 1 and 2). The draft regulations also state that each contract for exploration for polymetallic sulphides or cobalt-rich crust deposits would 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, against which to assess the likely effects of its programme of work for exploration of the marine environment and a programme to monitor and report on such effects. The draft regulations would require contractors to cooperate with the International Seabed Authority and the sponsoring State or States in the establishment and implementation of such monitoring programmes. With regard to the recommendations issued by the Legal and Technical Commission, the regulations indicate that they may list those exploration activities which may be considered to have no potential for causing harmful effects (ibid., regulation 34, para. 1).

The regulations would require that an application for approval of a plan of work for exploration should include a description of the programme for oceanographic and environmental baseline studies in accordance with the regulations and any environmental rules, regulations and procedures established by the Authority that would enable an assessment to be made of the potential environmental impact of the proposed exploration activities, taking into account any recommendations issued by the Legal and Technical Commission, and a preliminary assessment of the possible impact of the proposed exploration activities on the marine environment (ibid., regulation 20).

After approval of the plan of work for exploration in the form of a contract and prior to the commencement of exploration activities, the contractor is required to submit to the Authority:

(i) An impact assessment of the potential effects on the marine environment of the proposed activities;

(ii) A proposal for a monitoring programme to determine the potential effect on the marine environment of proposed activities;

(iii) Data that could be used to establish an environmental baseline against which to assess the effect of the proposed activities (ibid., annex 4, para. 5.2).

As exploration activities progress, the contractor is to gather environmental baseline data and develop and establish environmental baselines against which to assess the likely effects of its exploration activities on the marine environment (ibid., para. 5.3); establish and carry out a programme to monitor and report on such effects on the marine environment, cooperating with the Authority in the implementation of such monitoring (ibid., para. 5.4); and, within 90 days of the end of each calendar year, report in writing to the Secretary-General on the implementation and results of its monitoring programme and submit data and information in accordance with the regulations, taking into account any recommendations issued by the Legal and Technical Commission (ibid., annex 4, para. 5.5, and regulation 34, para. 2).

Article 165, paragraph 2 (e), of the United Nations Convention on the Law of the Sea states that the Legal and Technical Commission is to make recommendations to the Council of the Authority on the protection of the environment, taking into account the views of recognized experts in that field. The workshop on polymetallic sulphides and cobalt crusts: their environment and considerations for the establishment of environmental baselines and an associated monitoring programme for exploration, held in Kingston from 6 to 10 September 2004, was held in response to that requirement.

It is recalled that in June 1998 the International Seabed Authority convened a workshop on the development of environmental guidelines for exploration for polymetallic nodule deposits. The outcome of the workshop was a set of draft guidelines for the assessment of possible environmental impacts from exploration for polymetallic nodule deposits in the Area. The workshop noted the need for clear and common methods of environmental characterization based on established scientific principles and taking into account oceanographic constraints. Aspects of the guidelines for polymetallic nodules (ISBA/7/LTC/1/Rev.1) are relevant to the proposed guidelines for polymetallic sulphides and cobalt crust deposits.

The recommendations of the workshop are based on the current scientific knowledge of the marine environment and the technology to be used. Taking into account the progress of science and technology, in particular as they relate to knowledge of the environments where the deposits occur, deposit characterization and subsequent mining technology, the proposed guidelines may need to be modified. Unless otherwise noted, the recommendations contained in the present report relating to exploration and test mining of sulphides and crusts apply to both types of deposits. At some sites it may not be reasonably feasible to implement some of the specific recommendations. In such a situation, the contractor should provide arguments to that effect when submitting a work programme to the Legal and Technical Commission, which can then exempt the contractor from the specific requirement.

The nature of the environmental considerations associated with test mining of polymetallic sulphides and cobalt-rich crust deposits depends on the type of mining technology used to extract the minerals and on the scale of the operation (i.e., number of tons extracted per annum per region). Mechanical removal without initial processing at the seabed was deemed the most likely technology to be used and is the method of mineral extraction assumed in the present report. It is likely that future mining operations will employ techniques not considered here. The International Seabed Authority should revisit the environmental guideline considerations as technologies are developed and the proposed mining technology is identified to ensure that the assumptions and considerations described herein continue to be relevant.

2. Scope

2.1 Purpose

The recommendations contained in the present report describe the procedures to be followed in the acquisition of baseline data and the monitoring to be performed during and after any activities in the exploration area with a potential to cause serious harm to the environment. Their specific purposes are:

(i) To define the biological, chemical, geological and physical components to be measured and the procedures to be followed by contractors to ensure effective protection for the marine environment from harmful effects which may arise from the contractors' activities in the Area;

(ii) To facilitate reporting by contractors;

(iii) To provide guidance to potential contractors in preparing a plan of work for exploration for polymetallic sulphides and cobalt crusts in conformity with the provisions of the Convention, the 1994 Agreement relating to the Implementation of part XI of the Convention and the regulations.

3. Definitions

Except as otherwise specified in the present document, the terms and phrases defined in the draft regulations shall have the same meaning in these recommendations for guidance. A glossary of technical terms is contained in the annex to the present report.

4. Environmental studies

Every plan of work for exploration for polymetallic sulphides and cobalt crusts should take into consideration the following phases of environmental studies:

(a) Environmental baseline studies;

(b) Monitoring prior, during and after test mining.

5. Environmental baseline studies relevant to both resources

It is important to obtain sufficient information from potential test-mining sites to document the natural conditions that exist prior to test mining, to gain insight into natural processes such as the dispersion and settling of particles and benthic faunal succession and to gather other data which may make it possible to acquire the capability necessary for accurate environmental impact prediction. The impact of naturally-occurring periodic processes on the marine environment may be significant, but are not well quantified. It is thus also important to acquire as long a history as possible of the natural responses of surface and benthic communities to those processes.

Under the provisions of the draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area (hereinafter referred to as the draft mining code), contractors are required, in cooperation with the International Seabed Authority and the sponsoring State or States, to establish environmental baselines against which to assess the likely effects of the programme of work on the marine environment and a programme to monitor and report on such effects. To maintain the credibility of the environmental impact assessment, it is critical that qualified independent scientists be contracted to establish the environmental baseline and to monitor and report on potential impacts.

Contractors should also be required to permit the International Seabed Authority to send its inspectors on board vessels and installations used by the contractor to carry out exploration activities in the Area to, inter alia, monitor the effects of such activities on the marine environment.

6. Baseline data requirements

To set up the environmental baseline in the exploration area, the contractor, using the best available technology, should collect data for the purpose of establishing baseline conditions of physical, chemical, biological and other parameters that characterize the systems likely to be affected by exploration and test-mining activities. Baseline data document natural conditions in existence prior to test mining and are essential for monitoring changes resulting from test-mining impacts for prediction of the effects of commercial mining activities.

The workshop suggested that the Legal and Technical Commission, in developing guidelines for baseline data requirements:

(a) Advocate strategic selection of index parameters, with robust statistical design wherever possible, rather than haphazard inventories with inadequate, inappropriate sampling;

(b) Advocate using to best advantage baseline data-collection methods that are used during mineral exploration (e.g., imaging, mapping);

(c) Recognize that quantitative sampling of hard substratum environments (polymetallic sulphides, cobalt crusts, basalt) in the deep sea is a challenge that academic scientists do not routinely achieve. Small animals, or animals hidden in crevices, among coral, for example, would require several types of sampling equipment;

(d) Recognize that exposed mineral surfaces may be irregular, potentially steep sloped and difficult to image quantitatively without the use of a remotely operated vehicle or a new technology yet to be developed;

(e) Recognize that samples are required for taxonomic identification, DNA sequencing and voucher collections and that a repository (or multiple repositories, as appropriate) should be designated for voucher collections;

(f) Recognize the value of digital photographic and genomic libraries of faunal vouchers and microbial assemblages; a financially, logistically and scientifically rational programme for the acquisition of these types of databases is a requisite part of the baseline requirements;

(g) Understand that taxonomy by numbers (e.g., species 1, species 2, etc.), if consistent rules are used and vouchers are maintained, is a good basis for baseline studies, but that classical and molecular taxonomy must be supported, either directly by the contractor or as part of cooperative research programmes;

(h) Anticipate that molecular methods will advance rapidly during the next decade, making biotic surveys at all levels, especially at the level of micro-organisms, much more rapid and economically feasible than they are today. Molecular sequences should be deposited in Genbank or equivalent internationally-recognized sequence databases. The International Seabed Authority should monitor progress in these molecular technologies and revise baseline requirements as appropriate.

7. Regional environmental baseline data

While test mining may physically affect only a local area, the sensitivity of the ecosystem to the disturbance is a function of the degree to which the components of the system are unique or common. For this reason, the contractor must obtain some degree of regional-scale baseline data. The scope of this effort will likely be particular to the setting (e.g., seamount, polymetallic sulphide deposit, etc.).

Because the populations of fauna of sulphide deposits and cobalt crusts are subsets of meta-populations that interact through dispersal and colonization, it is important to know the degree of isolation of populations occupying the mineral deposits that are to be removed and whether a given population serves as a critical brood stock for other populations.

Regardless of the mining techniques to be employed, it is expected that some amount of particulate and/or dissolved mining by-products will be released into the water column in the vicinity of the mined deposits, the transport conduits and the processing sites. With the currently proposed exploration and test-mining techniques, the primary anticipated test-mining by-products are particles created by the mechanical break-up of the mined minerals. While it is expected that mining operators will minimize the loss of economically valuable minerals, it does not seem realistic to assume zero loss. Since the particle size range is not known, it is assumed that the by-products of test mining will include very small particles, which can remain in suspension for months. The possibility for the introduction of toxic substances cannot be excluded either. While bound metals are not biologically available, dissolution of metals, and consequently metal toxicity, may take place under particular environmental conditions (e.g., low pH in guts of marine invertebrates, oxygen minimum zones in the water column). Other possible examples include accidental or intended release of chemicals used during exploration and test mining. A primary goal of the physical baseline data collection consists of assessing the dispersal potential both for particles and for dissolved substances. Knowledge of the dispersal potential is also required for monitoring and mitigating the effects of accidental spills related to the test-mining operations. We recommend that the dispersal potential near future mining sites be assessed even if the design target of the mining technology includes avoidance of the release of any test-mining by-products into the environment.

8. Regional-scale physical and chemical oceanographic baseline data

Physical and chemical baseline data should be collected over the entire exploration area, including the perimeter. The recommended sampling resolution is loosely based on World Ocean Circulation Experiment and CLIVAR standards,[1] with station spacing not exceeding 50 km. In regions of large lateral gradients (e.g., in boundary currents and near major topographic structures), the horizontal sampling spacing should be decreased in order to allow resolution of the gradients. In the vertical, there should be at least five samples each in the top and bottom 200 m of the water column. In the interior, the vertical sample spacing should be no more than 100 m. Here too, the resolution should be increased in high-gradient regions (e.g., to locate and quantify any oxygen minimum). For parameters without significant horizontal gradients the determination of baseline ranges (e.g., means and standard deviations) is considered adequate. For parameters with significant spatial structure (gradients, extrema) the sampling resolution must allow the structure to be characterized. Because of the strong influence of topography on the spatial scales of oceanic features, it is expected that this will require a survey plan with station spacing depending on topographic scales, for example, with finer resolution on steep slopes.

Water-column sampling must include all standard parameters (i.e., temperature, salinity, oxygen, chlorophyll in the euphotic zone, particle load), as well as the chemical parameters listed in Table 3 of the International Seabed Authority report entitled "Standardization of Environmental Data and Information: Development of Guidelines"[2] (phosphate, nitrate, nitrite, silicate, carbonate alkalinity, oxygen, zinc, cadmium, lead, copper, mercury, total organic carbon). In addition, relevant physical and geochemical parameters (including pore-water chemistry) of the sediment should be determined, again with the same International Seabed Authority guidelines serving as a reference for the list of chemical parameters to be reported (ibid., Table 2: phosphate, nitrate, silicate, nitrite, carbonate alkalinity, Eh, pH, iron, manganese, zinc, cadmium, lead copper, mercury). Once details of the proposed test-mining techniques are known, the parameter lists should be extended to include any potentially hazardous substances that may be released into the water column during test mining. All measurements must be accurate to accepted scientific standards (e.g., CLIVAR). In order to allow for later analysis of additional parameters, water samples suitable for analysis of dissolved and particulate matter should be collected and archived in a repository accessible for scientific study.

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[1] International Research Programme on Climate Variability and Predictability (http://www.clivar.org/).

[2] International Seabed Authority, *Standardization of Environmental Data and Information: Development of Guidelines* (ISA/02/02) (Kingston, 2002). Available from http://www.isa.org.jm/en/seabedarea/StandWShop/StandRep_splash.htm.

A general scheme for physical and chemical oceanographic baselines includes:

(a) Collection of water-column hydrographic and light-transmission data of sufficient resolution to characterize the dominant patterns, taking into account the topographic characteristics of the exploration site;

(b) Collection of data appropriate for assessing the horizontal and vertical advective and eddy-diffusive dispersal potential for dissolved and particulate matter on the environmentally relevant time and space scales;

(c) Set-up and validation of a numerical circulation model that covers the temporal and spatial scales important for dispersal and carry out experiments, for example, to investigate the potential impact of accidental spills;

(d) Collection of water-column chemical data of sufficient resolution to characterize the dominant patterns, taking into account the topographic characteristics of the exploration site;

(e) Collection and archiving of water-column

samples for possible later analysis of additional parameters.

For each test-mining by-product, the timescale over which it causes significant environmental impact must be modelled. Such timescales may depend on dilution, in which case the determination of vertical and horizontal mixing rates near the target site must be included in the dispersal assessment. Dispersal potential must be assessed over timescales that range from the tidal frequencies to the largest of these "environmental-impact" timescales. Both advective and eddy-diffusive contributions to the dispersal potential must be assessed. An assessment of the dispersal potential in the deep ocean generally requires long-term monitoring efforts. Even the determination of mean-flow directions and speeds at depth can require several years' worth of current-meter data. Assessing eddy-diffusive dispersal is even harder and generally requires the application of Lagrangian techniques, such as neutrally-buoyant floats or dye-release experiments. For these reasons, it is recommended that an assessment of the regional dispersal potential at several levels in the water column begin early during exploration. It may be possible to assess dispersal near the surface and near 1,000 m from available data — surface drifters and Argo floats, respectively — and at the time of test mining additional data sets may have become available.

Before test mining is to begin, the dispersal potential must be assessed at all levels where environmentally significant test-mining by-products are to be released into the water column and where accidental spills are considered most likely. The required vertical resolution will depend on the regional dynamical regime (vertical shear of the horizontal currents), but it is anticipated that at least three levels would need to be sampled (near-surface, mid-depth, near-bottom). The flow near the seabed in particular must be temporally and spatially well resolved, for example, by using bottom-mounted acoustic Doppler current profiler measurements with sufficient sampling to resolve the dominant tidal flows. In regions of topographic relief near the test-mining site, both the horizontal and vertical resolutions must be increased to allow the dominant dynamical structures that are usually associated with deep-sea topography (boundary currents, trapped eddies, overflows, etc.) to be resolved. Near active hydrothermal vent fields, it is often possible to gain useful first-order dispersal information at the level of neutrally buoyant plumes from hydrographic, chemical and optical observations. Interpreting plume-dispersal observations in terms of dispersal potential for mining by-products is complicated by a variety of factors, including the generally poor knowledge of the temporal and spatial characteristics of hydrothermal sources, the fact that hydrothermal plumes disperse at their equilibrium level, which depends both on the source and environmental background characteristics, and by the fact that the particle composition (and, thus, the settling velocity) of hydrothermal plumes cannot be controlled. Nevertheless, it is expected that hydrothermal-plume dispersal observations will be useful, in particular for designing controlled follow-up dispersal studies.

In order to complete an assessment of the dispersal potential, a three-dimensional hydrodynamic numerical model that covers the temporal and spatial scales important for dispersal must be constructed and applied in a series of experiments. The contractor should use a model that is accepted by the ocean modelling community as well suited for dispersal studies near the seabed; simple box models or z-coordinate models with coarse vertical resolution at depth are not expected to be adequate. The details of this model will be dependent on the topographic and oceanographic settings of the target site. Resolution should be in accordance with the scales described above (i.e., gradients should be resolved by several points), and the model needs to be validated by comparison with the observational data. After validation, the numerical model should be used to investigate "what if" scenarios, for example, to estimate the potential impact of accidental spills or for certain extreme cases, such as atmospheric storms.

9. Regional-scale geological baseline data

The workshop recommended the following in connection with the collection of regional-scale geological baseline data:

(a) Regional maps should be produced of the size and distribution of sulphide deposits, cobalt crusts and other critical habitats (seeps, diffuse low-temperature vents, whale skeletons, etc.);

(b) High-resolution (at least 200 m horizontal, 10 m vertical), high-quality (accuracy of 1 % of water depth or better) bathymetric data should be collected over the area where the dispersal of test-mining by-products is expected to significantly affect the environment, that is, over the entire region covered by the numerical circulation model;

(c) As part of the high-resolution baseline survey, a suite of representative pre-mining cores of the deposit, as well as a suite of representative pre-mining cores of seafloor sediment (including the top few centimetres, which can be lost when standard corers are used) around the target area should be collected and stored in a suitable repository available for appropriate scientific study respecting the commercial implications to the contractor. A reasonable sampling strategy would consist of sediment cores taken at 1-km intervals starting at the margin of the deposit and extending at least 10 km along the four cardinal points;

(d) Water-column vertical particle flux time series at the target test-mining site near the surface, at mid-depth and near the seabed, must be determined. The temporal resolution of the particle-flux measurements must be one month or better and nephelometry time series should be recorded on the sediment traps;

(e) Knowledge of *in situ* settling velocities for test-mining discharge particles, both in mid-water and near the seafloor, will help to verify and improve the capacity of mathematical models for accurately predicting the dispersion of the mid-water and benthic plumes. This information is relevant to the concerns expressed regarding the mid-water plume and to the primary concern of impacts from the benthic plume on the benthic biota;

(f) For sulphide deposits, the status of hydrothermal activity must be classified as either dormant sites, which are still under the potential influence of a heat source although there is currently no venting of hydrothermal fluids, and extinct sites, which have been carried away from their heat sources, or the heat sources of which have been extinguished. From an ecological point of view, these two scenarios can be considered largely equivalent. What is important biologically, however, is whether there is active hydrothermal venting at the site (case 1), whether the planned test-mining operations will restart hydrothermal venting at an otherwise inactive site (case 2), or whether a site is hydrothermally inactive even when disturbed by test mining (case 3). It is therefore important that the baseline assessment include a determination of whether the target site is case 1, 2 or 3.

10. Regional-scale geochemical baseline data

The recommendations of the workshop in connection with regional-scale geochemical baseline data are as follows:

(a) Where applicable, sediment chemical data of sufficient resolution to characterize the dominant patterns should be collected;

(b) Representative pre-test-mining cores and sediment samples should be collected and archived (if deemed advisable by the Legal and Technical Commission);

(c) Water-column vertical particle-flux baseline data of sufficient resolution to assess potential environmental impacts should be collected.

11. Regional-scale biological baseline data

In the case of regional-scale biological baseline data, the workshop recommended the following:

(a) If there is potential for surface discharge, the plankton community in the upper 200 m of the water column should be characterized. Measurements should be made of phytoplankton composition, biomass and production, zooplankton composition and biomass and bacterial plankton biomass and productivity. Temporal variation of the plankton community in the upper surface waters on seasonal and inter-annual scales should be studied. Remote sensing can be used to augment field programmes. Calibration and validation of remote-sensing results are essential;

(b) Observations on marine mammals and, insofar as possible, other near-surface megafauna (e.g., turtles, fish schools) are required. Sightings of marine mammals and other pelagic megafauna should be recorded during the baseline study. It is recommended that marine mammal and megafaunal species and their behaviour be recorded on transects between stations. Temporal variability should be assessed;

(c) Information from samples, photographs, videotapes or other means will assist in determining the impact on the benthos. Such information will help to resolve questions about the significance of the impact and may assist in developing any appropriate mitigation strategies for commercial recovery operations. Information on the faunal succession that follows the test mining will help to determine the potential for the recovery of the benthic population from the effects of such mining. Data should include samples in the immediate test area before and after test mining, at selected distances away from the mined area to determine the effect of the benthic plume, and at selected times after test mining. Such impact experiments can be conducted collaboratively;

(d) A combination of monitoring and shipboard and laboratory experimentation may be necessary to resolve completely, prior to test mining, the issues of impacts on phytoplankton and zooplankton if there is surface discharge and the effects of trace metals;

(e) Information on other effects of the plume on the mid-water biota can be gathered by making observations of unusual events, such as fish kills from air embolism in the area of the test-mining discharge zone, and unusually large concentrations of fish, marine mammals, turtles and birds;

(f) The vertical distribution of light directly affects primary productivity in the euphotic zone. If there is surface discharge, vertical light-intensity profiles will show the effect of discharged particles on light attenuation and spectral bands (photosynthetically active radiation: 400-700 nm, and blue light: 475 nm) over time, depth and distance from the mining ship. Those values can be used to detect any accumulation of the suspended particles at the pycnocline;

(g) Data on the dispersion of mining-solid discharges will refine existing dispersion models to make accurate predictions of plume behaviour and to assist in extrapolating from test mining to commercial-scale mining.

12. Local baseline biological data

The fundamental requirement for a baseline study that can be used to assess whether serious harm has occurred to a marine environment as a result of test mining of polymetallic sulphides or cobalt crusts is a species-abundance matrix for those areas likely to be affected by the test mining. This is the basic information that biologists acquire to make an assessment of any community they encounter. Incremental sampling efforts should be used by the contractor to develop species-effort curves for representative hard substratum microhabitats likely to be affected by test-mining activities, from which robust measures of species richness may be determined. Specific recommendations for sampling protocols on hard substrata are provided below. Appropriate methods for acquisition of quantitative species-abundance matrices for soft-sediment and pelagic environments likely to be impacted by exploration and test mining of polymetallic sulphides and cobalt crusts are described in detail in the draft guidelines for manganese nodules and are not repeated here. The contractor is responsible for obtaining this baseline data where they are relevant to understanding the potential impact of test mining.

Hard substrata, especially where the organisms are small, are recognized as challenging environments to sample quantitatively. Slurp sampling, grab samples of any larger organisms in the area and video documentation or photographic transects may be the only means suitable for developing a species-abundance matrix. Remotely operated vehicles (ROVs) will be a better tool for documentation and sampling near or on vertical and hard substratum habitats than camera sleds. Autonomous underwater vehicles (AUVs) or hybrid ROV-AUVs may ultimately prove to be ideal survey/sampling platforms.

The general practices are described below:

(a) Baseline data from impact and preservation reference zones allow one to understand natural variability in time and space associated with natural geological, hydrodynamic and biological processes prior to test mining. Impact reference zones and preservation reference zones should be carefully selected and should be known (based on biotic surveys) to share the biotic characteristics of the habitats likely to be affected by test mining. The selection of these zones should be reviewed by the International Seabed Authority and an advisory board of scientists prior to approval of test mining. Impact zones and preservation zones are likely to be extremely useful in evaluating environmental impact (direct, indirect, cumulative and interactive);

(b) The biotic survey of polymetallic sulphide deposits or cobalt crusts prior to test mining should be of deposits that are biotically representative of the kind of deposit to be recovered or otherwise directly or indirectly affected during the test-mining programme;

(c) Methods for collecting baseline biological data prior to test mining must be adapted for each specific set of conditions;

(d) Geographic Information System mapping tools are recommended as a means to place habitat and sample characteristics in spatial contexts;

(e) Standard practices for the proper preservation of organisms should be followed, including discrete sampling of sub-habitats into separate sample containers (preferably insulated) with closed lids to prevent washing on recovery, recovery of samples within 12 hours of collection to obtain quality material, immediate processing and preservation of samples on deck or maintenance in cold rooms for durations of no more than 6 hours before preservation (less where molecular assays are planned);

(f) Multiple preservation methods should be required, including preservation in formalin for taxonomic studies, freezing or preservation in 100 % ethanol for molecular studies and drying of whole animals and/or selected tissues for stable isotope analyses;

(g) Colour photographic documentation of organisms should be obtained whenever possible (organisms in situ and/or fresh material on deck to document natural coloration). These photos should become part of an archival collection;

(h) All samples and sample products (photos, preserved material, gene sequences) should be linked to relevant collection information (e.g., date, time, method of sampling, latitude, longitude, depth, etc.);

(i) Identification and enumeration of samples at sea and in the laboratory should be complemented by molecular and isotopic analyses as appropriate. Species-abundance and species-biomass matrices should be standard products wherever practical;

(j) Exchange of identification codes, keys, drawings, sequences with major laboratories or collections that carry out taxonomic studies of vent fauna to facilitate identification is recommended;

(k) Specimens must be archived for comparison with taxonomic identifications from other sites and to verify the details of changes over time. If species composition does change, the change may be subtle, and reference to the original animals (where there might only have been a putative identification) is essential;

(l) Temporal variation must be evaluated for at least one potential test-mining site and the preservation reference site for the test-mining activity (ideally, once every year for three years; minimally, twice — once at the beginning and once at the end of a single year). This temporal study should be reviewed by the International Seabed Authority prior to the start of test mining. The temporal evaluation must include a video/photo survey of sub-habitat distribution and, for sulphide deposits, associated temperatures and sampling of any new sub-habitats that appear. In addition to baseline data on species abundance, biomass, community structure, etc., strategies (including cooperative research) for determining growth rates, recruitment rates and the trophic status of dominant taxa should be developed and executed as part of the time-series studies. Where multiple test-mining sites are identified, the contractor must assess the degree to which temporal studies at one site are applicable to another site; this assessment should also be reviewed by the International Seabed Authority and an advisory board of scientists;

(m) Spatial variation in the biological community must be evaluated prior to test mining by sampling at least three mineral deposits, if present, in the area, each separated by a distance greater than the projected deposition of 90% of the particles suspended by the mining operation;

(n) Standardization of methodology and reporting of the results is extremely important. Standardization should include instruments and equipment, quality assurance in general, sample collection, treatment and preservation techniques, determination methods and quality control on board vessels, analytical methods and quality control in laboratories and data processing and reporting. Method standardization will allow for the comparison of results across provinces and lead to the selection of critical parameters for monitoring efforts;

(o) Collection and analytical techniques must follow best practices such as those developed by the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization and available at world data centres and responsible national oceanographic data centres, or those established or recommended by the International Seabed Authority;

(p) To maintain the credibility of the environmental impact assessment, qualified independent scientists should be contracted to establish the environmental baseline and to monitor and report on potential impacts.

13. Specific environmental baseline requirements for sulphide deposits

Analyses of organic carbon, nitrogen and sulphur stable isotope compositions of selected organisms are useful preliminary screens for unusual trophic ecologies (i.e., reliance on chemoautotrophic or methanotrophic production rather than photosynthetic production). The workshop recommends that isotopic analyses (organic carbon, organic nitrogen and organic sulphur isotope analyses) be conducted on a statistically representative number of individuals for the one or more species that make up the bulk of the biomass within different sub-habitats.

The minimum requirements to be submitted to the International Seabed Authority prior to approval of test mining of polymetallic sulphide deposits are as follows:

(a) Identify and qualitatively assess the distribution of all major sub-habitats of the proposed test-mining site (e.g., mussel beds, tubeworm clumps, bacterial mats and peripheral fauna); note that in the case of inactive sulphides or hard substrata away from sulphides, there may not necessarily be easily recognized sub-habitats (in which case a random sampling strategy can be developed);

(b) For active sulphides, survey temperature-fauna relationships e.g., 5-10 discrete, video-documented temperature measures within each sub-habitat);

(c) Undertake bulk collection (slurp, grab or other quantitative or semi-quantitative sampling methods as appropriate to the sub-habitat) of invertebrates by sub-habitat into discrete sample boxes, seven samples per sub-habitat, where possible, plus selective acquisition of individuals of representative fauna. This will enable the determination of biomass, abundance or coverage dominants in a given sub-habitat. Discrete sampling methods should be designed to allow the contractor to estimate species richness using species-effort curves, where effort is the cumulative number of individuals or other suitable metric. Collections should be photo-documented (and indexed to video imaging) in situ to provide an archive of context/setting information for each sample;

(d) Each of the seven samples per sub-habitat should be separated into macro- and meiofauna using stacked 45 μm and 250 μm sieves. Five of those sets of samples collected on sieves should be preserved for 24 hours in 10 % buffered seawater formalin then in 70% ethanol for subsequent sorting, identification, enumeration and development of species-abundance matrices. Two of the sets of samples should be preserved in ethanol using methods appropriate for molecular sequencing and molecular archives. As an alternative method of preservation for molecular analyses, material sorted to individuals may be frozen;

(e) Other sampling efforts should be used to characterize the less-abundant but potentially key megafaunal invertebrates in the system (including fish, crabs and other motile organisms). Representative samples of those organisms should be preserved for taxonomic, molecular and isotopic analyses.

14. Specific environmental baseline requirements for cobalt crusts

Cobalt-enriched crusts are found on various hard substrata, including mid-ocean ridges and seamounts, but they have been explored predominantly on seamounts. We focus here on mining in the seamount environment, but the general recommendations could be applied to ridge systems. As a large proportion of the seamount community may have a highly-localized distribution, biological sampling should be carried out, insofar as possible, on a representative subset of all features of potential mining interest within each claim area in order to build a picture of the distribution of the community within that area. Benthic faunas typically vary in relation to local topography (e.g., summit, slope or base of a seamount), sediment cover, depth, seamount height and size, slope angle, oxygen content in the water, currents, regional productivity and potentially other factors. Habitat types should be assessed initially on the basis of photographic/video transects and by submersible or ROV, if possible. Imaging surveys carried out by the contractors to map sites of potential test-mining interest can serve several purposes, so long as there is adequate biological resolution (see below). Further biological sampling must be stratified by habitat type, which will be defined by seamount topography (e.g., summit, slope and base), hydrography, current regime, predominant megafauna (e.g., coral mounds), oxygen content of the water if the oxygen minimum layer intersects the seamount and potentially by depth as well, with replicate biological samples obtained using appropriate sampling tools in each stratum. A minimum of five replicate epibenthic sled samples per stratum is recommended for the collection of specimens and to assess species richness.

The minimum requirements to be submitted to the International Seabed Authority prior to approval of test mining of cobalt crusts are as follows:

(a) Undertake photographic transects to determine habitat type, community structure and associations of megafauna with specific types of substrata. Abundance, percentage cover and diversity of megafauna should be based initially on at least four photographic transects (1-cm resolution) to cover the four quadrants. The transects should extend from the flat seafloor 100 m or more from the base of the seamount, along the slope of the seamount and across its summit. More limited sampling may be required on larger seamount features. Further photographic transects should be carried out in crust areas of potential test-mining interest;

(b) To resolve megafaunal and macrofaunal species, biological sampling is required, using appropriate samplers within each habitat and community type. Hard substratum habitats should be sampled with a dredge or epibenthic sled with an inner cod-end mesh of 25 mm (e.g., the CSIRO seamount epibenthic sampler).[3]

(c) Meiofaunal and microbial community structure and biomass associated with the cobalt-enriched crust should be examined from rock dredge and rock drill samples or obtained from ROV or submersible sampling, where possible. At least 10 samples should be taken from cobalt crusts, from which species that live on the rock or in crevices and pits in the crust should be identified;

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[3] Lewis, M. "SCIRO-SEBS (Seamount, Epibenthic Sampler), a new epibenthic sled for sampling seamounts and other rough terrain", *Deep-Sea Research part I: Oceanographic Research Papers*, vol. 46, No. 6 (June 1999).

(d) Demersal fishes and other nekton living over the seafloor should be assessed by trawling, insofar as possible. At depths beyond trawl capabilities and on very rugged bottoms, this community should be assessed on the basis of towed photographic/video transects, with deployed cameras set up to record at different time periods or with submersible or ROV observations and photographs. Seamounts can be important ecosystems with a variety of habitats for a number of fish species that form aggregations there for spawning or feeding. Test mining operations could affect fish behaviour;

(e) Trace metals should be assessed in muscle and target organs of dominant benthic and benthopelagic fish and invertebrate species. This should be done at least four times before test-mining operations begin (to measure natural variability) and thereafter at least annually to monitor possible changes due to test-mining activity;

(f) The pelagic community structure of deep zooplankton and fish around the depth of the plume and in the benthic boundary layer need to be assessed prior to test mining. It is recommended that the fish community be assessed in the upper 1,500 m on the basis of depth-stratified sampling in at least three depth strata. Replicate sampling should be carried out on a diel basis and temporal variability examined.

15. Monitoring prior, during, and after test mining: environmental impact assessment

The purpose of environmental monitoring during test mining is to determine whether effects are consistent with those predicted in the existing environmental assessments and to ensure the detection of any unanticipated serious harm.

Monitoring results should be the primary basis for test-mining impact assessments. Prior to, during and after test mining, the regional and local baseline parameters should be collected. To obtain statistically defensible data, the period of monitoring should be determined in accordance with sound scientific principles. Impact assessment must be based on a properly designed before-after control-impact study with sufficient replication to detect impacts on the order of a 50 % change in community structure in surrounding areas. Environmental monitoring during test mining must therefore be carried out at test-mining impact and comparable reference sites, to be selected on the basis of an initial assessment of their faunal composition. The guidelines suggested here will help to identify and predict the relevant effects of the test mining and to ensure that environmental considerations are explicitly addressed and incorporated into the decision-making process.

The main environmental impacts are expected to be at the seafloor, with minor impact expected at the tailings-discharge depth and in the water column at depth. The impact assessment must include a study of impacts on both the benthic and pelagic environments. The test-mining operation will remove minerals and associated fauna and the test-mining vehicle will compress and damage the benthic fauna in areas adjacent to where it operates. The break-up and extraction of minerals may create a near-bottom plume, which may partly be transported to the ocean surface depending on the technology used for lifting the material.

Disposal in the surface waters may interfere with primary productivity by increasing the nutrient levels and decreasing the light penetration into the ocean, enter the food chain and disturb vertical and other migrations and lead to the reduction of manganese oxide and the solution of metal components in the oxygen-minimum zone. For these reasons, tailing discharge should be well below the oxygen-minimum zone. Because the oxygen-minimum zone varies regionally and to some extent seasonally, environmental studies must determine the depth range of the oxygen-minimum layer at each test-mining area. Baseline data in the upper water column should concentrate on the oceanographic properties around the discharge depth.

Available information on community structure and function of the sites where deep-sea test mining will take place is limited, therefore voucher collection repositories, a gene sequence database repository and a photo library of species and specimens will help to evaluate and to anticipate, avoid, minimize or offset the adverse effects of the activities considered in test mining and mining of deep seafloor sites. The goal of the impact assessment — to protect the productivity and capacity of natural systems and the ecological processes that maintain the functions of these natural systems — requires traceability.

Contractors should be required to permit the International Seabed Authority to send its inspectors on board vessels and installations used by the contractor to carry out activities in the exploration area to, inter alia, monitor the effects of such activities on the marine environment.

Monitoring of test mining will focus on acquiring a predictive capability for the impacts to be expected from the commercial or strategic system.

16. Activities not expected to cause serious environmental harm

Based on available information, a variety of technologies currently used in exploration are not considered to have the potential to provoke serious harm to the marine environment and thus do not require an environmental impact assessment. These include:

(a) Positioning systems, including bottom transponders and surface and subsurface buoys filed in notices to mariners;

(b) Meteorological observations and measurements, including instrument deployment;

(c) Satellite monitoring (e.g., advanced very-high resolution radiometer) for plumes in surface waters;

(d) Oceanographic observations, including hydrographic observations and measurements with instrument deployment;

(e) Gravity and magnetic observations;

(f) Towed plume-sensor measurements (chemical analysis, nephelometers, fluorometers, etc.);

(g) Bottom or sub-bottom acoustic profiling (without use of explosives), electromagnetic profiling, profiling of resistivity, self potential or induced polarization;

(h) Mineral sampling of a limited nature such as those using grab or bucket samplers;

(i) Shipboard mineral assay and analysis;

(j) Dye release or tracer studies;

(k) Sampling by box core, small diameter core, reamed reverse-circulation drilling or grab;

(l) Video/film and still photographic observation and measurements;

(m) Sampling of small quantities of water, sediment and biota;

(n) Sampling with epibenthic sled, dredge or trawl so long as the sampling area is less than approximately 5 % of the habitat area;

(o) In situ metabolic measurements (e.g., dissolved oxygen consumption);

(p) DNA screening of biological samples.

17. Test-mining activities with potential for causing environmental harm

Mining tests are to be conducted by all contractors unless they use mining equipment that has already been tested by other contractors. In a mining test, all components of the mining system will be assembled and the whole process of test mining, the lifting of minerals to the ocean surface and the discharge of tailings will be executed. It is assumed that the mining test will have a duration of up to several months and may be done with a somewhat scaled-down system. For environmental assessments, this test phase should be carefully monitored and investigated, as should tests of any test-mining component. After in-depth evaluation of the first mining test, impacts of other test-mining systems will be predictable and in later tests environmental studies may be restricted to unresolved questions, specific local environmental conditions or changes of impact due to different techniques. It seems reasonable to assume that a first mining test will extend our knowledge considerably and that all contractors will gain through the experience. Subsequent mining tests may be conducted with much less effort. For these reasons, it is expected that contractors will unite their efforts in the first and following mining test to achieve the maximum in knowledge increase with a minimum of effort on behalf of each contractor.

Current scientific information indicates that some environmental impacts may be caused by test mining during the exploration period, although the potential for serious environmental harm is not known. It is anticipated that the potential for serious environmental impact will be greatest at the seafloor and at the depth zone of discharge of mine tailings and effluent and below.

18. Potential benthic impacts

The potential benthic impacts include:

(a) Direct impacts of mineral recovery, where minerals and associated organisms will be crushed or dispersed in a plume as the mineral deposits are removed;

(b) Smothering or entombment of benthic organisms away from the site of mineral removal where the sediment plume settles. This may be especially critical for sessile organisms attached to hard substrata and for epifaunal or infaunal organisms that cannot move quickly enough to adjust their position;

(c) Alteration of the nutritive quality of surfaces used by surface deposit-feeders or chemosynthetic associations;

(d) Clogging of the feeding apparatus of suspension feeders and dilution of resources for deposit-feeders;

(e) Toxic effects associated with the deposition of fine and coarse particulate minerals in benthic habitats away from the site of sulphide removal;

(f) Loss of brood stocks for populations of species associated with polymetallic sulphides, cobalt crusts or other specialized and restricted habitats (whale falls, wood islands, etc.) within the dispersal shadow of the test-mining-generated plume.

19. Potential water-column impacts

The potential water-column impacts (deriving from discharge of tailings or effluent at depth) include:

(a) Mortality of and changes in composition of plankton exposed to discharge plume, effluent (including larval stages of invertebrates colonizing sulphide deposits) caused by toxicity, interference with feeding mechanisms and alteration of trophic interactions;

(b) Effects on meso- and bathypelagic fish and other nekton caused directly by sediment plume or associated metallic species or indirectly through the food web;

(c) Impacts on deep-diving mammals, such as through impacts on abundance of their prey;

(d) Depletion of oxygen by bacterial growth on suspended particles;

(e) Effects on fish behaviour and mortality caused by sediments or trace metals;

(f) Dissolution of heavy metals within the oxygen minimum zone and their potential incorporation into the food chain;

(g) Large-scale impact expected from discharged tailings over longer time spans (decadal).

20. Potential upper-water-column impacts

The potential upper-water-column impacts (if tailings, sediment or effluent are discharged near the surface) include:

(a) Trace metal bioaccumulation in surface organisms;

(b) Reduction in primary productivity due to shading;

(c) Effects (positive or negative) of trace metals on surface productivity;

(d) Effects on behaviour of marine mammals and seabirds due to reduced water clarity and/or reduction in the abundance of prey.

Each contractor should include in its programme specification of events that could cause suspension or modification of the activities owing to serious environmental harm if the effects of the events cannot be adequately mitigated.

21. Information to be provided by the contractor prior to test-mining operations

The contractor should provide the International Seabed Authority with a general description and a schedule of the proposed exploration programme, including the programme of work for the immediate five-year period, such as studies to be undertaken in respect of the environmental, technical, economic and other appropriate factors that must be taken into account during test mining. This general description should include:

(a) A programme for oceanographic and environmental baseline studies in accordance with the draft regulations and any environmental regulations and procedures issued by the International Seabed Authority that would enable an assessment of the potential environmental impact of the proposed exploration activities, taking into account any guidelines issued by the Authority;

(b) Proposed measures for the prevention, reduction and control of pollution and other hazards, as well as possible impact on the marine environment;

(c) A preliminary assessment of the possible impact of the proposed exploration activities on the marine environment;

(d) A delineation of the impact reference area and preservation reference area (recommended): the impact reference area should be selected on the basis of its being representative of the environmental characteristics, including the biota, of the site to be test mined. The preservation reference area should be carefully located and large enough so that it is not affected by the natural variations of local environmental conditions. Its species composition should be comparable to that of the test-mining area and it should be located upstream of test-mining operations. The preservation reference area should be outside the test-mining area and areas influenced by any test mining or processing plumes.

This general description should also include the following information, as appropriate to the activities to be conducted:

(a) Regional and local environmental baseline data;

(b) Size, shape, tonnage and grade of the deposit;

(c) Sulphide or cobalt crust collection technique;

(d) Depth of penetration into the seabed;

(e) Description of the running gear that contacts the seabed;

(f) Seabed processing methods, as applicable;

(g) Crushing methods, as applicable;

(h) Methods for transporting minerals to the surface;

(i) Mineral processing on the surface vessel;

(j) Volume, rate and depth of overflow discharge;

(k) Concentration of particles in the discharged water;

(l) Chemical and physical characteristics of the discharge;

(m) Location of the mining test and boundaries of the test area;

(n) Probable duration of the test;

(o) Test plans (collecting pattern, area to be perturbed, etc.);

(p) For mineral deposits, baseline maps (e.g., side-scan sonar, high-resolution bathymetry) of the deposits to be removed.

22. Observations and measurements to be made while performing a specific activity

The contractor should provide the International Seabed Authority with some or all of the following information, depending on the specific activity to be carried out:

(a) Width, length and pattern of the miner tracks on the seafloor;

(b) Actual depth of penetration of the miner;

(c) Lateral disturbance caused by the miner;

(d) Volume of material taken by the miner;

(e) Volume of material rejected by the miner at depth;

(f) Size and geometry of the discharged plume;

(g) Behaviour of the plume behind the miner;

(h) Area and thickness of resedimentation to the distance where resedimentation is negligible;

(i) Volume of overflow discharge from the surface vessel;

(j) Concentration of particles in the discharged water;

(k) Chemical and physical characteristics of the discharge;

(l) Behaviour of the discharged plume at surface or in mid-water;

(m) Modification of fluid discharge in hydrothermal settings (using photo documentation, temperature measurements and other metrics, as appropriate).

23. Observations and measurements to be made after the performance of a specific activity

The contractor should provide the International Seabed Authority with some or all of the following information, depending on the specific activity to be carried out:

(a) Resampling of local environmental baseline data at reference and test zones and evaluation of the environmental impact;

(b) Thickness of redeposited sediment on the side of the miner tracks;

(c) Behaviour of the different types of benthic fauna subjected to resedimentation;

(d) Changes of the benthic fauna in the miner tracks, including possible recolonization;

(e) Possible changes in the benthic fauna in adjacent areas apparently not perturbed by the activity;

(f) Changes in water characteristics at the level of the discharge from the surface vessel during the mining test and possible changes in the behaviour of the corresponding fauna;

(g) Changes in fluid flux and response of organisms to this change in hydrothermal settings;

(h) For mineral deposits, post-test-mining maps of the mined area, highlighting any changes in topography at one-metre scale resolution or better.

24. Cooperative research

Recent years have witnessed a revolution in the development of knowledge and technology in deep-sea sciences. A number of research institutes around the world are carrying out extensive research programmes on seamount and ridge systems. Those institutions have considerable biological and scientific expertise and could be willing to join with the mining contractors in conducting some of the required environmental research. They could provide sampling equipment and expertise and would likely be eager to join the mining contractor's vessel and to assist in sampling remote areas.

General guidelines for cooperative research:

(a) Cooperative research can involve interactions with multiple oceanographic disciplines and multiple institutions;

(b) Cooperative research can facilitate the establishment of baselines of natural variability on the basis of geological, biological and other environmental records acquired in selected areas;

(c) During the test-mining phase, mining companies and cooperative research programmes may prove especially synergistic, bringing together the expertise, research facilities, logistical capability and common interests of the mining companies and cooperative institutions and agencies. In this way, the mining companies may make the best use of expensive research facilities, such as vessels, and the extensive expertise in geology, ecology, chemistry and physical oceanography of academic colleagues;

(d) Voucher collection repositories, a gene sequence database repository, stable isotope analysis and interpretation and a photo library of species/specimens can be part of a partnership between scientific and corporate groups. The basic scientific information acquired in partnership should result in the cost-effective acquisition of information that will assist in development planning and decision-making and the timely recognition of any significant environmental effects or issues prior to and during test mining. This information can be used to find solutions with a minimum-conflict approach;

(e) Taxonomic expertise is extremely limited, even for major groups within the fauna (e.g. fish, molluscs, decapod crustaceans, corals, sponges and echinoderms). It will be important that at least these key groups — and as many others as possible — be assessed at each site. This can be accomplished most efficiently through the development of cooperative taxonomic centres or groups of experts who will be responsible for the taxonomic identification of each major group;

(f) To answer certain questions on the environmental impacts of mining, specific experiments, observations and measurements must be conducted. All contractors need not execute the same studies. Repeating certain experiments or impact studies would not necessarily add to scientific knowledge or to impact assessments, while needlessly consuming financial, human and technological resources. Contractors are advised to explore opportunities to unite their efforts in international cooperative oceanographic studies to the extent feasible;

(g) The potential risk of extinction for a significant fraction of a community of fauna within a potential test-mine site will depend largely on the distribution of the fauna: how localized or widespread the species are distributed. Assessment will require syntheses of the biogeography of the fauna. This assessment should be facilitated by collaboration among mining contractors and with the broader research community;

(h) The biology of dominant components of seamount fauna is poorly known but is of considerable importance in the assessment of the potential impact of test mining and population and ecosystem recovery rates after the cessation of test-mining activities. Critical parameters include rates of growth, longevity, age of reproductive maturity, modes of reproduction and dispersal and recruitment dynamics. Population genetic studies should be carried out to provide further insight into exchange processes between and among target sites. Such studies can be carried out collaboratively and/or the results shared among mining contractors;

(i) Modelling studies should be undertaken collaboratively, closely linked to the field studies, to assess extinction risks under various management strategies, including various options for the design of protected areas. Overall conservation strategies need to take into account non-test-mining impacts on the communities (e.g., in the case of seamounts, bottom trawling and coral harvesting);

(j) The International Seabed Authority should serve in an advisory capacity to mining contractors in terms of the identification of cooperative research opportunities, but contractors are free to seek their own links to academic and other professional expertise;

(k) The Authority and mining contractors should work together with cooperative research programmes to maximize the assessment of environmental impact while minimizing the cost of these assessments to the industry.

25. Data collection, reporting and archival protocol

25.1 Data collection and analysis

The types of data to be collected, the frequency of collection and the analytical techniques used, in accordance with the present recommendations, should follow the best available methodology and the use of an international quality system and certified operation and laboratories. Synthesis of such data can work to the advantage of all contractors. As an example, synthesized data on bathymetry, currents, winds, salinity, temperature and dissolved oxygen fields can form critical inputs for the modelling of regional- or basin-scale oceanographic processes. Models can be validated and fine-tuned by such sea-truth data and can then partially supplement costly data-collection exercises. Some claim areas may lie adjacent to or in the vicinity of other claims, providing further justification for data accessibility and the joining of efforts in modelling so that the impact of activities in neighbouring areas can be evaluated without repeating all aspects of environmental assessment.

25.2 Data archival and retrieval scheme

The contractor should provide the International Seabed Authority with all relevant data, data standards and inventories. Environmental data of non-commercial significance (including hydrographical, chemical and biological data) should be freely available for scientific analysis, and an inventory of the data holdings from each contractor should be accessible on the Internet. Metadata that detail the analytical techniques, error analyses, descriptions of failures, techniques and technologies to avoid, comments on sufficiency of data and other relevant descriptors should also be included in addition to the actual data.

25.3 Reporting

Assessed and interpreted results of the monitoring should be reported to the International Seabed Authority together with the data, according to the draft mining code.

25.4 Transmission of data

All data relating to the protection and preservation of the marine environment, other than equipment design data, collected pursuant to the present recommendations should be transmitted to the Authority to be freely available for scientific analysis and research within two years, subject to confidentiality requirements. The contractor should transmit to the Authority any other non-confidential data in its possession that could be relevant for the purpose of the protection and preservation of the marine environment.

26. Recommendations to close gaps in knowledge

Representatives of independent environmental consulting firms, scientists, engineers and contractors should be brought together to discuss in further detail approaches to environmental baselines in sulphide and crust environments. Microbiologists as well as benthic ecologists should be participants in such a workshop.

GLOSSARY (Annex to Document ISBA/11/LTC/2)

active sulphides: polymetallic sulphides through which warm water is flowing. Active sulphides (also called hydrothermal vents) deliver reduced compounds (e.g., sulphide) to the seafloor-seawater interface where they can be oxidized or otherwise autotrophically metabolized by free-living or symbiotic micro-organisms.

chemosynthesis: process by which micro-organisms metabolically transform inorganic carbon to organic carbon (cells) using energy derived from the oxidation of reduced compounds. Chemosynthesis is the basis for the food web associated with deep-sea hydrothermal vents. Chemoautotrophy is a more descriptive and precise term for the general phenomenon of chemosynthesis; the two words are often used interchangeably.

cobalt-enriched crusts: ferromanganese crusts with enriched cobalt content typically formed by precipitation and found on hard substrates in the deep sea on features with significant topographic relief, such as seamounts and ridges.

cumulative impacts: impacts resulting from incremental changes caused by other past, present or foreseeable actions.

direct impacts: impacts that are a direct result of an action, such as loss of habitat and populations, owing to removal of sulphides or other materials.

endemism: the degree to which a species is restricted to a particular geographic region; endemism usually occurs in areas that are isolated in some way. Biologists also use the term "endemic" to refer to an organism that might be geographically widespread but that is restricted to a specific habitat, e.g., hydrothermal vents.

fauna: the term fauna includes invertebrates and vertebrates.

hard substrata: outcrops in the form of carbonate concretions, solid material, crustal rocks or deposits of precipitated materials, metals and minerals discharged from the subsurface by hydrothermal systems.

impact zone: zone where impacts (direct, indirect, cumulative and/or interactive) result from the activity.

impact reference zones: areas used to assess the effect of activities in the Area on the marine environment; these impact reference zones must be representative of the environmental characteristics (physical, chemical, biological) of the area to be mined.

inactive (or dormant) sulphides: polymetallic sulphides through which warm water is no longer flowing into the overlying seawater (i.e., they are "cold"). Disturbance of these sulphides may result in renewal of hydrothermal fluxes into the water column, turning inactive sulphides into active sulphides (hence the concept of "dormant" sulphides).

indirect impacts: impacts on the environment that are not a direct result of the activity, often produced away from or as a result of a complex pathway (physical, chemical, biological). Often referred to as secondary (or even tertiary) impacts.

micro-organisms: includes bacteria, archaea and microscopic eukarya.

plankton: includes larval stages of benthic and pelagic organisms, phytoplankton (in surface waters), zooplankton, jellies and other drifting or weakly-swimming organisms.

polymetallic sulphides: hydrothermally-formed deposits of sulphide minerals which contain concentrations of metals including, inter alia, copper, lead, zinc, gold and silver (ISBA/10/C/WP.1, para. 3 (f)). These deposits include sulphides associated with active as well as inactive hydrothermal vent settings. They may occur as buried deposits or they may be exposed on the seafloor. They may occur on seamounts, mid-ocean ridges or back-arc ridges.

preservation reference zones: areas representative of the test-mining site, but in which no test mining shall occur; used to assess changes in the biological status of the environment caused by test-mining activities.

seamounts: isolated topographic features, usually of volcanic origin, of significant height above the seafloor.

subhabitat: a visually recognizable component of a larger habitat; for example, tubeworm and mussel beds may be subhabitats of a specific active polymetallic sulphide field; an operational term that facilitates an understanding of the habitat as a whole.

symbioses (chemosynthetic): associations between bacteria (symbionts) and invertebrates or vertebrates (hosts), in which the symbionts are chemosynthetic and provide nourishment to the host. The bacteria may be either endosymbiotic (living within the host tissues; e.g., tubeworms, clams, mussels) or episymbiotic (living on the outside of the host; e.g., bresiliid shrimp, alvinellid polychaetes).

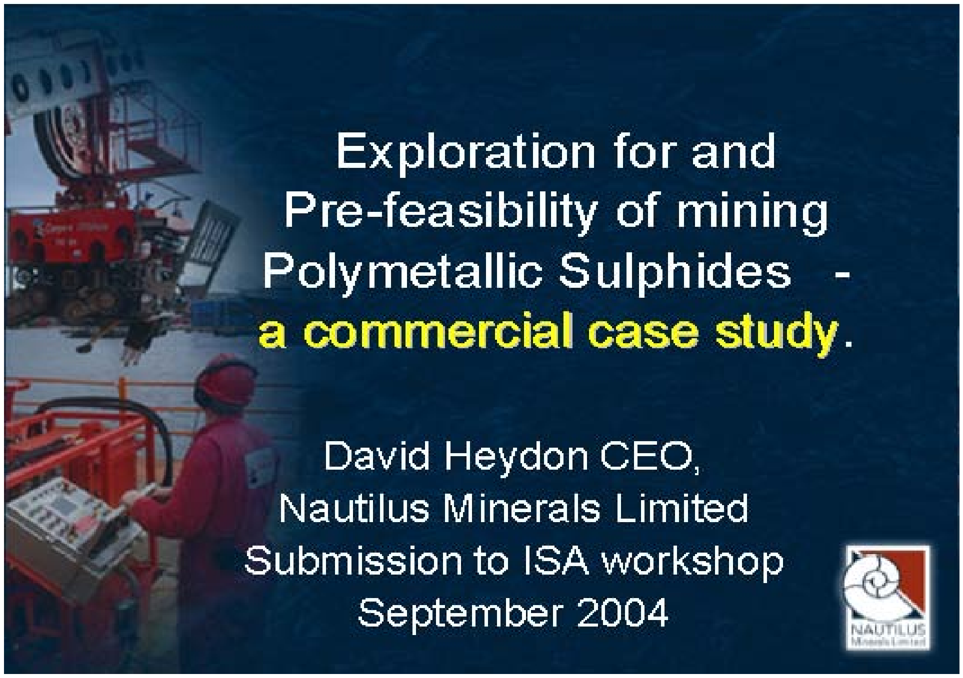
ANNEXES

Presentations by David Heydon of Nautilus Minerals Limited

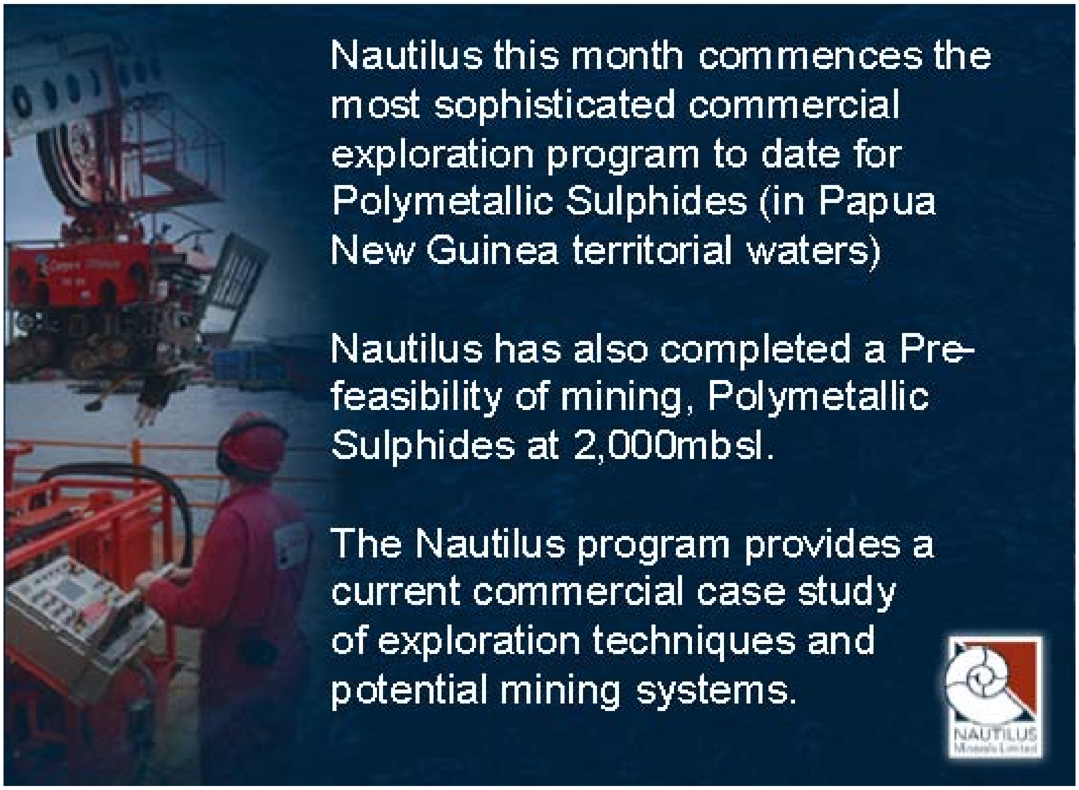
I Exploration for and Pre-feasibility of mining Polymetallic Sulphides – A Commercial Case Study

II Mining on land vs the seafloor – A Case Study
A presentation by David Heydon

ANNEX 1


Exploration for and
Pre-feasibility of mining
Polymetallic Sulphides -
a commercial case study.
David Heydon CEO,
Nautilus Minerals Limited
Submission to ISA workshop
September 2004
NAUTILUS


Nautilus Minerals Ltd
David Heydon
Chief Executive Officer.
25 years in the mining and exploration industry, with a strong record in technical innovation and project management.
NAUTILUS
www.NautilusMinerals.com


Nautilus this month commences the most sophisticated commercial exploration program to date for Polymetallic Sulphides (in Papua New Guinea territorial waters)
Nautilus has also completed a Pre-feasibility of mining, Polymetallic Sulphides at 2,000mbsl.
The Nautilus program provides a current commercial case study of exploration techniques and potential mining systems.
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Minerals Limited


Nautilus Minerals Limited
Technical Alliance Deep Sea Mining
Worley
• Project Manager, Owner's engineer
• Remote Operated Vehicles
Canyon Offshore
VOEST-ALPINE BERGTECHNIK
• Miner cutting tool – technology
SIEMAG
• Ore Hoisting
Seacore
• Resource Drilling
WILLIAMSON & ASSOCIATES
• Resource Geophysics
NAUTILUS
Minerals Limited

Exploration – Polymetallic Sulphides

An actual case study

- **This month, Nautilus is mobilising ships and survey equipment for a major exploration program in Papua New Guinea**

- Unlike on land, the exploration will not require a camp, nor land clearing for roads. Exploration will be conducted from a vessel where all equipment, rubbish wastes, sewerage wastes, fuel etc will be securely contained and removed upon completion of exploration program, leaving the area undisturbed

- Geophysics is a 'passive' non destructive survey

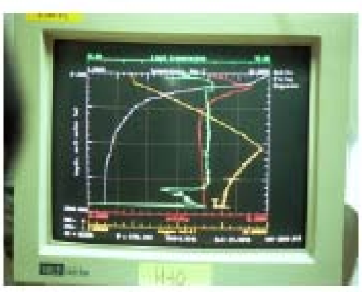
Exploration – Polymetallic Sulphides

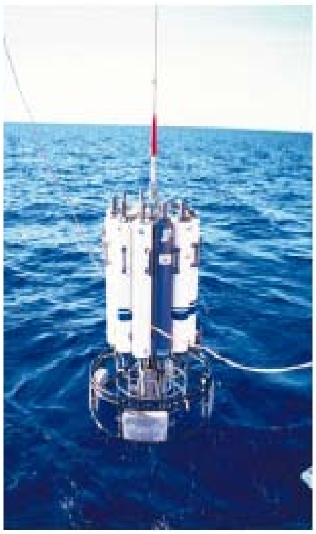
Water column testing

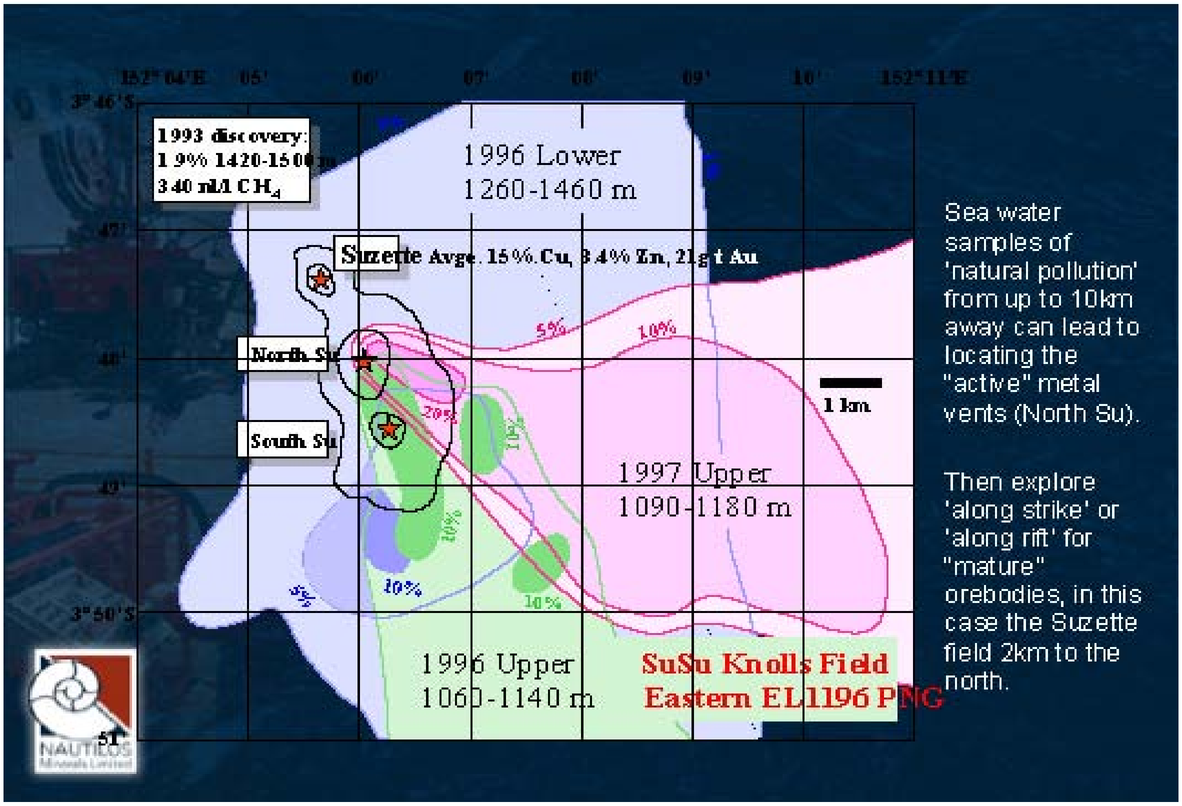
– efficient first pass exploration

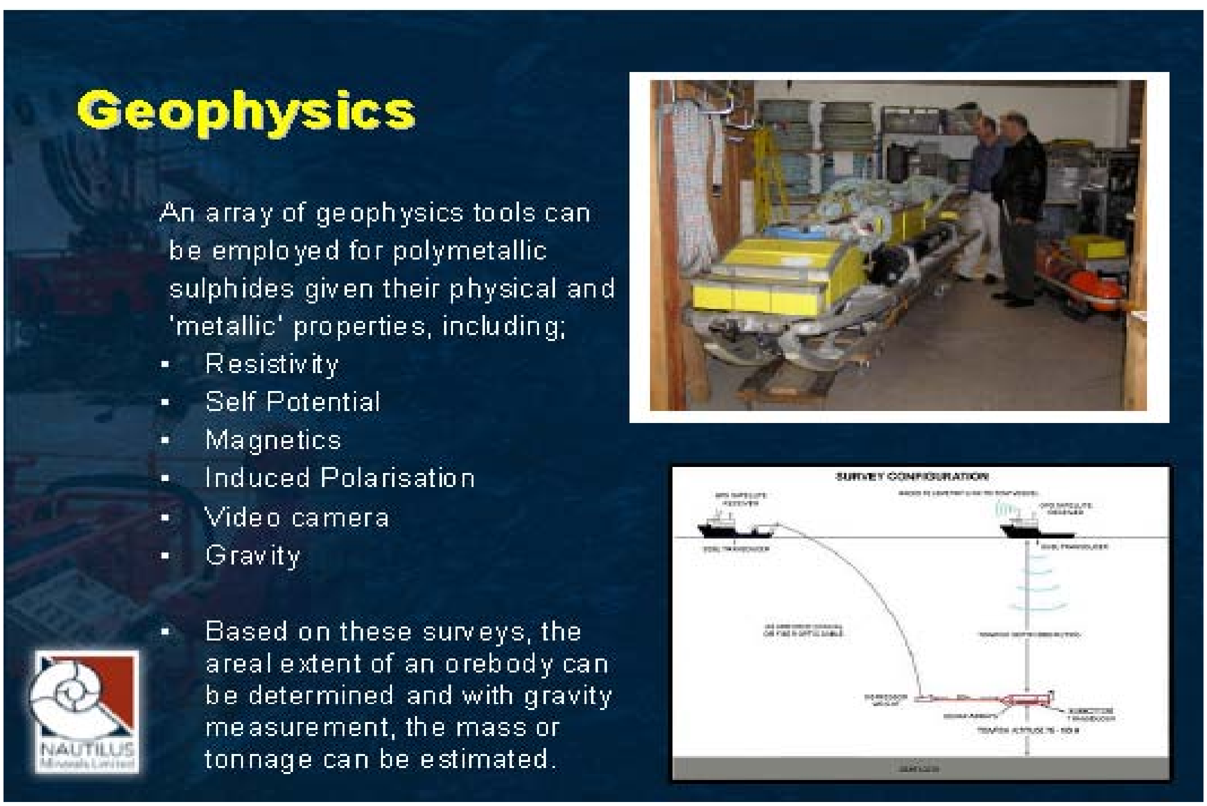
Locates evidence of active plumes ("vent smokers"). Uses natural 'pollution' to locate mineral fields

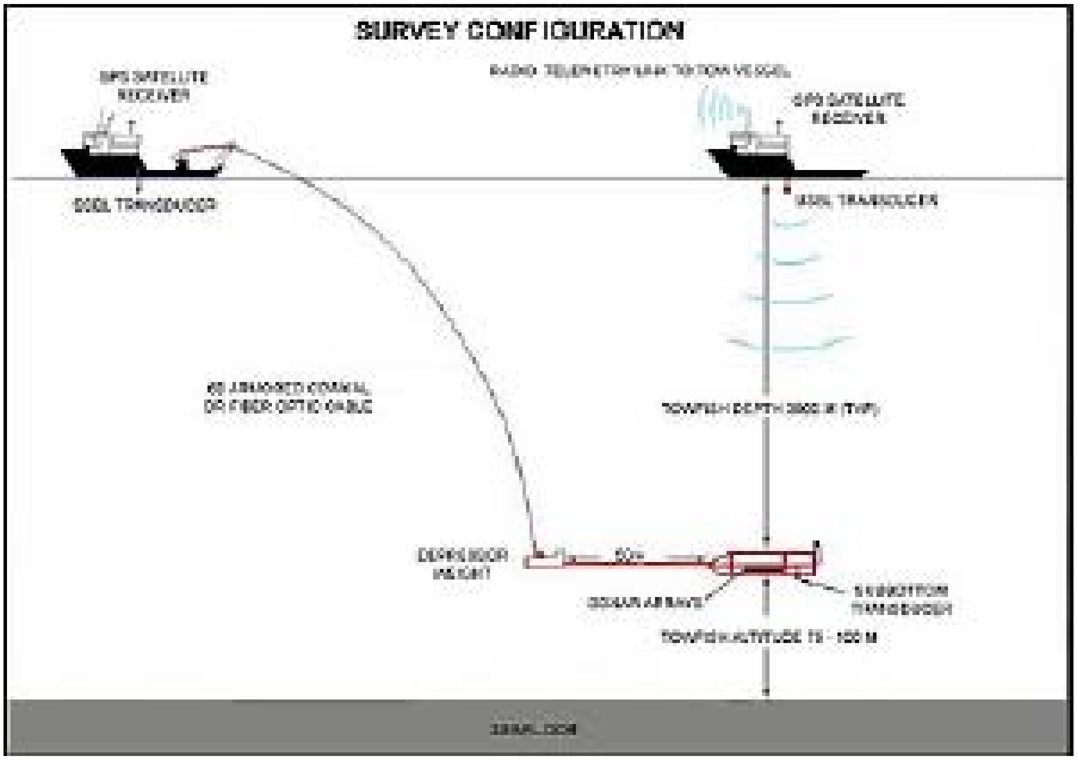
- Rapidly cover a prospective regional area
- Basis is that an "active vent field" may indicate a region where mineralisation may have been active in recent geological history and older, mature 'ore bodies' may occur 'along strike' or 'along rift'






152° 04'E
05'
06'
07'
08'
09'
10'
152° 11'E
3° 46'S
47'
48'
49'
3° 50'S
51'
1993 discovery:
1.9% 1420-1500 m
340 nl/l CH4
1996 Lower
1260-1460 m
Suzette Avge. 15% Cu, 3.4% Zn, 21g/t Au
North Su
South Su
5%
10%
20%
1 km
1997 Upper
1090-1180 m
1996 Upper
1060-1140 m
SuSu Knolls Field
Eastern EL1196 PNG
NAUTILUS
Sea water samples of 'natural pollution' from up to 10km away can lead to locating the "active" metal vents (North Su).
Then explore 'along strike' or 'along rift' for "mature" orebodies, in this case the Suzette field 2km to the north.


Geophysics
An array of geophysics tools can be employed for polymetallic sulphides given their physical and 'metallic' properties, including;
▪ Resistivity
▪ Self Potential
▪ Magnetics
▪ Induced Polarisation
▪ Video camera
▪ Gravity
▪ Based on these surveys, the areal extent of an orebody can be determined and with gravity measurement, the mass or tonnage can be estimated.
SURVEY CONFIGURATION
NAUTILUS


SURVEY CONFIGURATION
GPS SATELLITE RECEIVER
GPS SATELLITE RECEIVER
DEPRESSOR WEIGHT
SONAR ARRAYS
SEAFLOOR


Exploration – **Sampling**
A geophysical anomaly can be 'ground truthed' to confirm the source of the anomaly is in fact sulphides and also to determine the style and surface grade of mineralisation.
Simple dredges (right) or sophisticated grabs (left) can recover samples.
NAUTILUS
Minerals Limited

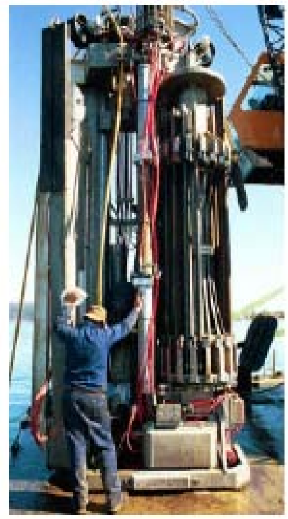
Exploration – **Drilling**

Unlike crusts or nodules which lay on the sea bed surface, Polymetallic Sulphides require drilling to test the vertical or depth extent of the mineralisation and to test any buried body.

Drilling assists in determining an average grade of the body.

Drilling can be by remote operated drill rig lowered to the sea floor. There are less than 6 of these currently in operation worldwide.

Core recovery by these rigs has to date been unacceptable for commercial ore grade assessment.



Exploration – **Drilling**

There has been very limited drilling in water depths from 1,500m to 2,000m, let alone deeper waters of the "Area". There are only a couple of ship based operators with capability to drill in 2,000m water. The Ocean Drilling Program (ODP) has not successfully recovered continuous core from the top 20 metre of the seabed where these sulphides may first be mined.

Drilling technology needs to be advanced to meet the standard of core recovery required for commercial ore grade assessment.

Nautilus's partner SEACORE (right) is a leading deep sea drilling company

Exploration - **Drilling**

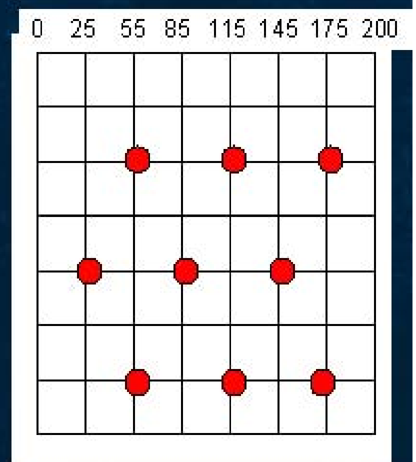
Nominal Mineral Deposit

200 metres x 200 metres x 18 metres deep = 2 million tonnes

First Phase Exploration:

Nominal Program

- 9 holes to start at approx 60m spacing, drilled to 20m depth
- 70mm core diameter
- Include one or two 300mm (12") holes reamed for larger sample for first phase metallurgy testing.



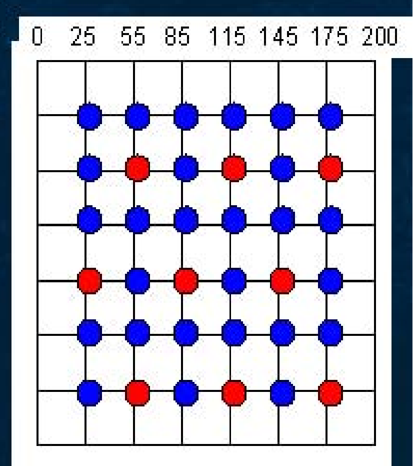
Exploration - **Drilling**

Mineral Deposit

200metres x 200metres x 18metres deep = 2 million tonnes (nominal size orebody)

Pre Mining Phase – For detailed Grade Control and pre Mine Planning

- Infill up to 27 holes (30m spacing) depending on variability of geology and grade. Less holes if geology and grade are consistent.
- May include more larger reamed holes for metallurgical samples.



Exploration – **MSR activity**

Exploration as described herein is 'passive' and no more than is already being done by Marine Scientific Research groups ("MSR"). In fact MSR work often focuses on a few know 'active fields' like TAG, Juan de Fuca etc with repeated surveys over these fields at a greater intensity level than would result from commercial exploration. MSRs have already drilled grab sampled and conducted geophysics on polymetallic sulphides in the Area just as described herein.

Exploration – **Crusts vs Sulphides**

- Crusts are thin average 40mm
- Polymetallic sulphides are relatively thick lenses average 15 – 20 metres
- 2 million tonnes of crust covers a surface area of **16 square KILOMETRES** whereas 2mt of sulphides is **only 200 METRES square**
- To sample a 2mt ore body of crusts therefore requires disturbing a large surface area.
- To sample Polymetallic sulphides disturbs a relatively small surface area as most of the sample is **sub surface drill core** (max 36 x 70mm holes over 200m x 200m area)

Trial Mining

- Advantage of trial mining is it allows both parties data, and the ISA gets info on which to make regulations & embody conditions into any subsequent Mining Lease based on this trial work.
- Logically you would not go to trial mining until you had a sufficiently large resource indicated to show sufficient mine life to justify future capital eg a minimum resource of 10 years at full scale production.
- Accordingly this implies you have found a large mineralised area and as such trial mining would only disturb a small portion eg 1/20th of this area leaving the remaining environment undisturbed. So trial mining by definition does not destroy the environment just a very small subset of a mineral environ.

(Right – trial mining nodules 1978)

Trial Mining – **crust vs sulphides**

- A trial mining program may entail mining 1 million tonnes trialling a 2mtpa mining system.
- 1 million tonnes of crust covers a surface area of **8 square KILOMETRES** whereas 1 million tonnes of polymetallic sulphides to 20m deep disturbs **only 140 METRES square** of surface area.
- Trial mining production should be allowed to be sold to a processor to determine process characteristics, recover costs of trial and ensure material from trial is not wasted but used by man.


Pre-feasibility of mining, Polymetallic Sulphides - a commercial case study.
Nautilus has completed a pre-feasibility engineering study of mining, Polymetallic Sulphides at 2,000mbsl.
NAUTILUS


Exploitation – The Mine
Parameters:
• Mine 2 million tonnes per annum
• Mine life plus 10 years = + 20mt
• Orebodies average 2mt
• 2mt is 200m x 200m x 20m thick
• "Mine" may stay in one spot anchored for a year or more over a field containing several deposits
• "Mine" then relocates to another area which may be several kilometres away to aggregate the +20mt required.
NAUTILUS

Exploitation – **Surface Assets**

The Mine

- A floating 'top side asset' either ship or semi submersible (right)
- Purpose is to provide a work platform, power, support, sub sea deployment, also for 'off take' of product.
- Nautilus study shows size and cost of ship/platform to either process or store at sea is prohibitive, uneconomic.
- Massive sulphides in one area lead to operating in one area for 12 months so can deep moor instead of dynamic positioning

Exploitation – **Remote Operated Mining**

ROV Miner

- 1,000hp ROV's (equivalent to a D11 bulldozer – right) exist
- ROV's are used for cable and pipe lay trenching. They are already 'mining' just not recovering the material.
- Nautilus study based on 5,000 hr pa operation and 2million tonnes pa = 400t per hour.
- Two mining vehicles per platform, powered by electric umbilical each mining 200t per hour.
  - Nautilus partner Perry Slingsby Systems is largest manufacturer of ROV's

Exploitation – **Remote Operated Mining**

ROV Miner

- Polymetallic Sulphides have strength of coal.
- Nautilus study proposes drum cutters as used in coal mining
- Drum cutter miner is 5m wide & cuts a 2m high 'face'.
- Each miner advances only 7 metres per hour. (1 track turn)
- Cutting teeth designed not to produce fines but average 50mm particles (up to 70mm)
    - Nautilus partner Voest Alpine is a leading manufacturer of cutters & road headers

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Exploitation – **Material Handling**

ROV Miner

- The ore body is 'rock' on a volcanic ridge so no silt - mud so no plume of fines as for nodules.
- The miner has a pump located near the cutting head & positive suction in to this pump ensures no fines are lost.
- This pump transports the material from the miner to the vertical ore hoisting system.
- This system can either be a wire rope hoist system like in underground mines or a hydraulic pump system up a riser pipe

Compare Cobalt Crust

Crust is 40mm thick on an uneven surface. To mine just 40mm (without dilution) means leaving the surface uneven so 'miner' cannot operate on flat road surface whereas for polymetallic sulphides the 'miner' after one track length has made a flat 'road' to operate on.

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SIEMAG

- World leader in hoisting ore from deep underground
- Systems to 3,000m
- SIEMAG have proposed a system to hoist at rate of 400 tonnes per hour from 2,000mbsl.
- Hoist 100t kibbles at 1.8 metres per second. (on land run at 16m/s)

Exploitation – **Pumping Option**

- Nautilus engineering study considered both slurry pumps (Warman) and positive displacement pumps (SIEMAG) which may be assisted by airlift.
- Electric powered Pumps located on sea bed.
- 70mm maximum particles up a 300mm internal diameter riser pipe.
- System offers efficient continuous mining and material handling.

Exploitation – **Mineral Processing**

- In EEZ or territorial waters, ore would be processed on land given the size of a 2 million tonnes per annum processing plant and 'cost' of land vs displacement (floating).
- In the AREA this issue may be a critical factor & require higher grade material to either justify cost of direct shipping large distance to a land plant or onsite processing (unlikely as extremely high cost for such large displaced ship)
  - Key factor why EEZ likely mined before AREA

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Exploitation – **EEZ vs the AREA**

- Polymetallic sulphides occur in many EEZs and in the AREA
- It is likely those in an EEZ will be developed before those in the AREA providing the ISA with environmental information on which to develop its own regulations.
- ISA terms (i.e. “taxes”) are less attractive to development than many State EEZ’s with ISA demanding an onerous 50% participation or 50% product sharing.

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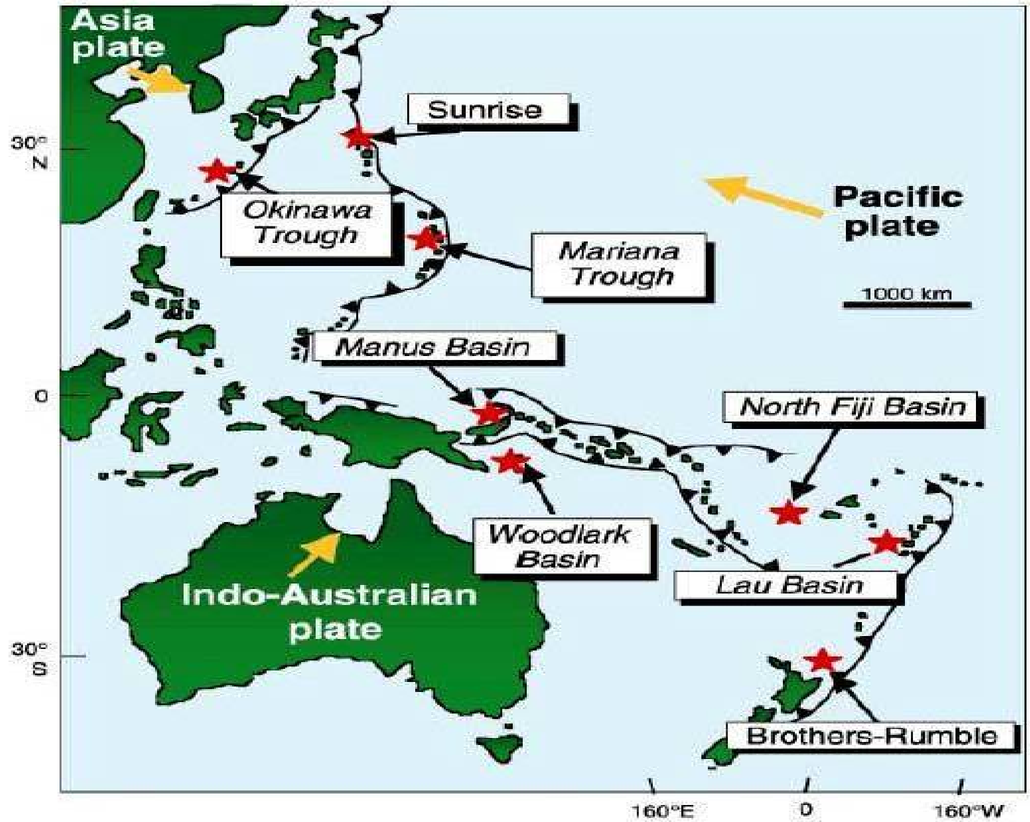
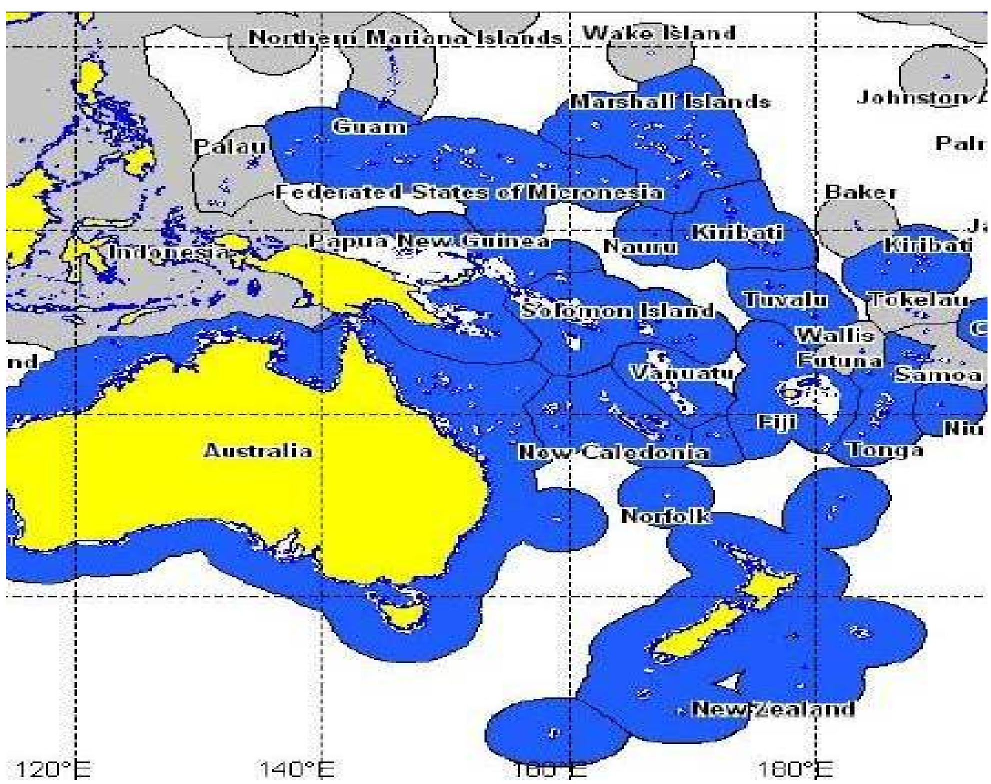
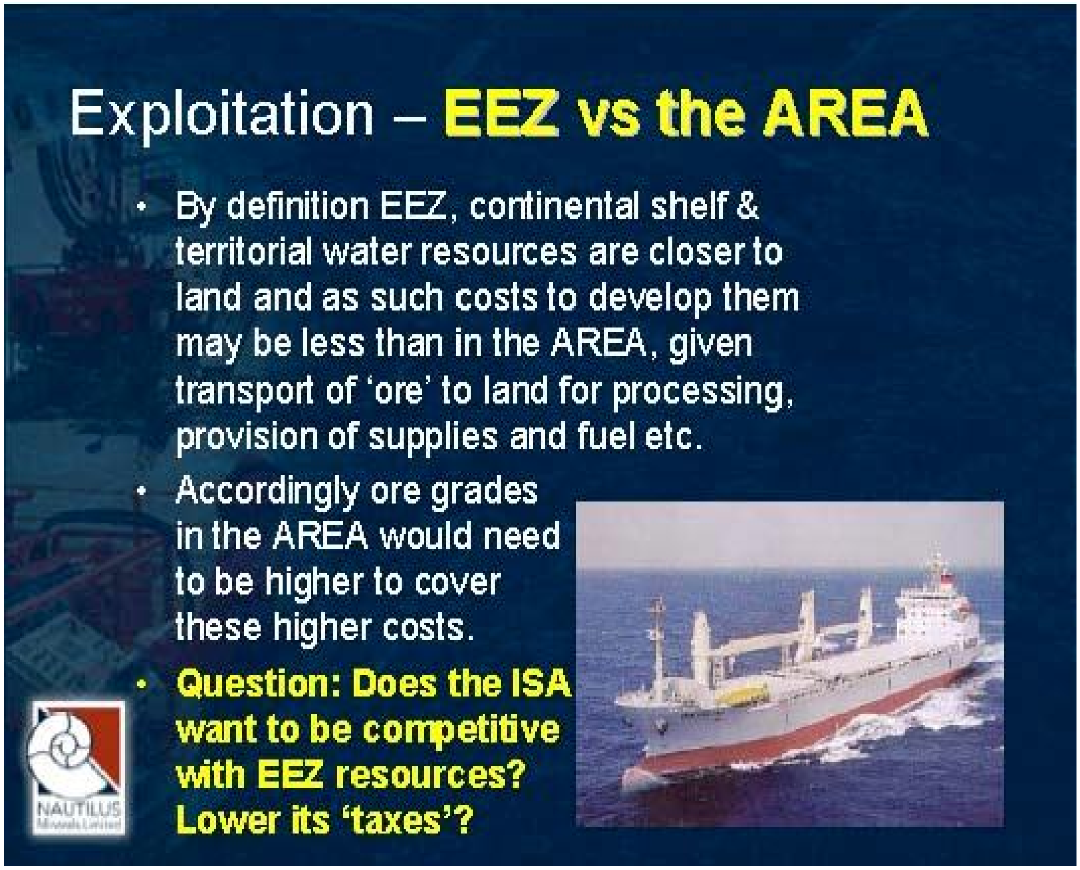

Asia plate
Sunrise
30° N
Pacific plate
Okinawa Trough
Mariana Trough
1000 km
Manus Basin
0
North Fiji Basin
Woodlark Basin
Indo-Australian plate
Lau Basin
30° S
Brothers-Rumble
160°E
0
160°W


Northern Mariana Islands
Wake Island
Marshall Islands
Guam
Palau
Federated States of Micronesia
Baker
Indonesia
Papua New Guinea
Nauru
Kiribati
Kiribati
Solomon Island
Tuvalu
Tokelau
Wallis
Futuna
Samoa
Vanuatu
Fiji
Australia
New Caledonia
Tonga
Norfolk
New Zealand
120°E
140°E
180°E


Exploitation – EEZ vs the AREA
• By definition EEZ, continental shelf & territorial water resources are closer to land and as such costs to develop them may be less than in the AREA, given transport of 'ore' to land for processing, provision of supplies and fuel etc.
• Accordingly ore grades in the AREA would need to be higher to cover these higher costs.
• Question: Does the ISA want to be competitive with EEZ resources? Lower its 'taxes'?
NAUTILUS


Environmental
considerations of exploration for and exploitation of, Cobalt Crusts & Polymetallic Sulphides
A commercial perspective.
NAUTILUS

Environmental – crust vs sulphides

Comparison based on a 2 million ton per annum operation

	Nodule	**Co Crust**	**Sulphide**
Attribute	25 kg/m3	40mm	20m deep
Surface area	**80 sq kilometres**	**16 sq kilometres**	**200m x 200m**
Surface Environ	silt, mud abyssal plain	volcanic seamount	volcanic ridge
Depth	>4,000mbsl	>500mbsl	>1,000mbsl
Metal	Ni, Co, Cu	Co, Ni, Cu	Cu, Au, Zn, Ag

Given the above differences it is clear that each resource requires different environmental regulations

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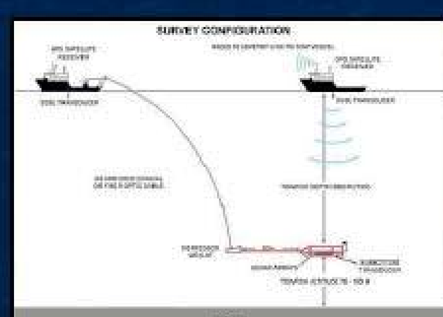
Environmental – Exploration

- **GEOPHYSICS**:
- Mostly 'non grounded' ie no contact with seabed. (like airborne survey over land)
- Passive measurement of natural features



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Environmental – **Exploration**

- **SAMPLING**:
- Disturbance of a very limited area
- In practice whilst commonly used by MSR's along with the grab, this tool is not overly used for commercial exploration as it provides limited information – only surface samples which may not represent the 'mass'.
- Can also provide valuable biological information

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Environmental – **Exploration**

- **DRILLING**:
- Limited surface disturbance (70mm – 2" core holes) as majority of sample material is gathered from depth.
- May also take several larger diameter holes for metallurgical samples eg ream hole 300mm – 12" diameter but once more limited surface disturbance.

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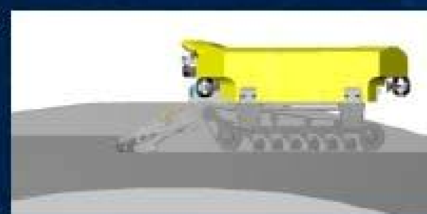
Environmental – **Exploration**

- **TRIAL MINING** :
- In practice would only involve disturbing 1/20th or 1/40th of the resource.
- Accordingly the majority of the mineralised environ is left undisturbed.
- Provides valuable data for State or ISA upon which regulations be based before any mining lease is granted.
- For cost reasons, elements of trial mining may first be conducted in another environ eg land quarry or a harbour channel.



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Environmental – **Exploitation**

- **MINING PLATFORM**:
- Platform is self contained with services and is re-supplied by ship.
- Probably moored in one spot for a year at a time supporting a mining operation
- Ore is dewatered and fines removed by cyclones and recovered as product
- Ore is transferred hydraulically (pipe) or mechanically (conveyor) to a barge or ore carrier for shipment to port.
- Can act as a weather station for a weather network etc.

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Environmental – **Exploitation**

- **MINING OPERATION**:
  - Electric powered Remote Operated Miners use similar technology to those already operating in the AREA laying telecommunication cables etc.
  - Operate on volcanic ridges (not muddy abyssal plains so no plumes).
  - Rock Cutting heads designed to not make small fragments.
  - Positive suction pump draws in any fines produced to the pump system & to the surface.

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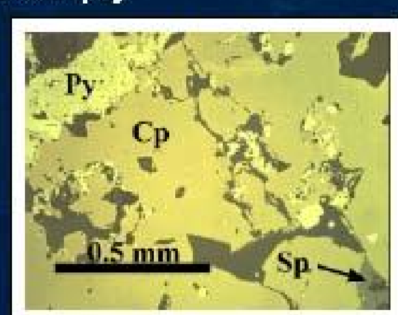
Environmental – **Exploitation**

- **OTHER ELEMENTS**:
  - Deleterious elements that might exist naturally in the ore such as lead and arsenic remain in the same stable mineralogy during mining. The mineral is not broken down from its stable constituent, the mass of ore is simply removed for further processing on land at a concentrator and then a smelter or similar.



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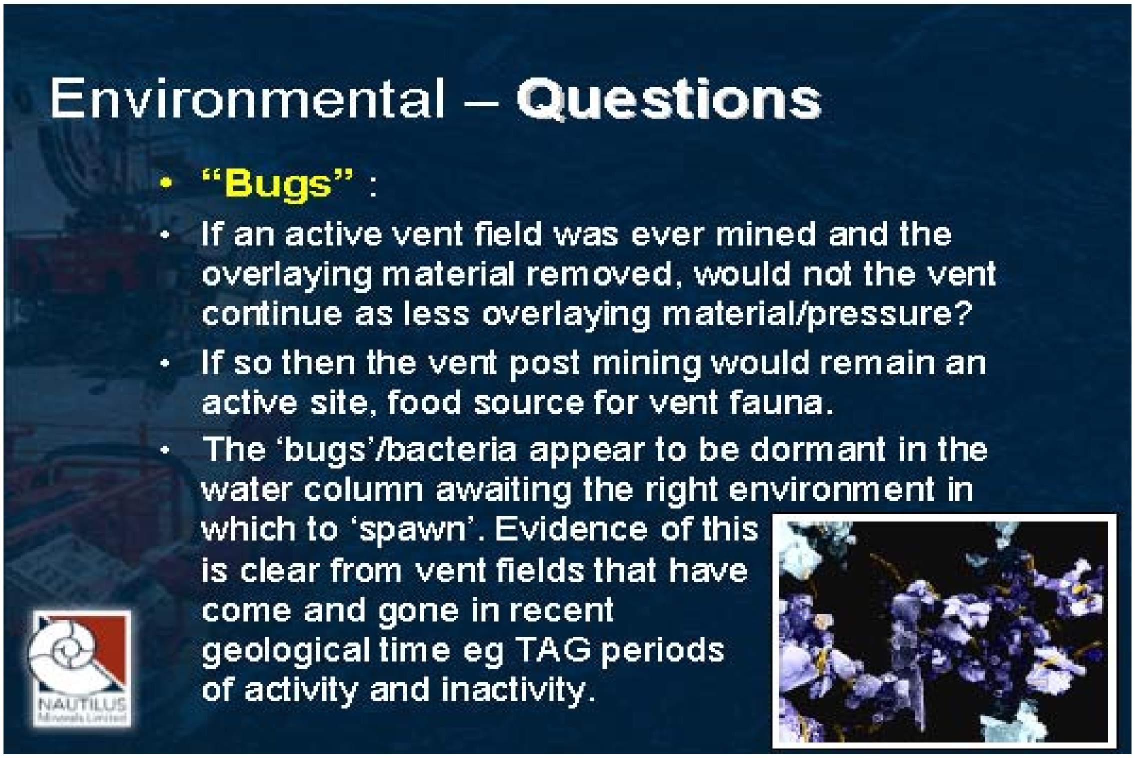
Environmental – **Exploitation**

- **PUMPING - RISER**:
- Ore is pumped to the floating platform up a 300mm riser (pipe).
- On the platform it is dewatered and fines removed by cyclones and recovered as product.
- Water can then either be
  - returned down a second pipe to an appropriate depth such as 500m where mixing can occur.
  - If it is seen as a positive to the environment eg fish breeding as in Hawaii around the OTEC plant, this nutrient rich water can be discharged at other levels.

Environmental – **Questions**

- **"Bugs" Bacteria Question**:
- Who administers the "bugs" contained **in** the material that would be mined, ie not those in the water column but those contained **within the seabed**?
- This bacteria appears in samples of NON active vents and appears to survive in a dormant state in the samples recovered to surface until a heat and food source is introduced by culture medium.


Environmental – Questions
• "Bugs" :
• If an active vent field was ever mined and the overlaying material removed, would not the vent continue as less overlaying material/pressure?
• If so then the vent post mining would remain an active site, food source for vent fauna.
• The 'bugs'/bacteria appear to be dormant in the water column awaiting the right environment in which to 'spawn'. Evidence of this is clear from vent fields that have come and gone in recent geological time eg TAG periods of activity and inactivity.
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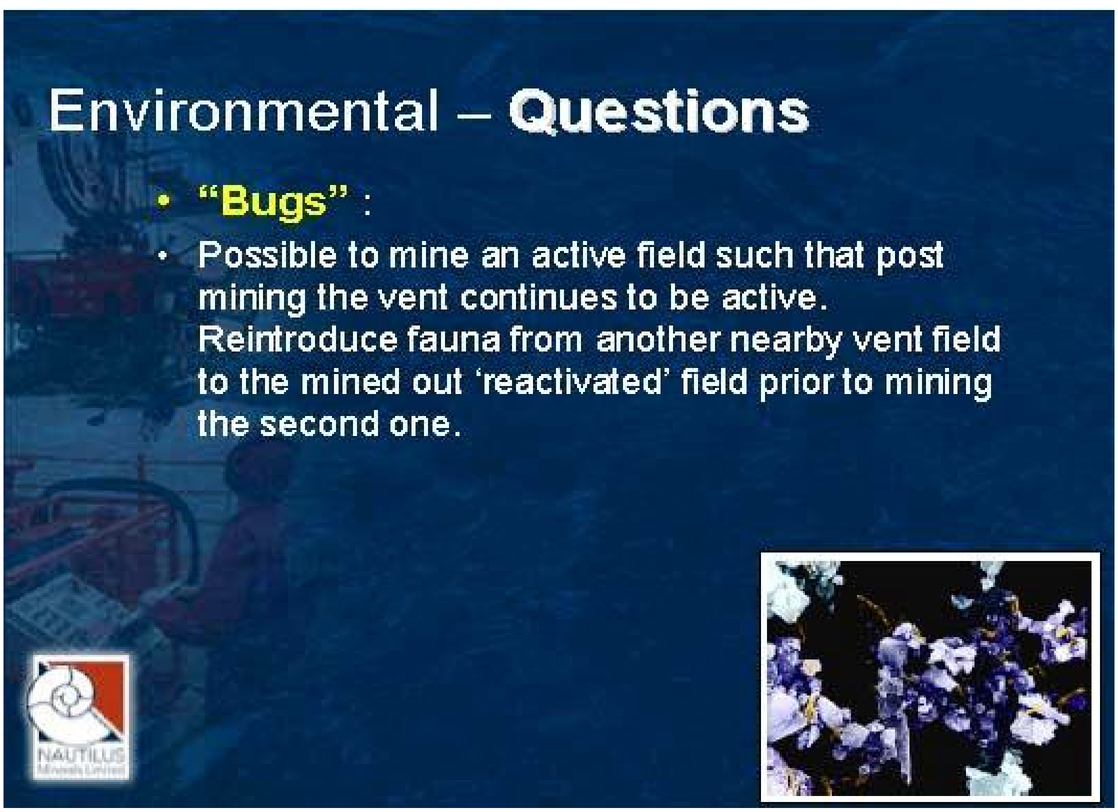
Environmental – Questions
• "Bugs" :
• Possible to mine an active field such that post mining the vent continues to be active. Reintroduce fauna from another nearby vent field to the mined out 'reactivated' field prior to mining the second one.
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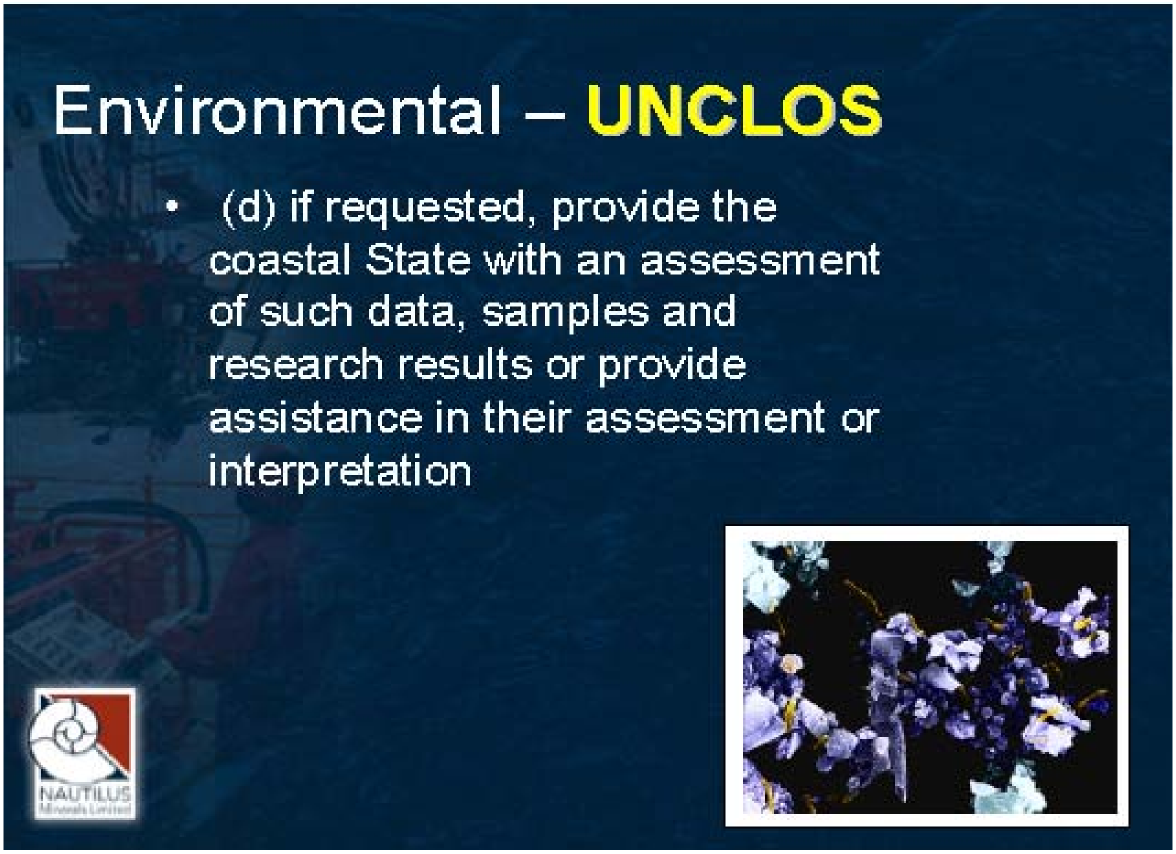
Environmental – **UNCLOS**

- Is all the data that has been gathered by MSR groups operating in the Area available to the ISA?
- ISA regulates that all Contractors exploring in the Area must provide data to ISA of all results etc. The rationale for this regulation should be applied to MSR data which if collected in the AREA should be managed by someone for 'the good of mankind".
- The more data the ISA has the better it can manage and administer the AREA.

Environmental – **UNCLOS**

- (c) undertake to provide **access** for the coastal State, at its request, to **all data and samples** derived from the marine scientific research project and likewise to furnish it with data which may be copied and samples which may be divided without detriment to their scientific value,


Environmental – UNCLOS
• (d) if requested, provide the coastal State with an assessment of such data, samples and research results or provide assistance in their assessment or interpretation
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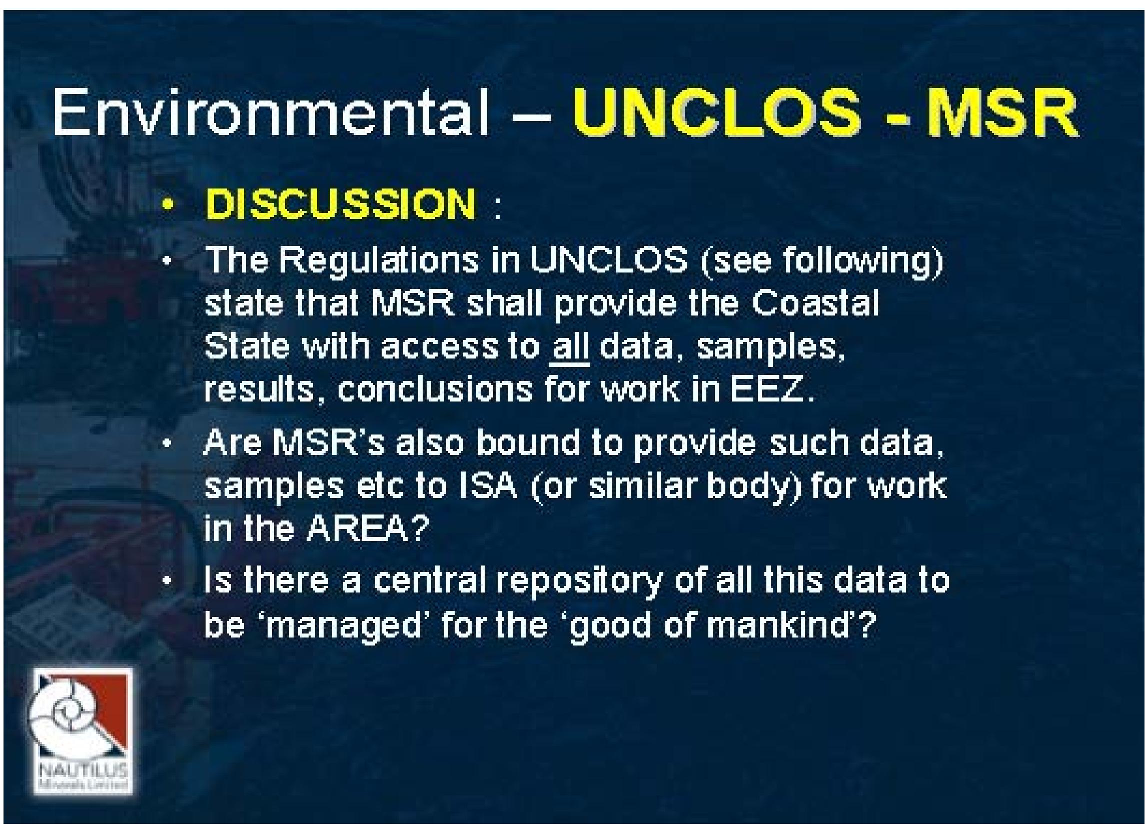
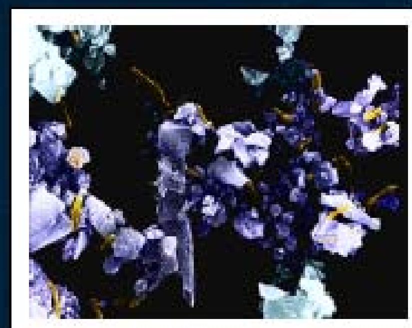

Environmental – UNCLOS - MSR
• DISCUSSION :
• The Regulations in UNCLOS (see following) state that MSR shall provide the Coastal State with access to all data, samples, results, conclusions for work in EEZ.
• Are MSR's also bound to provide such data, samples etc to ISA (or similar body) for work in the AREA?
• Is there a central repository of all this data to be 'managed' for the 'good of mankind'?
NAUTILUS

Environmental – **UNCLOS**

- UNCLOS regulations state that the MSR's shall:
- (b) provide the coastal State, at its request, with preliminary reports, as soon as practicable, **<u>and with the final results and conclusions</u>** after the completion of the research

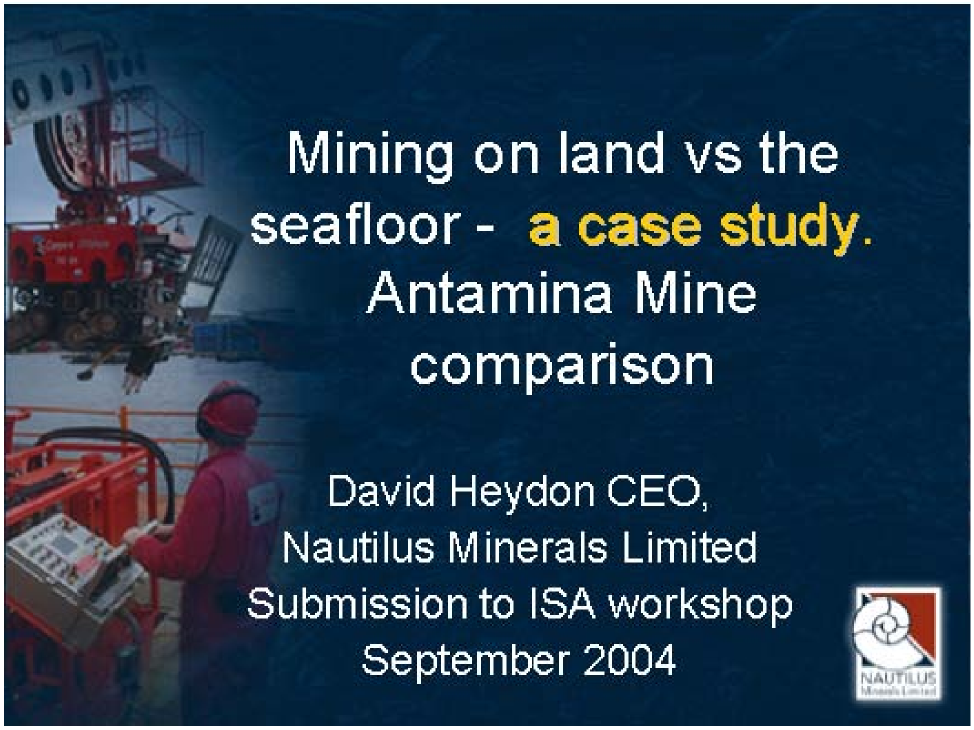


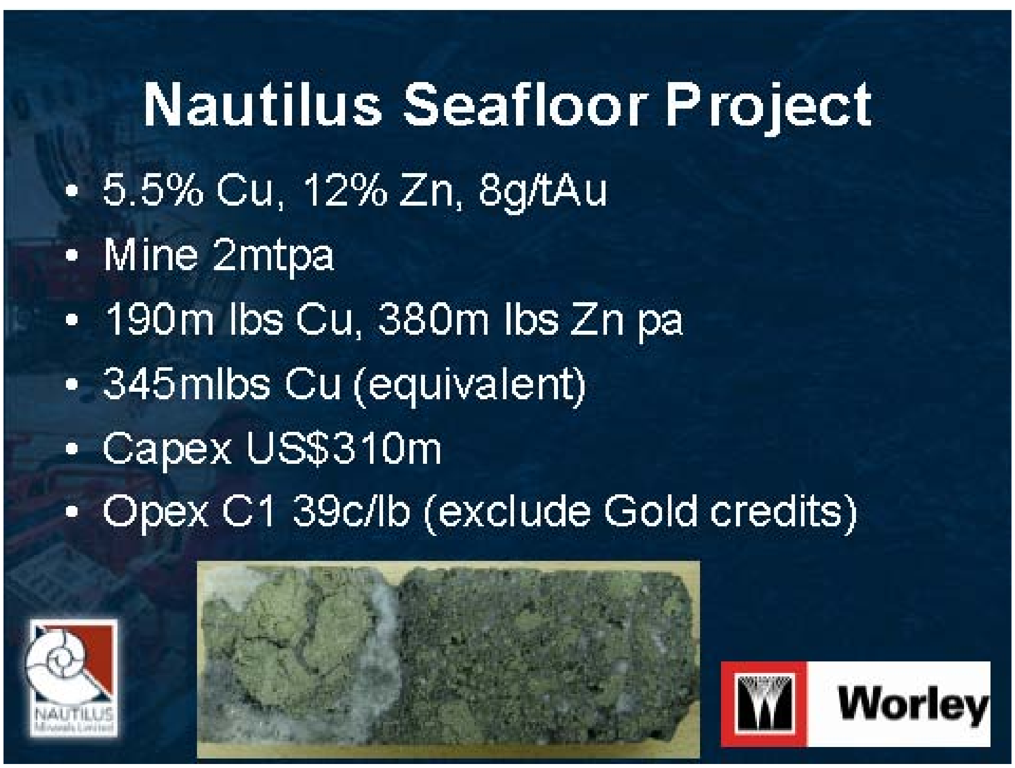
Environmental – **UNCLOS**

- If copies of ALL the MSR data gathered in the AREA (and subsets of all samples – rock, benthos etc,) had to be provided to the ISA (as MSR must do for the Coastal State) then the ISA would have a very valuable asset of data on which to;
- 1. formulate its regulations eg enviro baseline data we are discussing today
- 2. promote/market its resources to & attract potential Contractors
- 3. A data base that may allow the ISA to 'tender' out areas to Contractors

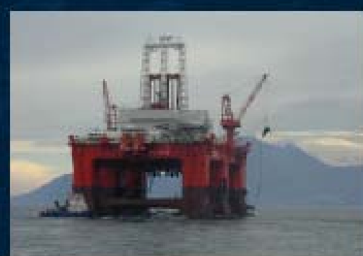

Nautilus Minerals Ltd
Whilst I cannot attend your workshop, I welcome the opportunity to discuss these thoughts further with any delegate who may wish to contact me.
With its forthcoming cruise & exploration program over next 12 months, Nautilus also seeks to collaborate with MSR groups to study the data collected.
David Heydon
Contact: Office@NautilusMinerals.com
NAUTILUS

ANNEX 2


Mining on land vs the seafloor - a case study.
Antamina Mine comparison
David Heydon CEO,
Nautilus Minerals Limited
Submission to ISA workshop
September 2004
NAUTILUS


Nautilus Seafloor Project
• 5.5% Cu, 12% Zn, 8g/tAu
• Mine 2mtpa
• 190m lbs Cu, 380m lbs Zn pa
• 345mlbs Cu (equivalent)
• Capex US$310m
• Opex C1 39c/lb (exclude Gold credits)
NAUTILUS
Worley

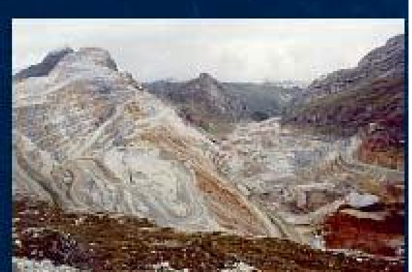
Comparison to Antamina

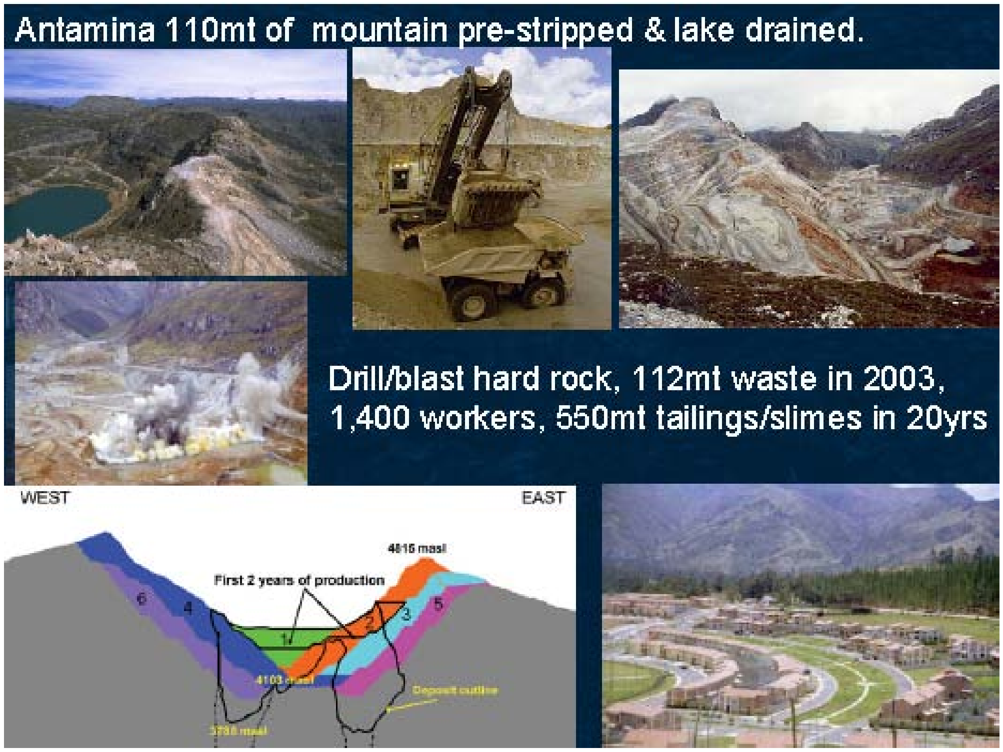


Antamina Mine

The Antamina mine, located at more than 4,300 meters above sea level in the Andes mountains, 385 kilometres north of Lima in Peru, is the one of the largest zinc and copper producers in the world.

Teck Cominco, Noranda BHP-Billiton and Mitsubishi Corp.





Overview

- **Antamina**
- 1.23% Cu, 1.03%Zn
- 675m lbs copper (avge)
- 625m lbs zinc (avge pa)
- **930m lbs Cu equivalent**
- **BHPBilliton owns 33.7%**
- **313m lbs Cu equiv BHP**

- **Nautilus**
- 5.5%Cu, 12%Zn
- 190m lbs copper (avge)
- 380m lbs zinc (avge pa)
- **345m lbs Cu equivalent**
- **Nautilus total is 37% of Antamina's copper**
- **345m lbs Cu equivalent More copper than BHP's share of Antamina**

Costs

- **Antamina**
- 110mt pre strip 4 years
- $2.26 billion Capex

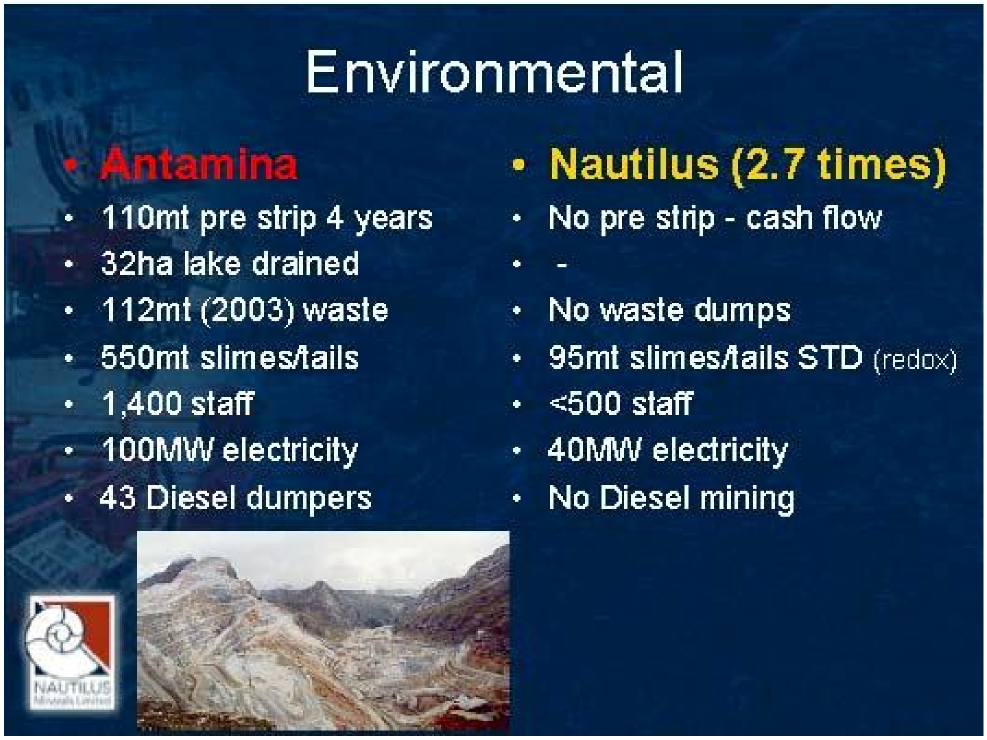
- **Nautilus (2.7 times)***
- No pre strip - cash flow
- $833m Capex
- **36% of the capital cost!!**
- C1 39c/lb (exclude gold)
- * Match full scale Antamina equiv. copper production

Worley

Mine, Mill Operations

- **Antamina**
- Mine built at 4,300m asl
- Mill built at 4,300m asl
- 112mt (2003) waste
- 26mt Ore pa
- 17,000 tonnes/hour
- Drill/Blast
- 4 Electric shovels
- 43 Diesel dumpers
- 2,000m tunnel to mill
- 300 km pipeline
- Ship concentrates o'seas

- **Nautilus (2.7 times)***
- "Mine" built in shipyard
- Mill built on coast - access
- No overburden
- 5.4mt Ore pa
- 1,000 tonnes/hour
- No drill/blast
- 5 continuous machines
- Semi submersible platform
- 2,000m riser pipe
- Ore carriers to concentrator
- Ship concentrates overseas
- * Match full scale Antamina equiv. copper production


Environmental
• Antamina
• 110mt pre strip 4 years
• 32ha lake drained
• 112mt (2003) waste
• 550mt slimes/tails
• 1,400 staff
• 100MW electricity
• 43 Diesel dumpers
• Nautilus (2.7 times)
• No pre strip - cash flow
• -
• No waste dumps
• 95mt slimes/tails STD (redox)
• <500 staff
• 40MW electricity
• No Diesel mining
NAUTILUS


Mine at 4,500mabls
or 2,000mbsl?
• <40% of capital
• 39c/lb Cu, C1 Opex
• higher grade
• less waste, enviro
• Higher exploration success
• No land claims
NAUTILUS

We all know we will mine the seafloor one day.
Why not today?
What stops us?
Costs? No!
Technology? No!
NAUTILUS