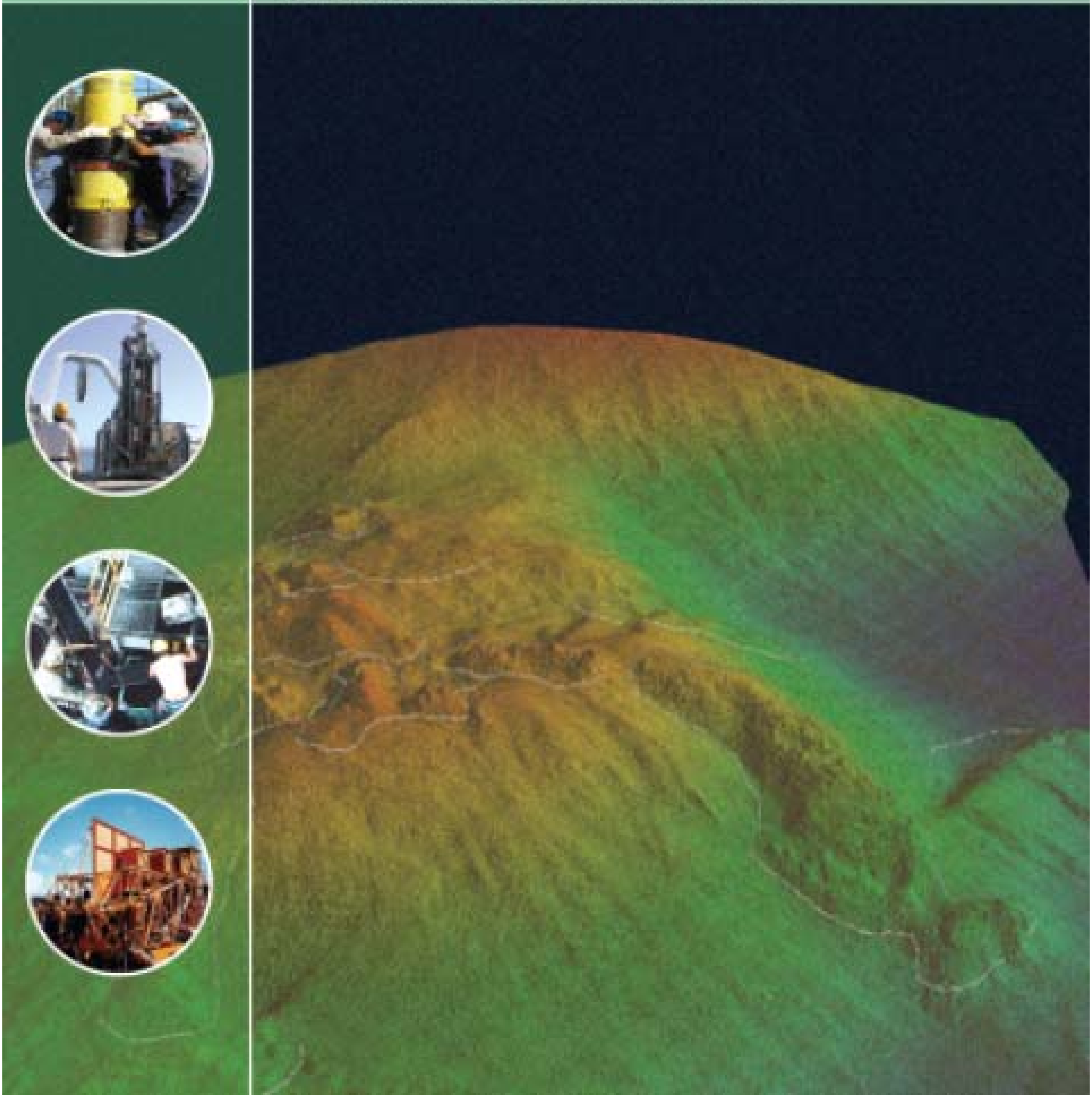
MINING COBALT-RICH FERROMANGANESE CRUSTS AND POLYMETALLIC SULPHIDES DEPOSITS: TECHNOLOGICAL AND ECONOMIC CONSIDERATIONS



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Proceedings of the International Seabed Authority's Workshop
held in Kingston, Jamaica, 31 July – 4 August 2006

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

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FOREWORD

Nii Odunton, Deputy to the Secretary-General, International Seabed Authority

Distinguished participants, on behalf of the Secretary-General of the International Seabed Authority I wish to welcome all of you to this, the 9th workshop in the Authority's series of workshops. As you all know this workshop is on "Prospects for mining cobalt-rich ferromanganese crusts and polymetallic sulphides in the Area". Ambassador Nandan, the Secretary-General, couldn't be here today; he is caught up in a meeting and will be with us tomorrow.

For those of you who have participated in any of the Authority's previous workshops, I wish to welcome you back; for first-timers, I welcome you to the Authority and to Kingston, Jamaica.

I wish to say a few words on our objectives for the workshop. In the life of the Authority, the 6th Session was one of the most auspicious because it was during that session that the Authority approved the Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area. Shortly thereafter, the Authority began consideration of regulations to govern prospecting and exploration for two additional mineral resources of the Area; cobalt-rich ferromanganese crusts and polymetallic sulphides. The work on those two sets of resources was undertaken by the Legal and Technical Commission of the Authority. I am very happy to see a few members of the Commission present at this workshop, and look forward to presentations by some of them on certain aspects of the draft Regulations. The Legal and Technical Commission completed the draft Regulations at the tenth session and submitted them to the Council for its consideration. The Council completed its first reading of these draft Regulations which are contained in document ISBA/10/C/WP.1 during the 11th session, and is scheduled to continue its consideration of these Regulations at the twelfth session.

Distinguished participants, the purpose of the workshop is to obtain information on the prospects for the development of cobalt-rich crusts and polymetallic sulphides deposits in the Area. It is to provide members of the Authority with an understanding of the process through which these resources become reserves of the metals that they contain while addressing some of the matters raised by the Council during its first reading of these draft Regulations.

The Agenda for the workshop includes, among other things, the legal framework for prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts deposits in the Area, and the available information on the geologic characteristics and geographic distribution of these resources in the Area. It also includes a perspective on the technological issues that have to be resolved for the international community to benefit from them, including competition from land-based sources of the metals of commercial interest. The agenda also contains presentations on supply and demand for the metals of commercial interest and a presentation on supply and demand issues in the People's Republic of China, which I think will be very informative. Other presentations include costs associated with environmental protection, which is a key mandate of the Authority, in particular that the Authority should protect the Area from activities related to prospecting, exploration and mining. The final presentations and discussions will be on hypothetical ventures for crusts and sulphides deposits mining in the Area. We will then break into working groups to examine the effects of the systems proposed in the draft Regulations for the participation of the Authority in both types of mining ventures.

The idea is that at the end of the week our deliberations will place all the members of the Authority in a position where they have a good perspective on these resources, what the commercial possibilities for them are, the type of search (prospecting/exploration) that is required to identify deposits containing the required amounts of the metals in the Area, preliminary cost models based on available information on technologies to be used and metal prices.

On behalf of the Secretary-General, I wish to thank all of you for taking the time required to come here and to participate in this workshop of the Authority.

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EXECUTIVE SUMMARY

The International Seabed Authority's workshop on technical and economic considerations for mining cobalt-rich ferromanganese crusts and polymetallic sulphides resources of the international seabed area ("the Area") was held in Kingston, Jamaica, from 31 July to 4 August 2006. The objective of the workshop was to assist the Authority by providing a more detailed analysis on matters relating to the adoption of regulations on prospecting and exploration for these two types of mineral deposits.

At the tenth session of the Authority (2004) the Legal and Technical Commission submitted document ISBA/10/C/WP.1 "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 of the Authority. At the eleventh session of the Authority (August 2005), following its first reading of the draft Regulations, the Council requested the Secretariat to clarify the technical content of some of the regulations. In particular, the Council requested the Secretary-General, in consultation, as necessary, with the Legal and Technical Commission, to provide the Council with a more detailed analysis and elaboration of the following aspects of the draft Regulations:

(a) With respect to prospecting, the Council requested further clarification of the relationship between prospecting and exploration and the justifications for the specific changes proposed by the Commission;

(b) With respect to the size of areas for exploration, the Council requested that further information be provided on the proposed system of allocating exploration blocks and the way in which it might operate in practice, as well as on the proposed schedule for relinquishment and its consistency with the provisions of the Convention;

(c) With respect to draft Regulations 16 and 19, relating to the proposed system for participation by the Authority, the Council requested a more detailed analysis of how the draft provisions might operate in practice in the light of the comments and opinions expressed in the Council.

It was noted that, compared to the regulations on prospecting and exploration for polymetallic nodules, the draft Regulations contained additional provisions aimed at protection and preservation of the marine environment. Many members of the Council supported the need for effective protection of the marine environment from the actual and potential adverse impacts of exploration activities. It was noted that some of the studies carried out by the Authority had suggested there was a greater risk of environmental damage from exploration for sulphides and crusts compared to exploration for polymetallic nodules, where the risk was comparatively low. Nevertheless, the Council also considered that it would be helpful if it could be provided with a more detailed analysis of the proposed changes to the draft Regulations and their relationship to the provisions of the Convention and the Agreement. Particular concern was raised over the proposed changes to the language in draft Regulations 33 to 36. It was suggested that further explanation of these changes would be useful.

During the five days of the workshop, 16 formal presentations were made in an effort to address some of the questions raised by the Council and to review some of the responses prepared by the Secretariat.[1] Following formal presentations, the participants formed two working groups to examine the effects of the proposed system of participation of the Authority in crusts and sulphides mines in the Area Work on cost models were superseded by discussions on a second option for payment of the initial application fee of USD$250,000. This option included a lower application fee, annual fees based on the number of blocks retained, and increasing the cost per block to take into account the relinquishment of blocks as required by the draft Regulations. A great deal of valuable discussion and interaction took place among the 37 participants and the Secretariat.

The workshop proceedings are structured in four parts. *Part I*, Regulations on Prospecting and Exploration for polymetallic sulphides and Cobalt-rich ferromanganese crusts in the Area, focussed on the general framework for the regulations, including the requirements of article 145 of the Convention on the protection and preservation of the marine environment, and the need to put into effect the parallel system. *Part II,* on the resources that are the subject of the regulations addresses the geologic characteristics and geographic distribution of potential deposits, prospecting and exploration for these resources, technological issues associated with the development of resources of the Area, criteria for exploration areas, and hypothetical mines of polymetallic sulphides and cobalt-rich ferromanganese mines in the Area. *Part III* examines the supply and demand of the metals of commercial interest in polymetallic sulphides deposits (copper, gold, lead, silver and zinc) and in cobalt-rich ferromanganese crusts deposits (cobalt) and *Part IV* contains the recommendations of the working groups on polymetallic sulphides and cobalt-rich ferromanganese crusts respectively.

Draft Regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area (ISBA/10/C/WP.1).

Mr Baïdy Diène, Member, Legal and Technical Commission of the International Seabed Authority.

Mr. Diène gave a presentation on the draft Regulations prepared by the Legal and Technical Commission that are being considered by the Council of the Authority. This was to ensure that all participants were aware of the proposed regulatory framework that had resulted in the meeting. As part of his outline, he defined some of the terms from the regulations. Mr. Diène noted that polymetallic sulphides and cobalt-rich crusts were potentially easier to exploit than polymetallic nodules. He further noted that since there was interest in mining these resources in national waters, this indicated the level of interest in these new resources and highlighted the importance of having regulations for the Area to ensure that resources were treated as the "common heritage of mankind".

Mr. Diène stressed that biological communities were closely related to the non-living resources of the ocean floor that could potentially be mined in the future. He said that the conduct of any activity in the Area needed to be in accordance with the Authority's mandate to protect and preserve the marine environment. He noted that one of the difficulties that the LTC had to address was the size of exploration areas. In this regard, he informed participants that in the case of polymetallic nodules, applicants for exploration licences have to identify and present to the Authority two areas of estimated equal commercial value. The system was for the Authority to choose one of these two areas to be managed by "the Enterprise", acting on behalf of mankind, and for the second site to be allocated to the applicant. He said that since polymetallic nodules occur as two-dimensional deposits on the seafloor in the Clarion-Clipperton Fracture Zone in

[1] ISBA/12/C/3 (Part I) - Exploration and mine site model applied to block selection for cobalt-rich ferromanganese crusts and polymetallic sulphides – Part I: Cobalt-rich ferromanganese crusts; ISBA/12/C/3 (Part II) - Exploration and mine site model applied to block selection for cobalt-rich ferromanganese crusts and polymetallic sulphides – Part II: Polymetallic sulphides

particular, it was relatively easy to define the size of exploration areas, and the Authority's participation in activities in accordance with the principle of "the common heritage of mankind". In the case of the sulphides and crusts deposits, Mr. Diène said that this was more difficult, as they occur in 3-dimensional space and were more irregularly distributed.

Prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area – Framework established by the Exploration code
Dr. Lindsay Parson, Member, Legal and Technical Commission of the International Seabed Authority.

Dr. Parson's presentation described the reasoning behind some of the provisions of the draft Regulations. He stated that the draft Regulations were still in development and would benefit from discussions at the workshop. He noted that the regulations had been written to satisfy the various stakeholders in the development of these resources, including scientists, policymakers and potential contractors. Dr. Parson noted that there were noticeable changes in the regulations compared to the regulations for prospecting and exploration for polymetallic nodules. He said that this was because there was less knowledge of polymetallic sulphides and cobalt-rich ferromanganese crusts resources. He noted that one of the changes in the current regulations was in the environmental protection clause as part of prospecting which was not included in the regulations for the nodules. Dr. Parson said that this clause was important because it meant that a prospector had an environmental commitment without exclusive rights to the deposit (s). In concluding, Dr. Parson noted that in 30 years of scientific research only two of all the sites investigated showed any potential of being commercially viable.

Environmental aspects of cobalt-rich ferromanganese crusts and polymetallic sulphides development – framework established by the code
Dr. Lindsay Parson made the presentation on behalf of Ms. Frida Armas Pfirter, a member of the Legal and Technical Commission. Ms Pfirter's complete paper is reproduced in Chapter 3.

Dr. Parson highlighted the various components of the draft Regulations that were of relevance to the environment, including any changes that had been introduced compared to the regulations for prospecting and exploration for polymetallic nodules. He pointed out that the regulations developed by the Legal and Technical Commission (LTC) for cobalt-rich ferromanganese crusts and polymetallic sulphides were largely derived from the former. He made comments about the significant workshops that had been held by the Authority and noted that the current workshop was going to be very useful to future discussions in the LTC. In summarising the changes between the current draft Regulations and the Regulations for polymetallic nodules, Dr. Parson stated that the objective of these changes was to strengthen the environmental aspects of the new draft Regulations.

Geologic characteristics and geographic distribution of potential cobalt-rich ferromanganese crusts deposits in the Area
Dr. James R. Hein, U.S. Geological Survey, Menlo Park, CA, USA.

Dr. Hein gave an overview of what was known about cobalt-rich ferromanganese crusts including their distribution and properties. He stated that cobalt-rich ferromanganese crusts occurred in all oceanic basins and that it was their physical properties that allowed them to absorb and concentrate metals from the surrounding seawater. He said that virtually all elements from the periodic table were enriched in crusts compared to other natural material. Dr. Hein noted that the main elements in crusts by wet weight per cent were Manganese (approximately 21%) and Iron (approximately 17%), and that crusts grew at 1-6 mm per million years. Dr. Hein said that there were complicated trends in crust chemistry and he attributed this to the chemistry of the water bodies they were found in. He gave a brief overview of seamount biology, stating that the ecology of seamounts was affected by their physical setting. He presented figures to indicate how metal prices and consumption had changed in recent years which highlighted that mining was becoming economically viable. He concluded by stating that the largest impediment exploration was the inability to measure crust thickness in real time.

Technological issues associated with commercializing cobalt-rich ferromanganese crusts deposits in the Area
Mr. Tetsuo Yamazaki, President, Japan Federation of Ocean Engineering Societies, Japan.

Mr. Yamazaki's presentation comprised a comparison of future cobalt-rich ferromanganese crusts mining to that for polymetallic nodules mining. He listed the published feasibility studies on polymetallic nodule mining, summarised their results and included a comparison between the depth, location and chemical characteristics of nodules and cobalt-rich crusts He noted that whilst their metal concentrations were different, their metal compositions were similar, and as such, he said there would be competition between them for development capital, and that only one of them might be mined commercially. Mr. Yamazaki outlined the general components of a mining system noting that crusts mining would be more cost effective than nodule mining because of the smaller amount of substrate rock recovered along with crusts during mining. He said the higher cobalt prices would reduce the relative impact of collecting excess substrate. He continued by outlining how different factors (such as metal content, location of processing plants, type of processing used etc.) would affect the profitability of a crusts mining operation and added that a more advanced validation analysis of crusts mining was required. Mr. Yamazaki concluded his presentation by stating that because of micro topographic undulations, excess substrate rock would often be collected and 70-80% of potential crusts mining sites would be less profitable than nodule mining scenarios.

Prospecting and exploration for cobalt-rich ferromanganese crusts in the Area
Dr. James R. Hein. U.S. Geological Survey, Menlo Park, CA, USA.

Dr. Hein stated that when selecting seamounts for cobalt-rich ferromanganese crusts mining, the summits of guyots on flat or shallowly, inclined surfaces would be most desirable. He noted that on steeper slopes crusts tended to be thinner and their metal contents were lower below the 2500 m water depth. He further noted that although the submarine flanks of islands and atolls would be above the 2500m depth, crusts found on them would be too thin to be commercially viable. Dr. Hein said that mineable crusts would be on old seamounts of cretaceous age as they would host thick crusts and would have stable slopes. He noted that generally, crusts bearing seamounts in the equatorial Pacific had adequate thickness and metal grades. He added that seamounts in the central north equatorial Pacific exhibited the best potential for crusts mining. Dr. Hein concluded his presentation with the calculations he generated in document *ISBA/12/C/3 - Part I: Exploration and Mine Site Model Applied to Block Selection for Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides*; describing an exploration and mine site model applied to block selection for cobalt crusts and polymetallic sulphides including some examples of potential mine sites and how relinquishment would work. His paper also constitutes part of the Secretariat's response to the requests made by the Council.

A Suggested Consideration to the Draft Regulations on Prospecting and Exploration for Cobalt-rich Ferromanganese Crusts
Mr. Yang Shengxiong, Guangzhou Marine Geological Survey, People's Republic of China.

Mr. Shengxiong presented alternative calculations to Dr. Hein's, suggesting that a final mining area of 2,800 km^2 was a more appropriate size than the 500 km^2 proposed by Dr. Hein. His arguments were that Dr. Hein's model included an economic evaluation, which would make some of the parameters very difficult to determine, such as annual production, crust thickness and square-metre tonnage. He also said that that there would be a need for appropriate security margins. Mr. Shengxiong said that not all of the mining blocks would be fully covered by crusts; some areas within the exploration and mining blocks would be covered by up to 75% sediments or base rocks. On the basis of certain parameters, Mr. Shengxiong presented calculations which showed that within a 500 km^2 mining area only about 14 tons of cobalt could be produced annually, which he said was inadequate for a commercial venture.

A hypothetical cobalt-rich ferromanganese crusts mine in the Area
Dr. Charles Morgan, Environmental Planner, Planning Solutions, Inc., Mililani HI, USA.

Dr. Morgan noted that methods for mining cobalt-rich ferromanganese crusts had been proposed in 1985 but that there had been little by way of further developments since then. He stated that the development scenario in 1985 had identified key issues, provided baselines for policy development and determined what needed to be measured for environmental impact assessment. Dr. Morgan discussed a document that had been prepared by Marine Development Associates Inc. in 1987 which investigated a mining development scenario for cobalt-rich ferromanganese crusts in the Hawaiian EEZ that was included in the background document for the workshop. However, he noted that a lot had changed since the publication. He also noted that issues associated with cobalt-rich crusts mining would be site specific. However, Dr. Morgan said that the values used in the scenario were within the range predicted by modern analysis. He said that the scenario had predicted the use of a self-powered system with a cutting head and collection system. The scenario assumed that there would be system downtime as a result of maintenance, repair and unfavourable conditions, and had calculated that mining could only take place for 206 working days each year. Dr. Morgan reported that this scenario also analysed the impact that small scale topographic variation would have on the efficiency of the system, and said that depending on various factors, cutting efficiency was estimated at 56-76% with a crust purity of 32-72%. Dr. Morgan noted that ideal recovery would occur where thick crusts were found on a smooth topography with hard substrate. In conclusion, Dr. Morgan stated that whilst crust mining could be a significant component of world production of the target minerals, the operation would impact a small area and the incorporation of substrate with the crust would be an issue that would have to be addressed.

Technological issues associated with commercialising polymetallic sulphides deposits in the Area
Mr. Tetsuo Yamazaki, President, Japan Federation of Ocean Engineering Societies, Japan

Mr Yamazaki's presentation focussed on a sulphides deposit in Japan's EEZ (the Sunrise deposit, a Kuroko type polymetallic sulphides deposit, of Myojin Knoll on the Izu- Ogasawara arc). He presented a technical and economic evaluation of the deposit, incorporating the results of studies he had conducted on the geotechnical and geophysical properties of the ore, the use of custom smelters for processing, the results of investment cost calculations and the results of his economic evaluations. Mr Yamazaki informed the workshop that the total investment costs are significantly lower than required for cobalt-rich ferromanganese crusts and polymetallic nodules at annual production rate of 300,000 tonnes of sulphides per year. He said that two of the technical issues to be addressed for the commercialization of polymetallic sulphides of the Area were the vertical extent of the sulphides ore body and the metal concentration contour lines in the ore body.

Global exploration models for polymetallic sulphides deposits in the Area
Dr. James R. Hein, U.S. Geological Survey, Menlo Park, CA, USA.

Dr. Hein presented a paper that had been prepared for the Authority, in partial response to the Council's request, by Mark Hannington and Thomas Monecke, which can be found on the Authority's website (*ISBA/12/C/3 Part I, "*Exploration and Mine Site Model Applied to Block Selection for Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides and *ISBA/12/C/3 Part II:* Polymetallic Sulphides*"*). The paper examines how the draft Regulations applied to the known global distribution of polymetallic sulphides deposits. Dr. Hein noted that 40% of known hydrothermal activity was in the Area and that one-third of the hydrothermal sites had associated polymetallic sulphides deposits. Of these, he said that only two were known to contain deposits in excess of one million tonnes although five others may be of this order of magnitude. He stated that individual occurrences covered less than 1 km diameter with the median tonnage of deposits in most 100 sq. km. blocks not being greater than 50,000 tonnes. Dr. Hein pointed out that the report presented two models; one that followed the draft Regulations where all blocks were contiguous which was not considered feasible, and the other to have the 100 blocks split into four clusters which was in the author's opinion, feasible. The blocks within each cluster should be contiguous although the clusters did not have to be contiguous. He said that to emphasise this point the report showed that the grid system as proposed in the draft Regulations would not have been profitable in cases where leases had been granted in National Waters.

A cost comparison of implementing environmental regulations for land-based mining and polymetallic sulphides mining
Mr. Michael Johnston, Vice President, Corporate Development, Nautilus Minerals, Australia.

Mr. Johnston noted that with land-based mining ventures an expected level of impact was agreed upon before exploration activity commenced as the impact would be low. This was a low cost activity. However, once a company believed a project was viable and further investigations needed to be carried out, an Environmental Impact Statement (EIS) would be prepared and this was a much more costly venture. He said that the EIS stage took up to two years to complete and could cost in excess of US$10 million. In land-based mining, Mr. Johnson said there were three types of activities: low impact (not ground disturbing, agreed in advance), higher impact (e.g. drill sampling, predicted impact graded and accepted levels agreed upon), and high impact (e.g. bulk sampling or test mining, some form of EIS required). Mr. Johnston felt that the ISA should have a similar approach, particularly as work at sea would have less impact during the early stages than the comparable stage in a land-based venture. He noted that the key advantages of a seafloor mine compared to a land-based mine were that the grades selected would be high (meaning that a small volume would be required resulting in a small footprint), there would be no waste dumps required (75% of the material mined on land was waste) and there would be no land-use conflicts. According to Mr. Johnston, during the prospecting and exploration stage, the impacts from mining would be similar to marine scientific research. He felt that it was not reasonable to get a full impact assessment and baseline surveys for non-impacting work, and remarked that since the first marine mines were likely to be in territorial waters or EEZs whose codes follow a modified version of land-based regulations, the Authority should follow this example. Mr. Johnston concluded that the International Seabed Authority should manage all data and make them available to improve environmental compliance and monitoring.

A hypothetical polymetallic sulphides mine in the Area
Mr. Michael Johnston, Vice President, Corporate Development, Nautilus Minerals, Australia.

Mr. Johnston stated that Nautilus had carried out test mining and that the "genetic models" for predicting grade and abundance held up well. He said that Nautilus found that there were high metal grades and that it was possible to "cut the material". However, he noted that topographic variations would present engineering challenges. From test mining, he said that values of 15 g/tonne of gold and 12-13 per cent copper had been found. Mr. Johnston suggested that a continuous mining system should be used with pumping or airlifting to transport material to the surface and that the technology was available to carry out seabed mining. Mr. Johnston said that it was estimated that it would cost US$260 million to mine a deposit and 2-3 g/tonne of gold would be needed to recover costs. Mr. Johnston stated that the further a venture was from land, the harder it would be to operate at a profit because of increased costs and the fact that legislation was formulated by more than one government. He concluded that work in EEZs was likely to occur first and these should be used by the International Seabed Authority as case studies. Mr. Johnston noted that a question that needed answering was whether there was a desire to mine the resources or whether it was a last resort when all other resources had been exhausted as this would affect the regime. If there was a desire to mine the resources, then the regulations needed to be competitive with land-based mining. He noted that profit sharing was not a desirable model for companies as they would be taking a lot of risk for little profit. He felt that an equity split model would be preferred, and hence more likely to become a reality, as it would be less risky but would result in less return for the International Seabed Authority.

Review of the nickel, cobalt and manganese markets

Ms. Caitlyn L. Antrim, Director, Center for Leadership in Global Diplomacy, USA.

Ms. Antrim gave three presentations that divided the relevant metal markets into three sections. In the first presentation on the nickel, cobalt and manganese markets, she noted that it was very difficult to predict future demand for metals as they were subject to unpredictable factors both transient and transformational. She proved this point by highlighting how much four long-term predictions from the mid-1970s differed from what actually occurred in the mineral markets. For nickel, cobalt and manganese Ms. Antrim noted the uses, recent production trends and current land-based reserves. She stated that the factors affecting future demand included changes in the automobile industry moving toward electric and hybrid motor vehicles and economic growth in developing countries including China and India.

Review of the copper, lead and zinc markets

Ms. Caitlyn L. Antrim, Director, Center for Leadership in Global Diplomacy, USA.

Copper, lead and zinc were the major metals of commercial interest in polymetallic sulphides deposits. Ms. Antrim said that these basic metals were of importance in the entire industrialization path of every country in the world. She listed their major uses, the main producers, their reserves as well as consumption trends. She said that future demand strongly depended on the growth and the transformations of the economies in developing countries.

Review of the silver and gold markets

Ms. Caitlyn L. Antrim, Director, Center for Leadership in Global Diplomacy, USA.

In her last presentation on metal markets Ms. Antrim reviewed the precious metal markets, listed the major producers and reserves and drew conclusions on prospects for the metals contained in her three presentations. Ms. Antrim gave an overview of exploration for the metals summarised by region and materials. Most of the exploration efforts involved gold or silver either as principal metals or as by-products. Ms. Antrim stressed that precious metals were a major driving factor that also make other metals attractive to look for. In this respect she said that gold and silver were major incentives to exploration on land and potentially could provide incentives for exploration for seabed minerals.

Ms. Antrim noted that for each of the metals she had reviewed in the three presentations there were ample reserves on land for the immediate future, and as such seabed mineral extraction needed to compete with more traditional suppliers if it were to become a reality. She stated that since the 1970s metal prices had remained relatively constant but the costs involved in developing seabed mining (labour, processing, etc.) had increased, making it less appealing to investors than had been predicted when it was first considered. However, she said that in general, prices had been increasing over the last few years. Ms. Antrim concluded her presentation stating that seabed minerals had the potential to become a major source of metals in the world economy but that it would take initial pioneers to prove the technology to make it more appealing to future investors.

Demand for Mineral Resources in the People's Republic of China – Short, Medium and Long Term Projections

Mr. Haiqi Zhang, China Geological Survey, Beijing, People's Republic of China.

Mr. Zhang outlined the geological work that had been carried out by China, noting that 92 per cent of energy and 80 per cent of raw materials consumption came from mineral resources. He informed the workshop that since 1990, consumption had increased faster than production and that only 24 of the 45 minerals mined in China would be sufficient to meet national demand after 2010. Of those, Mr. Zhang said that only 6 would be able to meet national demand until 2020. Mr. Zhang stated that between 60 per cent and 95 per cent of the demand for certain metals (iron, copper, chromium and manganese) were met through imports. He further stated that the supply of mineral resources was not secure and that the situation was getting severe due to the limited domestic reserves of the metals and rapidly-increasing consumption. To meet the challenges, Mr. Zhang said that China pursued a number of mid-term and long-term strategies. He said that one strategy was the expansion of exploration in the western part of China. Another was to mine low-grade deposits through improved mining technologies. The third strategy was international cooperation where in the last few years China had made great efforts to establish ties with a number of countries in terms of long-term supply relationships. The fourth strategy was to reduce metal consumption through more efficient use e.g. reducing the quantity of manganese in steel production.

Apart from these strategies, a participant suggested that a fifth strategy could be to promote prospecting and exploration for minerals on the seabed. The participant, a member of the Chinese delegation, pointed out that although exploration for mineral resources of the seabed was being pursued by China, at this point in time it was unknown when commercial mining would take place.

Working Groups

After all the presentations had been made, the participants split into two working groups to consider the main aim of the workshop which was to examine the draft Regulations to determine commercial feasibility of cobalt-rich crust and polymetallic sulphide mines in the Area. The cobalt-rich crust working group was led by Dr. James Hein and the polymetallic sulphides group was led by Dr. Charles Morgan. The working groups spent a day deliberating before presenting their conclusions in plenary. The reports of the working groups are summarised below.

Report of the polymetallic sulphides working group

The polymetallic sulphides working group suggested that there was a need for a preamble in the regulations that emphasized the fact that the intent of the Authority was to promote utilisation of deep seabed minerals whilst ensuring protection of the marine environment, remembering that the resources were the common heritage of mankind. The working group agreed with the draft Regulations with the exception that a second option for the application fee was proposed, based on escalations in the cost of areas held for exploration. The suggestion was that if a contractor wished, rather than paying US$250,000 as an initial investment, it could elect to pay a lower initial application fee and then pay annual fees based on the number of blocks retained, increasing the cost per block over time to take into account the relinquishment of blocks as required by the draft Regulations. The second option that the group proposed would result in more money being paid to the Authority in the long term. Figures were presented by the working group showing that using the second option, the Authority would obtain US$50,0000 per year throughout the exploration contract and the process would encourage involvement by contractors as less investment would be required at the early stages when risks were high. The increase in cost per block would encourage early relinquishment. The final suggestion made by the working group was that the final area available for mining should not necessarily be 25 full blocks but should comprise a series of smaller sub-blocks (divided using a method considered appropriate by the Authority) "equivalent" to 25 blocks.

Recommendations of the ferromanganese cobalt-rich crusts working group

The cobalt-rich crusts working group came to a consensus that the exploration area should comprise exploration blocks of 100-square kilometre areas. The group recommended that exploration blocks should be formed of 5 sub-blocks each of a 20-square kilometre area. The sub-blocks should be contiguous, but the exploration blocks need not be so. The group recommended that the relinquishment method contained in the draft Regulations should be retained, but should occur as 20 square kilometre sub-blocks with the retained blocks not needing to be contiguous. There was no consensus on the number of exploration blocks that should be awarded and hence the size of the final mining area. However, the group suggested that 25 blocks was suitable as an exploration area (2500 square kilometres) with 25 sub-blocks being retained for mining (500 square kilometres). This was a reduction in the figure presented in the draft Regulations and some participants did not feel it was appropriate. The cobalt-rich crusts working group supported the two option system of application as outlined by the polymetallic sulphides working group. It also produced a preliminary cost model of a cobalt-rich ferromanganese crusts mining operation in the Area, with processing on land.

Based on this model, the effects of the system of participation contained in the draft Regulations would be examined. The overall profitability of the project was estimated at 18.6 per cent internal rate of return (IRR). The model indicates that the greatest impact on profitability is from the initial Authority investment of 10 per cent equity purchase and 30 per cent equity participation. For the Authority, the internal rate of return achieves its highest rate at that level. This may be attributed to the high ratio of equity participation to share of investment. The model reveals an inverse relationship between the scale of participation by the Authority and the return on its investment, with increased investment resulting in a lower IRR even though the total financial return will still increase with increased equity share.

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Part I

REGULATIONS ON PROSPECTING AND EXPLORATION FOR POLYMETALLIC SULPHIDES AND COBALT-RICH FERROMANGANESE CRUSTS IN THE AREA

Chapter 1 Draft Regulations on Prospecting and Exploration for Polymetallic Sulphides and Cobalt-rich Ferromanganese Crusts in the Area (ISBA/10/C/WP.1)
Mr. Baïdy Diène, Chairman, Legal and Technical Commission, International Seabed Authority

Chapter 2 Prospecting and Exploration for Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides in the Area – Framework Established by the Code
Dr. Lindsay Parson, Member, Legal and Technical Commission, International Seabed Authority

Chapter 3 Environmental Aspects of Cobalt-Rich Ferromanganese Crust and Polymetallic Sulphide Development – Framework Established by the Code
Ms Frida Armas Pfirter, Member, Legal and Technical Commission, International Seabed Authority

Chapter 1: Draft Regulations on Prospecting and Exploration for Polymetallic Sulphides and Cobalt-Rich Ferromanganese Crusts in the Area (ISBA/10/C/WP.1)

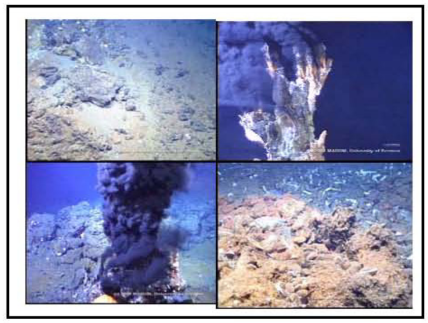
Mr. Baïdy Diène, Chairman, Legal Technical Commission of the International Seabed Authority

INTERNATIONAL SEABED AUTHORITY

Workshop on Mining Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides

KINGSTON 31 july to 04 august 2006

Baïdy Diene



DRAFT REGULATION

ON PROPECTING AND EXPLORATION FOR POLYMETALLIC SULPHIDES AND COBALT-RICH FERROMANGANESE CRUSTS IN THE AREA

(ISBA/10/C/WP.I)

PRINCIPLE

In accordance with the United Nations Convention on the Law of the Sea ("the Convention"), the seabed and ocean floor and the subsoil thereof beyond the limits of national jurisdiction, as well as its resources, are the common heritage of mankind, the exploration and exploitation of which shall be carried out for the benefit of mankind as a whole, on whose behalf the International Seabed Authority acts. The objective of this set of Regulations is to provide for prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts.

(b) "cobalt crusts" means hydroxide/oxide deposits of cobalt-rich iron/manganese (ferromanganese) crust formed from direct precipitation of minerals from seawater onto hard substrates containing minor but significant concentrations of cobalt, titanium, nickel, platinum, molybdenum, tellurium,cerium, other metallic and rare earth elements;

"polymetallic sulphides" means hydrothermally formed deposits of **sulphide minerals which contain concentrations of metals including, inter alia, copper, lead, zinc, gold and silver;**

PROSPECTING

"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 2
Prospecting

1. Prospecting shall be conducted in accordance with the Convention and these Regulations and may commence only after the prospector has been informed by the Secretary-General that its notification has been recorded pursuant to regulation 4, paragraph 2.

Prospecting shall not be undertaken in an area covered by an approved plan of work for exploration for polymetallic sulphides or cobalt crusts or in a reserved area; nor may there be prospecting in an area which the Council has disapproved for exploitation because of the risk of serious harm to the marine environment.

Prospecting shall not confer on the prospector any rights with respect to resources. A prospector may, however, recover a reasonable quantity of minerals, being the quantity necessary for testing, and not for commercial use.

There shall be no time limit on prospecting except that prospecting in a particular area shall cease upon written notification to the prospector by the Secretary-General that a plan of work for exploration has been approved with regard to that area.

6. Prospecting may be conducted simultaneously by more than one prospector in the same area or areas.

Regulation 5

Protection and preservation of the marine environment during prospecting

proposed prospector shall notify the **Notification of prospecting** Authority of its intention to engage in prospecting.

2. Each notification of prospecting shall be in the form prescribed in annex 1 to these Regulations, addressed to the Secretary-General, and shall conform to the requirements of these Regulations.

3. Each notification shall be submitted:

(a) in the case of a State, by the authority designated for that purpose by it;

(b) in the case of an entity, by its designated representative;

(c) in the case of the Enterprise, by its competent authority.

4. Each notification shall be in one of the languages of the Authority and shall contain

(a) the name, nationality and address of the proposed prospector and its designated representative;

(b) the coordinates of the broad area or areas within which prospecting is to be conducted, in accordance with the most recent generally accepted international standard used by the Authority;

(c) a general description of the prospecting programme, including the proposed date of commencement and its approximate duration;

(d) a satisfactory written undertaking that the proposed prospector will:

(i) comply with the Convention and the relevant rules, regulations and procedures of the Authority concerning:

a. cooperation in the training programmes in connection with marine scientific research and transfer of technology referred to in articles 143 and 144 of the Convention; and

b. protection and preservation of the marine environment;

(ii) accept verification by the Authority of compliance therewith; and

(iii) make available to the Authority, as far as practicable, such data as **may be relevant to the protection and preservation of the marine environment.**

Consideration of notifications

1. The Secretary-General shall acknowledge in writing receipt of each notification submitted under regulation 3, specifying the date of receipt.
2. The Secretary-General shall review and act on the notification within 45 days of its receipt. If the notification conforms with the requirements of the Convention and these Regulations, the SecretaryGeneral shall record the particulars of the notification in a register maintained for that purpose and shall inform the prospector in writing that the notification has been so recorded.

The Secretary-General shall, within 45 days of receipt of the notification, inform the proposed prospector in writing if the notification includes any part of an area included in an approved plan of work for exploration or exploitation of any category of resources, or any part of a reserved area, or any part of an area which has been disapproved by the Council for exploitation because of the risk of serious harm to themarine environment, or if the written undertaking is not satisfactory, and shall provide the proposed prospector with a written statement of reasons. In such cases, the proposed prospector may, within 90 days, submit an amended notification. The Secretary General shall, within 45 days, review and act upon such amended notification.

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:
(a) a general description of the status of prospecting and of the results obtained;
(b) information on compliance with the undertakings referred to in regulation 3, paragraph (4) (d);

(c) information on compliance with the relevant future guidelines in this regard.

2. If the prospector intends to claim expenditures for prospecting as part of thedevelopment costs incurred prior to the commencement of commercial production, the prospector shall submit an annual statement, in conformity with internationally accepted accounting principles and certified by a duly qualified firm of public accountants, of the actual and direct expenditures incurred by the prospector in carrying out prospecting.

Regulation 7

Confidentiality of data and information from prospecting contained in the annual report

with the exeption of data for environmental issues

The Secretary-General may, at any time, with the consent of the prospector concerned, release data and information relating to prospecting in an area in respect of which a notification has been submitted. If the Secretary-General determines that the prospector no longer exists or cannot be located, the Secretary-General may release such data and information.

Regulation 8
Objects of an archaeological or historical nature
A prospector shall immediately notify the Secretary-General in writing of any finding in the Area of an object of an archaeological or historical nature and its location. The Secretary-General shall transmit such information to the Director-General of the United Nations Educational, Scientific and Cultural Organization.

EXPLORATION

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;

Applications for approval of plans of work for exploration in the form of contracts

Regulation 9
Subject to the provisions of the Convention, the following may apply to the Authority for approval of plans of work for exploration:
(a) the Enterprise, on its own behalf or in a joint arrangement;
(b) States Parties, state enterprises or natural or juridical persons which
possess the nationality of States or are effectively controlled by them or their
nationals, when sponsored by such States, or any group of the foregoing which
meets the requirements of these Regulations.

Regulation 10
Form of applications
1. Each application for approval of a plan of work for exploration shall be in the form prescribed in annex 2 to these Regulations, shall be addressed to the Secretary-General, and shall conform to the requirements of these Regulations.
2. Each application shall be submitted,
(a) in the case of a State by the authority : designated for that purpose it;
(b) in the case of an entity, by its designated representative or the authority designated for that purpose by the sponsoring State or States;

Regulation 11

Certificate of sponsorship

Regulation 12

Total area covered by the application

1. The area covered by each application for approval of a plan of work for exploration shall be comprised of not more than 100 blocks.

block" means a cell of a grid as provided by the Authority, which shall be approximately 10 kilometres by 10 kilometres and no greater than 100 square kilometres;

2. For polymetallic sulphides or cobalt crusts the exploration area shall consist of contiguous blocks. For the purposes of this regulation two blocks that touch at any point shall be considered to be contiguous.

Notwithstanding the provisions in paragraph 1 above, where a contractor has elected to contribute a reserved area to carry out activities pursuant to annex III, article 9, of the Convention, in accordance with regulation 17, the total area covered by an application shall not exceed 200 blocks.

Regulation 13

Financial and technical capabilities

Each application for approval of a plan of work for exploration shall contain specific and sufficient information to enable the Council to determine whether the applicant is financially and technically capable of carrying out the proposed plan of work for exploration and of fulfilling its financial obligations to the Authority.

2. An application for approval of a plan of work for exploration by the Enterprise shall include a statement by its competent authority certifying that the Enterprisehas the necessary financial resources to meet the estimated costs of the proposedplan of work for exploration.

3. An application for approval of a plan of work for exploration by a State or a state enterprise shall include a statement by the State or the sponsoring State certifying that the applicant has the necessary financial resources to meet theestimated costs of the proposed plan of work for exploration.

An application for approval of a plan of work for exploration by an entity shall include copies of its audited financial statements, including balance sheets and

if the applicant is a newly organized entity and a certified balance sheet

if the applicant is a subsidiary of another entity, copies of such financialstatements of that entity and a statement from that entity if the applicant is controlled by a State or a state enterprise, a statement from the State or state enterprise certifying

Each application shall include:

(a) a general description of the applicant's previous experience, knowledge,skills, technical qualifications and expertise

b) a general description of the equipment and methods expected to be used

(c) a general description of the applicant's financial and technical capability to respond to any incident or activity

Regulation 15

Undertakings

(a) accept as enforceable and comply with the applicable obligations created by the provisions of the Convention and the rules, regulations and procedures of the Authority, the decisions of the organs of the Authority and the terms of its contractswith the Authority;

(b) accept control by the Authority of activities in the Area, as authorized by the Convention; and

(c) provide the Authority with a written assurance that its obligations under the contract will be fulfilled in good faith.

Each applicant, including the Enterprise, shall, as part of its application for approval of a plan of work for exploration, provide a written undertaking to the Authority that it will:

(a) accept *the Authority, the decisions of the organs of the* Authority and the terms of its contracts with the Authority;

(b) accept control by the Authority of activities in the Area, as authorized by the Convention; and

(c) provide the Authority with a written assurance that its obligations under the contract will be fulfilled in good faith.

Regulation 16

Applicant's election of a reserved area contribution or equity interest or jointventure or production sharing participation . Each applicant s hall, in the application, elect either to:

(a) contribute a reserved area to carry out activities pursuant to Annex III, article 9, of the Convention, in accordance with regulation 17; or

(b) offer an equity interest in accordance with regulation 19; or

(c) enter into a joint venture arrangement in accordance with regulation19; or

(d) enter into a production-sharing contract in accordance with regulation 19.

Regulation 17
Data and information to be submitted before the designation of a reserved area
1. Where the applicant elects to contribute a reserved area, the area covered by the application shall be sufficiently large and of sufficient estimatedcommercial value to allow two mining operations. The applicant shall divide the blocks comprising the application into two groups of equal estimated commercial value and composed of contiguous blocks. The area to be allocated to the applicant shall be subject to the provisions of regulation 27

Regulation 19
Equity interest, joint venture or production sharing participation
1. Where the applicant elects to offer an equity interest, joint venture or a production sharing, it shall submit data and information in accordance with regulation 20. The area to be allocated to the applicant shall be subject to the provisions of regulation 27

Equity interest: the Equity interest, which shall take effect at the time the applicant applies for a contract for exploitation, shall include the following:
The Enterprise shall obtain a minimum of 20 per cent of the equity participation in the venture arrangement on the following basis:
(a) Half of such equity participation shall be obtained without payment, directly or indirectly, to the applicant and shall be treated *pari passu* for all purposes with the equity participation of the applicant;

b) The remainder of such equity participation shall be treated *pari passu* for all purposes with the equity participation of the applicant except that the Enterprise shall not receive any profit distribution with respect to such participation until the applicant has recovered its total equity participation in the venture.

3. Joint venture: notwithstanding paragraph (2) above, the applicant shall nevertheless offer the Enterprise the opportunity to obtain up to 50 per cent participation in a joint venture on the basis of *pari passu* treatment with the applicant for all purposes:

(a) In the event the Enterprise elects not to accept 50 per cent of such equity participation, the Enterprise may obtain a lesser per cent on the basis of *pari passu* treatment with the applicant for all purposes for such lesser participation;

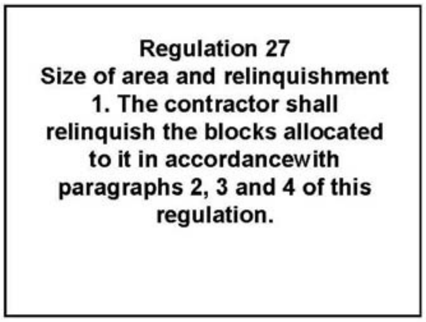
(b) Except as specifically provided in the agreement between the applicant and the Enterprise, the Enterprise shall not by reason of its participation be otherwise obligated to provide funds or credits or issue guarantees or otherwise accept any financial liability whatsoever for, or on behalf of, the joint venture arrangement, nor shall the Enterprise be required to subscribe for additional participation so as to maintain its proportionate participation in the joint venture arrangement.

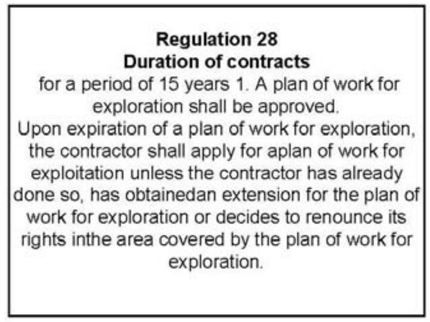
4. Production sharing: A production sharing contract shall include a requirement that the applicant will be responsible for all the management and execution of the operations during the exploration phase with its own capital, manpower, technology and equipment at its sole risk and cost. During the exploitation phase, the applicant is entitled to recover these costs. Thereafter, profits will be split on a 50:50 basis between the applicant and the Enterprise.

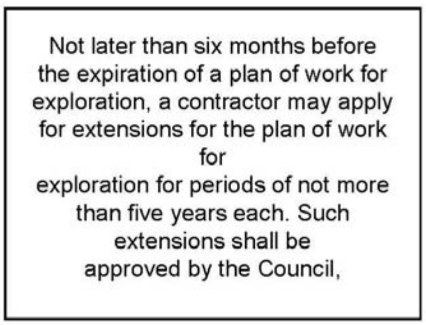
Regulation 25
The contract
1. After a plan of work for exploration has been approved by the Council, it shall be prepared in the form of a contract between the Authority and the applicant as prescribed in annex 3 to these Regulations. Each contract shall incorporate the standard clauses set out in annex 4 in effect at the date of entry into force of the contract.
2. The contract shall be signed by the Secretary-General on behalf of the Authority and by the applicant. The Secretary-General shall notify all members of the Authority in writing of the conclusion of each contract.

Regulation 26
Rights of the contractor
1. The contractor shall have the exclusive right to explore an area covered by a plan of work for exploration in respect of **polymetallic sulphides or cobalt crusts**. The Authority shall ensure that no other entity operates in the same area for resources other than **polymetallic sulphides or cobalt crusts** in a manner that might interfere with the operations of the contractor.

A contractor who has an approved plan of work for exploration only shall have a preference and a priority among applicants submitting plans of work for exploitation of the same area and resources.







Summary of the presentation

The Chairman of the Legal and Technical Commission (LTC), Mr. Diène introduced the draft Regulations prepared by LTC. He stated that polymetallic sulphides and cobalt-rich ferromanganese crusts may be easier to exploit than polymetallic nodules because they occurred closer to land, were found at shallower depths than nodules, and could be found in marine areas within national jurisdiction. As a result, he said that he thought that they could be exploited sooner than polymetallic nodules.

Mr. Diène said that the draft Regulations on Prospecting and Exploration for Polymetallic Sulphides and Cobalt-Rich Ferromanganese Crusts were contained in document ISBA/10/C/WP.1, (available on the Authority's website). He stressed that all actions and regulations of the Authority were guided by the fundamental principle of the United Nations Convention on Law of the Sea that the seabed, the ocean floor and the subsoil thereof beyond the limits of the national jurisdiction were the common heritage of mankind and that exploration and exploitation should be carried out for the benefit of mankind as a whole.

Mr. Diène underlined that biological communities were closely related to the non-living resources on the ocean floor, in particular the mineral resources that were to be mined in the future. He emphasised that any activities related to the exploitation of these mineral resources needed to be in accordance with the Authority's mandate to protect and preserve the marine environment.

With regard to the definition of the two types of mineral resources, Mr. Diène said that according to the draft Regulations, 'cobalt crusts' meant "hydroxide/oxide deposits of cobalt-rich iron/manganese (ferromanganese) crusts formed from the direct precipitation of minerals from seawater onto hard substrates containing minor but significant concentrations of cobalt, titanium, nickel, platinum, molybdenum, tellurium, cerium and other metallic and rare earth elements." He also pointed out that the regulations defined 'Polymetallic sulphides' as "hydrothermally-formed deposits of sulphides minerals containing concentrations of metals, *inter alia*, copper, lead, zinc, gold and silver."

Mr. Diène outlined the mandate and the responsibilities of the International Seabed Authority. He said that the Authority has been established with the responsibility to encourage, develop and promote prospecting, exploration and exploitation of all minerals to be found in the international area. He also said that a set of regulations was required for each of these activities. Mr. Diène said that any party could start prospecting, provided the activities were in accordance with the United Nations Convention of the Law of the Sea and with the regulations adopted by the Authority. With regard to prospecting, Mr. Diène said that this activity could be conducted in the same area by more than one prospector. He said that in accordance with the draft Regulations there was no time limit for prospecting. Mr. Diène said that notifications to prospect have to be submitted in one of the six languages of the UN system to the Secretary-General, indicating name; nationality; address; coordinates of the area and a general description of the work proposed.

He further explained that under the draft Regulations, the Secretary-General would acknowledge receipt of the notification and respond to it within 45 days. If the notification was satisfactory, it would be recorded in a register with the Authority. He continued that a prospector could start work when he/she receives confirmation from the Authority that the notification had been recorded. Mr. Diène said that the Secretary-General and his employees could not put any application on hold and that prospectors were required to make available to the Authority all data relevant for the protection of the marine environment and to submit an annual report. In this regard, Mr. Diène said that the report should substantiate that the undertakings were in compliance with the regulations. Furthermore, he said that the annual report should contain an audited financial statement about the prospector's expenditures. Mr. Diène pointed out that all the information and data given to the Authority were confidential, except for environmental data. Mr. Diène added that if the prospector came across sites of archaeological interest this information was to be immediately reported to the Secretary-General who would then to convey the information to UNESCO.

Mr. Diène stated that the rules and regulations established by the Authority should facilitate prospecting without much bureaucracy. Even though the Authority encouraged prospecting, Mr. Diène said that its aim was to facilitate exploration. He said that during the exploration phase a contractor receives more rights and security for the investments it makes. He said that according to the relevant definition of exploration a contractor gets exclusive rights to the minerals. He also said that it was assumed that during exploration the necessary preparations for exploitation were being conducted, that is, the analysis of the deposits, the use and testing of recovery systems and equipment as well as processing facilities and transportation systems, and the carrying out of studies of the environmental, technical, economic, commercial aspects and other relevant factors. He said that prospectors did not necessarily have to complete prospecting before applying for an exploration license. He further explained that the type of entities that may apply for a licence included the Enterprise acting for all mankind, State Parties or state enterprises, and natural or juridical persons who possess the nationality of the states or were sponsored by a state.

Mr. Diène said that one of the difficulties the LTC faced in drafting the regulations was to define the size of exploration areas for cobalt-rich ferromanganese crusts and polymetallic sulphides. He pointed out that in the case of polymetallic nodules, applicants have to identify and to present to the Authority two areas of estimated equal commercial value. Under the polymetallic nodule regulations, Mr. Diène said that the Authority would choose one of the areas which would then be managed by the Enterprise, acting on behalf of mankind, and the second would be allocated to the applicant. Since polymetallic nodules occurred as a two-dimensional deposit on the seafloor in the wide area of the Clarion-Clipperton Fracture Zone, he said that it was relatively easy to define exploration areas and the participation by the Authority according to the principle of "common heritage of mankind". In the case of the two types of mineral resources currently under consideration, Mr. Diène said this was more difficult, as they were 3-dimensional mineral deposits with irregular aerial distribution. Mr. Diène informed participants that in the draft Regulations, application areas were defined by a grid of blocks. He said that exploration areas consist of no more than 100 blocks, each of them no greater than 10 km x 10 km (100 km²). Blocks were to be contiguous, i.e. 2 blocks are considered as contiguous if they touch each other at least at one point.

In relation to an application for exploration, Mr. Diène said that under the regulations, the application must contain sufficient information to enable the Council to determine whether the applicant possesses the necessary financial and technical capability to implement the plan of work. He said that the application must also include a description of the applicant's previous experience showing its knowledge, skills, technical qualifications and expertise as well as a description of the equipment and technology it would use. Mr. Diène said that once a contractor started an operations, the contractor must accept control by the Authority with respect to the technology applied which may differ from the one proposed in the application and which may cause harm to the environment. Mr. Diène said that the Authority should therefore be in a position to inspect the contractor's activities independently of the contractor's annual report. Mr. Diène said that decisions by the Authority and those of its organs must be accepted at all times by the contractor.

With regard to the participation of the Authority in activities in the area, Mr. Diène explained that it was up to the applicant to select either a reserved area contribution, an equity interest, joint venture or production sharing participation agreement with the Enterprise. In the case of a reserved area contribution, he said that the total application area should be sufficiently large and of sufficient estimated commercial value to allow two mining operations. For equity interest participation, he said that the Enterprise was to obtain a minimum of 20 per cent of the equity participation in the arrangement. Where the applicant elects to offer joint venture participation, Mr. Diène said that the applicant shall offer the Enterprise the opportunity to obtain up to 50 per cent participation in the joint venture on the basis of *pari passu* treatment with the applicant. Mr. Diène said that in the case of production sharing, after recovery of costs, profits would be split 50:50. He said that after a plan of work for exploration has been approved by the Council, a contract would be prepared and signed between the Secretary-General of the Authority and the applicant. Following signature of the contract, Mr. Diène said that the Secretary-General of the International Seabed Authority was obliged to notify all the members of the Authority. Mr. Diène said that the contract gives the applicant exclusive right to explore the area covered by the plan of work in respect of polymetallic sulphides or cobalt-rich crusts as relevant, and that the Authority shall ensure that no other entity operated in the same area. He noted that even though an area was granted, there was a requirement for relinquishment of certain portions of the area following a timeline. He said that the philosophy behind relinquishment was that no entity could hold an area just for the benefit of holding it, and that relinquishment was also an incentive for applicants to undertake their activities in a quick and efficient manner.

Summary of the Discussion

Asked whether an entity could apply for a plan of work for exploration without prospecting, Mr. Diène replied that this was possible and reminded participants that during prospecting other parties may conduct prospecting in the same area. However, once a party had successfully applied for exploration in this area, other parties would no longer be able to continue prospecting in the area.

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Chapter 2: Prospecting and Exploration for cobalt-rich ferromanganese crusts and polymetallic sulphides in the Area – Framework established by the code

Dr. Lindsay Parson, Member of the Legal and Technical Commission of the International Seabed Authority

Prospecting and exploration for cobalt-rich ferro-manganese crusts and polymetallic sulphides in the Area - Framework established by the code

International Seabed Authority
Workshop. Kingston, Jamaica
31st July - 4th August 2006

Dr Lindsay Parson
National Oceanography Centre
UK

Structure of the presentation

- The draft regulations
- Generic considerations
- Definitions
- Approach of the LTC adapting nodule code
- Rationale behind framework set up by the code/draft regs
- Regs at the 12th Session

The draft regulations - 1

- Definition of terms
- Prospecting - notification, outline description, SG
- Protection and preservation of the Marine evironment- necessary measures, establishment and implementation programmes
- Annual Reporting

The draft regulations - 2 (Exploration)

- Plan of work, sponsorship certification
- Area:100 blks, contiguous
- Financial and experience statement
- Reserved area/equity interest/joint venture
- Fees, processing by ISBA,LTC, Council
- Relinquishment
- Part V: Marine environment, emergency orders
- Confidentiality, general procedures
- Annexes of contracts, etc

Generic considerations

- Physical differences between Mn nodules and both Co-rich/FeMn crusts and PMS
- "Cherry-picking"
- Alternative to site banking provisions
- Environmental issues
- Encouraging to contractors

Definitions

- Prospecting
- Exploration
- Co-rich ferro-manganese crusts
- Polymetallic sulphides

Prospecting

- Phase preliminary to exploration and exploitation
- Activities in the Area
- General survey large area, view to evaluation

Exploration

- Searching with exclusive rights
- Adoption of certain responsibilities

The resources

- Cobalt-rich FeMn crusts
- Polymetallic sulphides

Polymetallic manganese nodules

Co-rich FeMn crusts

- Complex nucleation of metallic minerals
- Seamount and guyots
- Depth limit to viability of deposit
- Distribution non-uniform
- Site specific biomass

Co-rich FeMn crusts

- Sediment cover
- Grade, age, thickness
- Mining technique
- Annual tonnage for viable mining operation
- Summit of seamounts, large surface area
- Clusters preferred

Co-rich FeMn crusts - Mine Site

- 3-7 av. sized seamounts for viable 20yr mining operation

Polymetallic sulphides (PMS)

- High-temperature hydrothermal vent products
- Massive metallic minerals
- MORs and other volcanic settings
- Volcanic/ tectonic controls
- Distribution constrained
- Active and inactive
- Site specific biomass
- Site modelled every 50-100km of ridge
- 300 sites recorded, 100 host PMS

PMS

- Different substrates
- Different levels of maturity
- Different levels of tectonic significance, segmentation/dismemberment
- Poorly known in three dimensions
- Slow vs fast sites (largest HT systems, some off-axis, wider spaced)
- 10s to 100s m across, stockwork few km wide, and 100s m deep
- Use ancient analogues

PMS -mine site

- Only two sites quantified: TAG, Middle Valley
- Bulk wet tonnages 2.7 m, 10-15 m, respectively
- 'Cyprus'-type ophiolite-hosted PMS - 1.6 mt av.

Environmental considerations

- Baseline
- State of knowledge
- Current political consensus
- Realistic/practical requirements

The draft regs at the 12th Session

- 31st July - 4th August workshop
- Number and size of exploration area, block size
- Geometry of exploration areas, contiguity, clusters
- Relinquishment provisions
- Joint venture options
- Environmental considerations
- Speed of development of code

Summary

- Context of geological character of the deposits and the development of the draft regulations/code
- The significance of the environmental aspects of these deposits
- The revenue options to the Authority
- The absence of a worked-through mining model

Summary of the presentation

Referring to Mr. Diène's introduction of the draft Regulations, Dr. Parson stated that the objective of his presentation was to apply the Regulations to the real world and to explain the rationale by which the Legal and Technical Commission (LTC) put them together. There was a necessity for these draft Regulations because of the differences between each of the mineral resource types that were considered by the Authority (i.e. between polymetallic nodules and cobalt-rich ferromanganese crusts and polymetallic sulphides deposits) and that were the subjects of the present draft Regulations. Dr. Parson stated that it was his intention to address the fabric and framework of the draft Regulations, and to provide a focus on the modifications and additions to the polymetallic nodule exploration code template that had been in existence for a number of years. Dr. Parson noted that the draft Regulations for cobalt-rich ferromanganese crusts and polymetallic sulphides were still in development and the processes envisaged by this workshop, especially the development of model mine sites and their theoretical exploration and exploitation under a regulatory regime would contribute considerably to its development. He pointed out the need for all parties including the stakeholders, the LTC, the Council and the Authority to understand how the draft prospecting and exploration regime needed to be modified or enhanced by the understanding that would be developed during the workshop.

Dr. Parson further noted that after the Council's first reading of the draft Regulations, there were a number of requests for changes. He said that the draft Regulations has to be a tool that satisfied a number of different stakeholders; scientists, environmentalists, some Non-governmental organisations (NGOs), but most of all the Convention and the members of the Council. He said that there was a need to promote a convergence of ideas and to develop a broader understanding of their overall context.

Dr. Parson went through the definition of terms and the provisions for prospecting and exploration contained in the draft Regulations. He said that prospecting involved the process of notification to the Secretary-General and required a description of the project. He said that prospecting meant surveying a large area in order to find the most promising locations for which an exploration plan was to be formulated. As per the provisions for the protection and preservation of the marine environment contained in the draft Regulations, Dr. Parson noted that the prospector would cooperate in the establishment and implementation of programmes for monitoring and evaluating the potential effects of exploration and exploitation in terms of pollution and other hazards. Dr. Parson further noted that this responsibility made prospecting different from an informal survey. He mentioned that the particular text in the draft Regulations on Prospecting and exploration for cobalt-rich ferromanganese crusts and polymetallic sulphides in the Area was the same text which occurred in the Regulations for prospecting and exploration of polymetallic nodules and noted that these obligations for cobalt-rich ferromanganese crusts and polymetallic sulphides marked a significant difference to that of the Regulations on polymetallic nodules. He informed participants that this difference had been identified as one of the contentious parts of the draft Regulations. With regard to prospecting, he also mentioned that there was a requirement for annual reporting by prospecting entities.

With respect to exploration, Dr. Parson said that this stage involved significant investment in terms of completing an application, formulating the plan of work and fulfilment of sponsorship requirements. As per the existing draft Regulations, Dr. Parson said that the exploration area was to be no greater than 100 contiguous blocks of 10 by 10 square kilometres each. Dr. Parson noted that the aspect of contiguity and the size of exploration blocks was a major topic for further discussion during the workshop in response to the request by the Council. He disclosed that the Council was not satisfied with the requirement of contiguity of exploration blocks and that the reason why the LTC agreed to this requirement was that there had been 20-30 years of academic investment in survey and prospecting which had resulted in the identification of a small number of interesting sites that were scattered around the world's oceans. It was felt that initial exploration contractors would have a potential of claiming these known prime areas and exploiting this advantage at the expense of subsequent investors. In order to restrict the selection of these well-described and identified areas, Dr. Parson said that the LTC thought that the requirement for contiguous blocks could be a way of encouraging additional exploration by linking these key areas to a wider area. However, he said this was one of the provisions that the Council had objected to the most and noted that a number of alternative concepts had recently been published which would also be presented in the course of the workshop.

Dr. Parson mentioned that the draft Regulations required a statement on the applicant's financial standing and experience. With regard to other deviations from the polymetallic nodule exploration code, he stressed that the 'reserved area' or 'site banking' principle that was obvious to implement for polymetallic nodules could not be applied in the same way for polymetallic sulphides and cobalt-rich ferromanganese crusts. He explained that this was due to the nature of the distribution of these deposits and how the minerals formed. He said that site banking, i.e. identifying two areas of equal commercial value and characteristics would be difficult for contractors, and added that consequently, joint venture agreements, equity interest participation and production sharing were considered as alternative options for participation by the Authority. Dr. Parson also noted differences in the draft Regulations when compared to the Regulations for polymetallic nodules in regard to the application fee, the way of processing applications and the procedures for relinquishment.

Dr. Parson turned his attention to the environmental provisions of the draft Regulations. He said that Part V of the draft Regulations dealt with the protection and preservation of the marine environment and pointed out that the same provision could be found in the regulations on polymetallic nodules. Additionally, the concepts of 'impact reference zones' and 'preservation reference zones' were also stipulated in paragraph 4 of regulation 33 of the draft Regulations. Dr. Parson defined impact reference zones as areas used to assess the effect of activities on all the aspects of the marine environment including the chemicals in the water column, and the physical and the biological environments. He defined preservation reference areas as areas representative of the test mining site and in which no mining takes place. He described a deviation from the Regulations on prospecting and exploration for polymetallic nodules code as regulation 35 on Emergency orders. Dr. Parson said that this regulation was introduced in case of a threat of serious harm to the environment. He said that even though there was similar text in the polymetallic nodules regulations, the wording in the draft Regulations for cobalt-rich ferromanganese crusts and polymetallic sulphides was much stronger and required greater efforts by future exploration contractors. Dr. Parson said that the regulations need to address the greater political and community awareness of the environment and its potential damage than the awareness that existed when the regulations for polymetallic nodules were developed.

Dr. Parson also addressed other generic considerations that had to be taken into account in drafting the current regulations. He said that these considerations included the physical differences between polymetallic nodules and the latter two types of mineral deposits.

Using a power point slide featuring the deposits, he pointed out that whereas polymetallic nodule deposits occur as two-dimensional deposits on the seafloor, cobalt-rich ferromanganese crusts deposits have an extension in the third dimension. He noted that polymetallic sulphides deposits were fully three-dimensional deposits, and said that the physical characteristics of the deposits as well as their spatial distribution have strong implications for extraction and consequently for the draft Regulations. With regard to the participation of the Authority, he said that the nature of the deposit seemed to weigh against the reserved area option, so other methods were considered and presented.

He said that the language used for the protection and prevention of damage to the marine environment was strengthened, mainly as a consideration of the uniqueness of the faunal and floral assemblages. He added that the diversity of life that can be found in these ecosystems, of which extremely little is known, was highly astonishing and that it was a challenge to develop regulations that were satisfactory for these newly-discovered environments, which were perceived as relatively fragile.

Dr. Parson said that the task undertaken by the LTC was to present a set of regulations that were practical, appropriate, and encouraging to potential contractors.

With regard to 'prospecting', he explained that the term signifies a phase preliminary to exploration and exploitation, including the search for deposits in the Area, the estimation of the composition, sizes and distributions of these deposits and their economic values. He also noted that prospectors do not get exclusive rights to search areas in which they conduct prospecting.

Dr. Parson informed participants that exploration as used in the draft Regulations meant the search for deposits of cobalt-rich ferromanganese crusts or polymetallic sulphides in the Area with exclusive rights, the analysis of such deposits, the testing of recovery systems and equipment, processing facilities and transportation systems, and the conduct of studies of the environmental, technical, economic, commercial and other aspects that have to be taken into account during exploitation. Dr. Parson explained that while exploration provides the contractor with exclusive rights in an exploration area, these rights are accompanied by more responsibilities than under prospecting.

With regard to 'cobalt-rich crusts' Dr. Parson informed participants that the term meant hydroxide/oxide deposits of cobalt-rich iron/manganese crusts formed from direct precipitation of minerals from seawater onto hard substrates containing minor but significant concentrations of cobalt, titanium, nickel, platinum, molybdenum, tellurium, cerium other metallic and rare earth elements. He said that polymetallic sulphides are defined as hydrothermally-derived deposits containing concentrations of metals; among which are gold, silver, copper, lead and zinc.

Dr. Parson outlined the major characteristics of cobalt-rich ferromanganese crusts with respect to their relevance to the establishment of the draft Regulations. He said that crusts form on elevated, hard substrates, either on seamount flanks and summits, which is either steep sided or conical in form, and flat upper surfaces of seamounts (guyot-type seamounts) which have at some stage of their evolution been at or near the sea surface. These have either been weathered (planed off) or modified by coralline biothermal colonization and are biologically flattened. He said that the depth to which harvesters may be active can be in the region of up to 2500 m depth. He noted that one of the most crucial elements was the non-uniform distribution of accumulation sites, and explained that the majority of sites were scattered on seamounts, separated by large expanses of the deep ocean abyssal plain. He added that this was why contiguous contract area blocks covering multiple seamounts did not seem attractive to contractors and that the idea of contiguity of exploration blocks as a means for avoiding cherry picking needed to be eased in some way. He was confident that the exercise of developing a theoretical mine site during the workshop would assist in determining how fair or unfair the draft Regulations would be considered.

With regard to the ecosystems and seamount faunal assemblages, Dr. Parson referred to the Authority's Workshop on Cobalt-Rich Crusts and the Diversity and Distribution Patterns of Seamount Fauna', held in March 2006 in Kingston, Jamaica.

Dr. Parson said that other aspects taken into consideration for cobalt-rich ferromanganese crusts included:

- The degree of sediment cover as a crucial factor in the development and also the recovery of cobalt-crusts;
- Volume, purity and age, as well as location of the deposits;
- The estimates of required tonnage suitable for establishing a viable mining system sustained over a number of years;
- The surface structure of mine sites and the identification of flat-topped guyots with large surfaces in order to minimize re-location of mining operations after exhaustion of a mine site; and
- In terms of further details of the potential geometry of cobalt-rich crust sites during exploration, the proposal to address clusters of seamounts/guyot sites is preferable to contiguity.

With regard to polymetallic sulphides deposits, Dr. Parson summarized the relevant characteristics of this deposit type as follows:

- Polymetallic sulphides are derived from high-temperature hydrothermal vent systems which produce extremely pure metallic ores;
- They occur at very locally-focused settings with extensions of tens or hundreds of metres;
- They are almost all tied to mid-ocean ridges and other active spreading ridges and volcanic settings around the world's oceans – there are about 55,000 km of active spreading mid-ocean ridges as well as 25,000 km ridges at back arc settings;
- There are obviously volcanic and tectonic controls on the locations of the hydrothermal systems;
- There are active and inactive sites; the active ones can be found relatively easily, as they produce a plume of smoke, which can be picked up by snifters in the water column. Inactive ones are harder to find, but more attractive for mining;
- About 300 sites are recorded, 100 of them are known hosts of polymetallic sulphides. From modelling the thermal structure of ridges it is assumed that hydrothermal vents occur every 50 to 100 kilometres along the ridges;
- They form on different substrates; and
- Polymetallic sulphides occur as truly three-dimensional deposits with depths of several hundreds of metres, and are poorly known in the depth dimension. Only two sites have been identified so far that could have the potential of supporting a mining operation.

On the environmental protection requirements of the draft Regulations, Dr. Parson said that there was a requirement to monitor exploration activities, in order to understand the impacts of these activities and to establish environmental baselines. Noting, however, that knowledge of the associated ecosystems is poor, Dr. Parson said that it would be difficult to develop guidelines based on the present state of knowledge, adding that the development of guidelines is a political process requiring consensus. With regard to the general character of environmental regulations, Dr. Parson stated that the regulations needed to be realistic and practical, and not prohibitive because of the lack of knowledge.

On the deliberations of the draft Regulations during the 12th Session of the Authority, Dr. Parson noted that there had been some constructive suggestions on the number and size of the exploration blocks and areas since the LTC put together its draft in 2005. He noted that suggestions had been made in relation to the geometry of exploration areas, the question of contiguity of exploration blocks, and the relinquishment provisions, which were different from those contained in the regulations for polymetallic nodules, as well as in relation to different production sharing and joint venture options. He mentioned that the Secretariat had already prepared a set of papers addressing many of these issues, in particular the joint venture options, pointing out some significant difficulties with production sharing. Of particular importance were the environmental considerations which would need to satisfy both potential contractors and the other stakeholders in the Area, including the Authority, which was responsible for the preservation and protection of the marine environment. With regard to speed in the development of the code, Dr. Parson urged participants to work through the process gradually, rather than developing a code without knowing enough of the biological aspects, the impact on the environment and the mining technology. He concluded his presentation by saying that there was no need to develop the code immediately.

Summary of the discussions

A participant asked how commercial prospecting could be distinguished from marine scientific research in terms of giving a commercial prospector an incentive to register with the International Seabed Authority.

Another participant replied that the only incentive for applying for a prospecting licence was that a contractor show proof of his investments in prospecting and offset costs during the exploitation phase, which was not possible in the case of marine scientific research.

Another participant noted that a prospector had no exclusive rights during prospecting as was the case for exploration and exploitation and suggested that under the draft Regulations, a company would rather go straight to exploration to secure its investments for the benefit of its shareholders.

In relation to this argument Mr. Odunton noted that a contractor going straight to exploration without applying for a prospecting licence may not be able to satisfy the requirements for an approved plan of work, in particular the requirements relating to reserved areas or other ways of participation by the Authority.

With regard to the environmental regulations, a participant said that bio-geographic aspects were different for cobalt-rich crusts and polymetallic sulphides and continued that some organisms that occurred around hydrothermal vents were endemic to certain areas, but that in general, along spreading centres biological communities have the same species for hundreds of kilometres along the ridge axis. The participant concluded that the biological aspects might be less complex for polymetallic sulphides than for cobalt-rich crusts, which occured on seamounts where communities differed from one seamount to the next.

Dr. Parson agreed that there was a general sharing of faunal regimes along ocean ridges, noting that the occurrence of endemic vent fauna at certain locations would need to be taken into account.

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Chapter 3: Legal Framework for the Environmental Protection on Prospecting and Exploration for Cobalt-Rich Crusts

Ms Frida Armas Pfirter, Member of the Legal and Technical Commission of the International Seabed Authority. Presented by Dr. Lindsay Parson on her behalf

Environmental Aspects of cobalt-rich ferromanganese crust and polymetallic sulphide crust development - Framework established by the code

International Seabed Authority
Workshop. Kingston, Jamaica
31st July - 4th August 2006

The Legal and Technical Commission

Article 165, para 2 (e)

- The LTC is to make recommendations to the Council of the Authority on the protection of the environment, taking into account the views of recpognised experts in that field

Relevant workshops/LTC sessions

- June 1998
- September 2004
- 10th ISBA session
- 11th ISBA session
- March 2006
- July/August 2006

September 2004 Workshop - "Polymetallic sulphides and crusts: their environment and considerations for the establishment of environmental baselines and an associated monitoring programme".

- Define the biological components
- Facilitate reporting by contractors
- Provide guidance to contractors re. plan of work

Results - ISBA/11/LTC/2

- Based on current scientific knowledge, may need to be modified
- Type of mining system not certain, assumptions made
- Provided recommendations for procedures/practices
- Baseline data: geochemical, biological and physical required
- Test mining impacts
- Cooperative research
- Recommendations to close gaps in knowledge

Draft regulations on Co-rich crusts and PMS

- Redrafting of ISBA/6/A/18

- Regulation 5
- Regulation 7
- Regulations 33 - 38

Draft 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:

(a) adverse environmental impacts from prospecting; and

(b) 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.

Draft regulation 7

Regulation 7
Confidentiality of data and information from prospecting contained in the annual report

1. The Secretary-General shall ensure the confidentiality of all data and information contained in the reports submitted under regulation 6 **applying mutatis mutandis the provisions of regulations 38 and 39, provided that data and information relating exclusively to environmental monitoring programmes shall not be considered confidential.**

Draft regulation 33

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"

Draft regulations 34-36

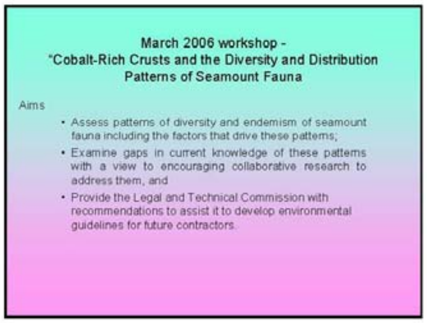
- Language change - introduction of phrase "threat of serious harm" rather than previously "harmful effects"

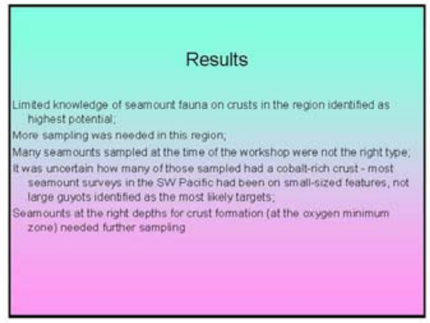
Draft regulation 36

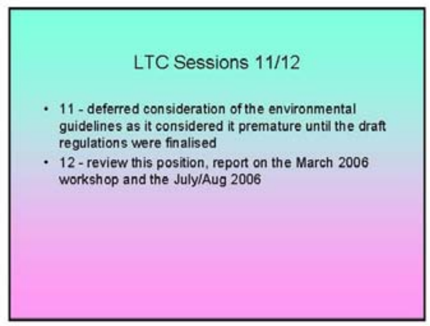
4. Contractors shall take all measures necessary to ensure that their activities are conducted so as not to cause damage by pollution to the marine environment under the jurisdiction or sovereignty of other States, and that pollution arising from incidents or activities in its exploration area does not spread beyond such area.

Draft regulation 38

2. Data and information that is necessary for the formulation by the Authority of rules, regulations and procedures concerning protection of the marine environment and safety, other than equipment design data, shall not be deemed proprietary.







I – International Seabed Authority

The International Seabed Authority (ISA) is an intergovernmental organization created by the Convention as the autonomous body through which States Parties shall organize and control activities in the Area, with the specific aim of managing its resources[1].

There was general agreement on negotiations prior to the Third United Nations Conference on the Law of the Sea, that international machinery would be needed to manage the new international regime for the area of the seabed beyond national jurisdiction. However, it was not until 1974 (Second Session of UNCLOS III) that it was generally accepted that an International Seabed Authority (ISA) would be established to deal with seabed activities and the resources of the Area.[2]

The importance of the Authority keeps growing proportionally to the importance of discoveries and economic development of the resources as well as to the conservation of the marine ecosystem. An author pointed out: If the Authority didn't exist, we would have had to invent it[3]!

The norms that rule its functioning are contained in Part XI of UNCLOS and in the 1994 Agreement. The Agreement relates "to the implementation" of the Convention, which means that the application of UNCLOS must be carried out in accordance with the Agreement from the moment of its entry into force. It is beyond the scope of this work to analyze in detail the modification that such instrument introduced in the regime of Part XI.

The fundamental principle that gave origin to the whole regime of the Area is that the seabed and ocean floor and its resources are the common heritage of mankind[4]. Therefore, no State shall claim or exercise sovereignty or sovereign rights over any part of the Area or its resources, nor shall any State or natural or juridical person appropriate any part thereof and all rights over the resources of the Area are vested in mankind as a whole, on whose behalf the Authority shall act. Minerals extracted from the Area could only be alienated in accordance to relevant rules of UNCLOS, the 1994 Agreement and the provisions adopted by the Authority[5].

This principle, embodied in Resolution 2749 (XXV) of the General Assembly, has been included in UNCLOS and has not been modified by the 1994 Agreement. It is the Authority's responsibility to ensure that the scope of this principle is not modified through the functioning of its own organs or the activities of States.

II – Functions of the Authority and instruments adopted in its framework

According to the mandate provided for in the Convention and the Agreement, the Authority elaborates and adopts rules, regulations and procedures for exploration and exploitation of minerals of the deep seabed. Such rules, regulations and procedures shall incorporate applicable standards for the protection and preservation of the marine environment.

The Authority has already adopted the "Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area" – the Mining Code – and, accordingly, entered into the first 15-year contracts for exploration for polymetallic nodules with the seven pioneer investors. Its elaboration and adoption involved a great legislative task. It took three years of negotiations in formal, informal and "informal-informal" meetings, and was finally adopted by consensus on July 13th 2000[6]

The Code establishes the rules that States, companies or other entities shall follow when exploring the seabed for polymetallic nodules.

The Legal and Technical Commission's functions include making recommendations to the Council with regard to the protection of the marine environment, taking into account the views of recognized experts in that field. In 2001, the Legal and Technical Commission adopted the "Recommendations for the Guidance of the Contractors for the Assessment of the Possible Environmental Impacts Arising from Exploration for Polymetallic Nodules in the Area"[7]. The aim is to define the biological, chemical, geological and physical components to be measured and the procedures to be followed by the Contractor to ensure the effective protection of the marine environment from harmful effects which may arise from its activities in the Area, and to provide guidance to prospective contractors in preparing work plans for exploration for polymetallic nodules. Given that these recommendations are based on current scientific knowledge about the marine environment and available technology, they will have to be reviewed in the future taking into account improvements in science and technology, which are foreseen in the regulations.

In May 2004, the Legal and Technical Commission (LTC) submitted to the Council the "Draft regulations for the prospecting and exploration for polymetallic sulphides and cobalt-rich crusts in the Area"[8]. The LTC used as a basis for the new regulations the framework of the regulation for polymetallic nodules, and making necessary adjustments to reflect the difference in nature and distribution of the different minerals.

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 be in conformity with the provisions of the Convention and the Agreement relating to part XI[9].

Discussions on environmental considerations indicated lack of adequate knowledge of seamount and vent communities. Biological communities vary according to position on the seamount, the depth of the oxygen minimum zone in reference to the seamount and the substrate on which they live. There is also great variation between seamounts which makes it difficult to predict impacts on one seamount from research on another one. While environmental considerations were discussed at length, there was agreement that greater attention is required when granting exploitation licences rather than when granting exploration licences and that, as such, some of the more critical questions could be addressed at a later date. Dealing with the nature and fundamental principles of the Authority, UNCLOS established that the Authority shall have the powers and functions expressly conferred by the Convention[10]. They are not limited to Part XI and its Annexes; powers and functions of the Authority are also established in other parts of the Convention[11].

Additionally, the Authority has such "incidental powers – consistent with the Convention – as are implicit in and necessary for the exercise of its powers and functions with respect to activities in the Area[12]. "Incidental powers" are those unwritten powers that are necessary for an international organization to effectively perform such powers and functions as are expressly conferred upon it[13].

One of the powers and functions of the Assembly and the Council – the latter due to provisions of the 1994 Agreement – is "to initiate studies and make recommendations for the purpose of promoting international cooperation concerning activities in the Area and encouraging the progressive development of international law relating thereto to its codification" [14].

III – Environmental Protection in the Area

The objective of protecting and preserving the marine environment and its living resources is expressly established all along UNCLOS starting with its Preamble.

In relation to the Area, the main provision is article 145, which derives from paragraph 11 of Resolution 2749 (XXV)[15]. At the beginning of negotiations of this article, there was no agreement on who could implement the necessary rules to protect the marine environment. During the fourth session (1976), "the Authority was specified as the entity empowered to adopt rules, regulations and procedures in this regard[16].

Article 145 established the need to adopt measures to ensure an effective protection of the marine environment from harmful effects which may arise from activities in the Area. To this purpose, the Authority may establish rules, regulations and procedures for 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, among others. The regulations which the Authority must adopt are also those needed for "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" [17].

Therefore, protection and preservation of communities associated with cobalt-rich crusts and hydrothermal vents derives from article 145[18].

The 1994 Agreement, in its preamble, states "the importance of the Convention for the protection and preservation of the marine environment and of the growing concern for the global environment" and goes on to establish that between entry into force of the Convention and approval of the first work plan for exploitation, the Authority shall concentrate on the "Adoption of rules, regulations and procedures incorporating applicable standards for the protection and preservation of the marine environment" [19].

Since its establishment in 1994, the Authority has kept environmental protection as one of its highest priorities, as evidenced by the comprehensive regime for monitoring and protecting the marine environment in the Area contained in the Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area and by the adoption of the environmental guidelines by the Legal and Technical Commission of the Authority[20]. We must remember that nowadays, more than in 1982, the development of the international environmental law leads to the application of a precautionary approach to ocean management[21].

IV – Protection of the marine environment in the draft Regulations

1. Definitions

This section contains the same provisions included in the nodules' regulations. The term marine environment is defined including a list of various elements and factors which interact and determine the productivity, state, condition and quality of the marine ecosystem, waters of the seas and oceans and airspace above those waters, as well as the seabed and ocean floor and subsoil thereof[22].

"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.

It is also stated that these Regulations may be supplemented by further rules, regulations and procedures, in particular on protection and preservation of the marine environment and that these Regulations shall be subject to the provisions of the Convention and the Agreement and other rules of international law not incompatible with the Convention.

2. Prospecting

Items relating to marine environment contemplated in the nodules' regulations are conserved.

For example, prospecting shall not be undertaken when substantial evidence indicates risk of serious harm to the marine environment[23] or in an area covered by an approved exploration work plan for polymetallic sulphides and cobalt crusts or in a reserved area; nor may there be prospecting in an area disapproved by the Council for exploitation due to risk of serious harm to the marine environment.

Notification on prospecting shall contain a satisfactory written undertaking that the proposed prospector will comply with the convention and the relevant rules, regulations and procedures of the Authority, concerning protection and preservation of the marine environment.

It was added that the prospector will also make available to the Authority, as far as practicable, data which may be relevant to protection and preservation of the marine environment[24].

An important regulation was introduced, related to Protection and preservation of the marine environment during prospecting[25]. This regulation goes beyond the obligation of each prospector to 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.

It established the obligation for prospectors to cooperate with the Authority in the establishment and implementation of programmes for monitoring and evaluating the potential impacts of exploration and exploitation of polymetallic sulphides and cobalt-rich crusts on the marine environment. This was foreseen for exploration contracts, but not during the prospecting stage.

It includes the provision already contemplated in nodules regulations that 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 or irreversible damage to the marine environment. Upon receipt of such notification the Secretary-General shall act in a manner consistent with regulation 35[26].

3. Plans of work for exploration and information to be submitted

In Part III of the Regulations "Applications for approval of plans of work for exploration in the form of contracts", as well as in Annex II and IV, most of the regulations are somehow related to the protection of the marine environment.

In relation to the financial and technical capabilities, each application shall include a general description of the applicant's financial and technical capability to respond to any incident or activity which causes serious harm to the marine environment[27].

In relation to the data and information to be submitted for approval of the work plan for exploration, each applicant shall submit[28]:

(a) general description and schedule of the proposed exploration programme, including the activities' programme for the immediate five-year period, such as studies to be undertaken with respect to the environmental, technical, economic and other appropriate factors that must be taken into account in exploration;

(b) description of the programme for oceanographic and environmental baseline 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;

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

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

Among the subjects to be reviewed by the LTC is to determine whether the proposed exploration work plan will provide effective protection and preservation of the marine environment[29].

The Commission shall not recommend approval of the exploration work plan when part or all the area covered by the proposed plan is included in an area disapproved for exploitation by the Council in cases where substantial evidence indicates risk of serious harm to the marine environment[30].

In the periodic review of the implementation of the exploration work plan, the Secretary-General shall indicate in his report whether any observations transmitted to him by States Parties to the Convention concerning the manner in which the contractor has discharged its obligations under these Regulations relating to the protection and preservation of the marine environment were taken into account in the review[31].

The contractor's responsibility shall continue for any damage arising from wrongful acts in the conduct of its operations, in particular damage to the marine environment, after completion of the exploration phase[32].

4. Specific regulations

The whole of Part V is related to the protection and preservation of the marine environment[33]. 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 and harmful effects which may arise from activities in the Area[34].

In order to ensure effective protection of 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[35] to such activities. The Legal and Technical Commission shall make recommendations to the Council on the implementation of this obligation. 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[36] using for this purpose the best practicable means at its disposal.

5. Monitoring, baselines and special zones

As already stated above, it is established for prospectors to cooperate with the Authority in the establishment and implementation of programmes for monitoring and evaluating the potential impacts on the marine environment.

One of the goals of the Regulations is the establishment and implementation of programmes in order to monitor, evaluate and report likely effects of the contractor's programme of activities under the exploration work plan on the marine environment. For this purpose, 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[37]. Such programmes may include proposals for areas to be set aside and be used exclusively as impact reference zones and preservation reference zones. "Impact reference zones" means areas to be used for assessing 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[38].

Each contract shall require the contractor to gather environmental baseline data and to establish environmental baselines, taking into account any recommendations issued by the Legal and Technical Commission, against which to assess the likely effects of its programme of activities under the work plan for exploration of 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 prorgamme[39].

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

Reports and other environmental data and information required in order to carry out its functions shall be transmitted to the Commission for its consideration[40].

6. Emergency orders[41]

When the Secretary-General has been notified by a contractor or otherwise becomes aware of an incident resulting from or caused by contractor's activities in the Area which poses a threat of serious or irreversible damage to the marine environment, the Secretary-General shall notify in writing the contractor and the sponsoring State or States, and shall report immediately to the Legal and Technical Commission and to the Council[42]. A copy of the report shall be circulated to all members of the Authority, to competent international organizations and to concerned sub regional, regional and global organizations and bodies. The Secretary-General shall monitor developments with respect to all such incidents and shall report on them as appropriate to the Commission and to the Council.

Pending any action by the Council, the Secretary-General shall take such immediate measures of a temporary nature as are practical and reasonable in the circumstances to prevent, contain and minimize the threat of serious or irreversible damage to the marine environment. Such temporary measures shall remain in effect for no longer than 90 days, or until the Council decides what measures to take, if any, pursuant to paragraph 5 of this regulation, whichever is the earlier.

After having received the report of the Secretary-General, the Commission shall determine, based on the evidence provided to it and taking into account the measures already taken by the contractor, which measures are necessary to respond effectively to the incident in order to prevent, contain and minimize the threat of serious or irreversible damage to the marine environment, and shall make its recommendations of the Commission and any information provided by the Contractor, may issue emergency orders, which may include suspension or adjustment of operations, as may be reasonably necessary to prevent, contain and minimize the threat of serious or irreversible damage to the marine environment arising out of activities in the Area.

If a contractor does not promptly comply with an emergency order to prevent a threat of serious or irreversible damage to the marine environment arising out of its activities in the Area, the Council shall take by itself or through arrangements with others on its behalf, such practical measures as are necessary to prevent, contain and minimize any such serious harm to the marine environment.

In order to enable the Council, when necessary, to take immediately practical measures to prevent, contain and minimize the threat of serious or irreversible damage to the marine environment, the contractor, prior to commencement of testing of collecting systems and processing operations, will provide the Council with a guarantee of its financial and technical capability to comply promptly with emergency orders or to assure that the Council can take such guarantee, the sponsoring State or States shall, in response to a request by the Secretary-General, take necessary measures to ensure that the contractor provides such guarantee or shall take measures to ensure that assistance is provided to the Authority in discharge of its responsibilities[43].

7. Rights of coastal States[44]

Rights of coastal States, in accordance with article 142 and other relevant provisions of the Convention are contemplated in the Regulations. Any coastal State which has grounds for believing that any activity in the Area by a contractor is likely to cause a threat of serious or irreversible damage to the marine environment under its jurisdiction or sovereignty may notify the Secretary-General in writing of the grounds upon which such belief is based. The Secretary-General shall provide the Contractor and its sponsoring State or States with a reasonable opportunity to examine the evidence, if any, provided by the coastal State as the basis for its belief. The contractor and its sponsoring State or States may submit their observations thereon to the Secretary-General within a reasonable time.

If there are clear grounds for believing that serious harm to the marine environment is likely to occur, the Secretary-General shall act in accordance with the emergency orders.

Contractors shall take all necessary measures to ensure that their activities are conducted so as not to cause damage by pollution to the marine environment under the jurisdiction or sovereignty of other States, and that pollution arising from incidents or activities in its exploration area does not spread beyond such area[45].

V- Conclusions

In the draft Regulations on prospecting and exploration for polymetallic sulphide and cobalt-rich ferromanganese crusts, the Commission stresses the environmental aspects and is more specific with regard to the requirement – already included in the case of nodules – that prospectors shall cooperate with the Authority in the establishment and implementation of programmes for the purpose of monitoring and evaluating the potential impacts of the exploration and exploitation activities on the marine environment.

It is necessary for the Legal and Technical Commission to have more knowledge about the impact that prospecting and exploration activities related to cobalt-rich crusts will have on seamounts and their associated biodiversity. Consequently, the LTC will be able to establish data and information that will be required from contractors when establishing environmental baselines and associated monitoring programmes.

The fact that the development of international environmental law leads to the application of a precautionary approach to the ocean management, must be specially taken into account nowadays, even more than in 1982. This is particularly emphasized in the last General Assembly Resolution on Oceans and the Law of the Sea (60/63), which takes note of the importance of the responsibilities entrusted to the Authority by article 145 of the Convention, which refers to protection of marine environment. It also reiterates the importance of the ongoing elaboration by the Authority, pursuant to article 145 of the Convention, of rules, regulations and procedures to ensure effective protection of the marine environment, protection and conservation of natural resources in the Area and damage prevention to its flora and fauna from harmful effects that may arise from activities in the Area.

Notes

1. Art. 157 UNCLOS and 1994 Agreement, Annex, Section 1, 1). Besides, it is established that the Authority will have the powers expressly conferred by the Convention and the necessary powers, compatible with itself, which may be implicit and necessary for the exercise of those faculties and functions with regard to the activities in the Area. Its status as an autonomous international organization is explicitly acknowledged in the Agreement subscribed with the United Nations (ISBA/3/L.2 and ISBA/3/C/L.2).

2. Cfr; NANDAN, S.N.; LODGE, M.W.; ROSENNE, S.; *op.cit.*, Volume VI, p. 336.

3. Elizabeth Mann Borgese, "Biodiversity and Climate Impact in International Waters – The International Seabed Authority: New Tasks", in Papers of Workshop "The International Seabed Authority: New Tasks", International Ocean Institute Canada, Dalhousie Univesity, 1999, p.1. The Authority began to perform functions in Kingston (Jamaica), on November 16, 1994 and since then ten periods of sessions have taken place (until 2004).

4 General Assembly Resolution 2749 (XXV) from 17th December 1970.

5. Arts. 133, 136 and 137 UNLCOS.

6. The Legal and Technical Commission commenced work on the draft regulations for prospecting and exploration for polymetallic nodules in March 1997. As the basis for its work, the Commission used the working papers prepared by Special Commission 3 of the Preparatory Commission for the International Seabed Authority and for the International Tribunal for the Law of the Sea between 1984 and 1993. The Commission also took into account the provisions of the Agreement and the special situation of the registered pioneer investors under resolution II of the Final Record of the Third United Nations Conference on the Law of the Sea (UN7CLOS III). The Commission worked extensively on the draft regulations during its meetings in March 1997, August 1997 and March 1998 (the third and fourth sessions of the Authority), completing its work in March 1998. The draft regulations proposed by the Commission were submitted to the Council under the symbol ISBA/4/C/4/Rev.1. On 13 July 2000 the Council decided to adopt and apply provisionally the Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area, pending their approval by the Assembly (ISBA/6/C/12.). The Regulations were approved by the Assembly on 13 July 2000 (ISBA/6/A/18). Cf. ISBA/6/A/9, para. 24-31, "Report of the Secretary-General of the International Seabed Authority under article 166, paragraph 4, of the United Nations Convention on the Law of the Sea, 3-14 July 2000.

   One of the consequences of the existence of such a contractual relationship is the obligation for contractors to submit annual reports in accordance with the provisions of the contract. In that regard, the standard clauses set out in annex 4 to the Regulations contain detailed provisions relating to the format and content of such annual reports. The objective of these reporting requirements is 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, particularly those relating to the protection of the marine environment from the harmful effects of activities in the Area.

7. ISBA/7/LTC/1. See also

8. ISBA/10/C/WP.1

9. ISBA/10/C/4

10. Article 157.2.

11. Articles 82, 84.2, 143, 144, 160.2.j, 209, 256, 273, 274, 287.2, 288.3, 305, 308.3.5, 311.6, 314, 316.5, 319.1.1 y b y 318.3

12. Article 157.2.

13. Cfr; NANDAN, S.N.; LODGE, M.W.; ROSENNE, S.; *op.cit.*, Volume VI, pp.360-62.

14. Art. 160.2.j.

15 Resolution 2749 (XXV), paragraph 11, which established that with respect to activities in the Area, States shall take appropriate measures and cooperate in the adoption and implementation of international rules, standards and procedures for the prevention of pollution and contamination, and 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.

16. Cfr; NANDAN, S.N.; LODGE, M.W.; ROSENNE, S.; *op.cit.*; Volume VI, pp. 194-195.

17. Article 145, b). Also cfr. NANDAN, S.W.; LODGE, M.W.; ROSENNE, S. *op.cit*, Vol. VI, p 76: It should be noted, however, that article 145 (b) requires the Authority to adopt appropriate rules, regulations and procedures for 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". This clearly envisages that the Authority may take regulatory action, for the purposes of environmental protection, in respect of, for example, biological communities occurring in conjunction with deep sea hydrothermal vents."

18. ISA, *An Environmental Protection Regime for the International Area*, Brochure, December 2000.

19. 1994 Agreement, Annex, Section 1, para 5

20. Cf. NANDAN, S.N.; LODGE, M.W.; ROSENNE, S.; *United Nations Convention on the Law of the Sea 1982 - A Commentary*, Volume VI, Martinus Nijhoff Publishers, The Hague-London-New York, 2002, pp. 192-196. The Regulations on Prospecting and Exploration for Polymetallic Nodules in the Area (RPEN) contain extensive provisions on the protection and preservation of the marine environment that elaborate upon the provisions of article 145 and the 1994 Agreement and define more clearly the obligations of the Authority, sponsoring States, and contractors in relation to the protection of the marine environment. The Regulations give some indication as to the scope of the "necessary measures" referred to in the chapeau of article 145 by requiring the Authority to establish and keep under periodic review environmental rules, regulations and procedures to ensure effective protection for the marine environment arising from its activities in the Area as far as reasonably possible using the best technology available to it (31.3). At the same time, the Regulations require that "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 is to make recommendations to the Council on the implementation of this requirement (31.2). The LTC may from time to time 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 (38). Individual contractors are required, as a condition of the contract, to gather environmental baseline data to establish environmental baselines against which to assess the likely effects of their plans of work for exploration on the marine environment. Contractors are to report to the Authority on the implementation of such programmes and, prior to the commencement of testing of collecting systems and processing operations, are required to carry out a more detailed environmental impact assessment (31.4.5.7 Annex 4 Section 5). There is also a general obligation on all contractors, sponsoring States and other interested States and entities to cooperate with the Authority in the establishment and implementation of programmes for monitoring and evaluating the impacts of deep seabed mining of the marine environment. Also ISA, *An Environmental Protection Regime for the International Area*, Brochure, December 2000.

21 Statement by Satya N. Nandan, Secretary-General of the International Seabed Authority in Commemoration of the 20th Anniversary of the Opening for Signature of the 1982 United Nations Convention on the Law of the Sea, Fifty-seventh Session of the General Assembly United Nations, 9 December 2002.

22 Regulation 1, (3) (e) "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.

23 Regulation 2 and Article 162 of UNCLOS

24. Regulation 7: In relation to the confidentiality of all data and information contained in the reports submitted it is provided that data and information relating exclusively to environmental monitoring programmes shall not be considered confidential.

25 Regulation 5

26 Regulation 5. Last paragraph was contained in Regulation 7 of nodules.

27 Regulation 13, the same as nodules.

28 Regulation 20. The same as nodules. See also Annex II, Section III and Section V.

29 The Regulations on sulphides and crusts establishes that data and information which is necessary for the formulation by the Authority of rules, regulations and procedures concerning protection of the marine environment and safety, other than equipment design data, shall not be deemed proprietary (Regulation 38).

30 Regulation 23.

31 Regulation 30.

32. Regulation 32. See also: Annex IV: Section 16: Responsibility and liability: the contractor shall be liable for the actual amount of any damage to the marine environment, arising out of its wrongful acts or omissions, and those of its employees, subcontractors, agents and all persons engaged in working or acting for them in the conduct of its operations under this contract, including the costs of reasonable measures to prevent or limit damage to the marine environment, account being taken of any contributory acts or omissions by the Authority. Section 21: Suspension and termination of contact and penalties: In the event of termination or expiration of this contract, the Contractor shall comply with the Regulations and shall remove all installations, plant, equipment and materials in the exploration area and shall make the area safe so as not to constitute a danger to persons, shipping or to the marine environment.

33 Partially Regulations for polymetallic nodules, regulation 31, ISBA/6/A/15. During the ninth session of the Authority, the Working Group on Environmental Issues of the LTC produced a preliminary draft of regulations relating to the protection and preservation of the marine environment during prospecting and exploration, The working group pointed out that, in developing environmental regulations relating to nodule exploration, the Commission had been dealing with a "post facto" situation. This was not the case with respect to the crusts and sulphides and, given the lack of scientific information on these deposits, the Commission had some scope for reviewing the obligations to be placed on contractors in relation to the protection and preservation of the marine environment. The group also considered that it was appropriate in this context to reflect in the draft regulations the development in international environmental law achieved since the adoption of the Convention in 1982.

34. Convention, article 145; Agreement, Annex, section 1, paragraph 5 (g) and (k).

35 Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1991 (United Nations publication, Sales No. E.91.I.8 and corrigenda), vol I: Resolutions adopted by the Conference, resolution 1, Annex I. The precautionary approach is reflected in Principle 15 of the Rio Declaration on Environment and Development, which provides that "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".

36 Convention, article 145. A similar obligation is imposed on contractors in section 5.1 of Annex4 to the Regulations.

37 Agreement, Annex, section 5, paragraph 1 (c). Section 5 of Annex 4 to the Regulations contains the standard clauses in the contract for exploration on environmental monitoring.

38 Regulation 33. New paragraph added by the Environmental WG during the ninth session of the Authority. See ISBA/10/LTC/CRP.1, p.7, under regulation 31.

39 Annex IV, Section 5. Originally paragraphs 4 to 5 of regulation 31 of the Regulations on polymetallic nodules, ISBA/6/A/15, regrouped and modified by the WG during the ninth session of the Authority. See ISBA/10/LTC/CRP.1, p.7, under regulation 31 bis.

40 Art. 165 UNCLOS. Originally last sentence of paragraph 5, regulation 31 of the Regulations on polymetallic nodules, ISBA/6/A/15, modified by the WG during the ninth session. See ISBA/10/LTC/CRP.1, p.7 under regulation 31 bis, para 3.

41. Regulation 35. Basically regulation 32 of the Regulations for polymetallic nodules, ISBA/6/A/15, modified by the WG during the ninth session. See ISBA/10/LTC/CRP.1, pp.8-9, under regulation 32. See also Annex II, Section 6 and 14.

42 Convention, articles 162 (2)(w) and 165(2)(k).

[43] Articles 139 and 235 of UNCLOS. See ISBA/6/C/12 (Decision of the Council relating to the regulations on prospecting and exploration for polymetallic nodules in the Area).

[44] Basically regulation 33 of the Regulations for polymetallic nodules, ISBA/6/A/15, modified by the Environmental WG during the ninth session. See ISBA/10/LTC/CRP.1, p.9, under Regulation 33.

[45.] Added by the Environmental WG during the ninth session. Article 194 under the Convention is under the title of "Measurements to prevent, reduce and control pollution of the marine environment".

Summary of the presentation

Ms Frida Armas Pfirter, a member of the Legal and Technical Commission was requested to prepare and present a paper on the framework established by the draft Regulations on the environmental aspects of cobalt-rich ferromanganese crusts and polymetallic sulphides development. Ms Pfirter prepared a paper for the workshop but could not participate in it due to unforeseen circumstances. Dr Lindsay Parson agreed to make the presentation on her behalf.

In introducing the presentation, Dr. Parson referred to Article 165, paragraph 2 (e) of the United Nations Convention on the Law of the Sea, which states that "The LTC 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".

Dr. Parson said that the LTC had taken advice from recognized experts on a number of occasions over the last decade, and that a number of workshops had been convened by the Authority to address environmental issues relevant to rule making by the body. He reminded participants that during the annual session of the Authority in June 1998 environmental guidelines on polymetallic nodule exploration and exploitation resulting from one of the workshops had been reviewed by the LTC. He said the Regulations that the LTC developed for cobalt-rich crusts and polymetallic sulphides had been largely derived from the guidelines for polymetallic nodules.

Dr. Parson said that in September 2004, the Authority convened a workshop on "Polymetallic sulphides and cobalt-rich ferromanganese crusts: their environments and considerations for the establishment of environmental baselines and an associated monitoring programme." He noted that the workshop's objectives were to define the relevant biological components of the environments of deposition of the two types of mineral resources, to facilitate environmental reporting by contractors and to provide guidance to contractors regarding implementation of their plans of work. Dr. Parson said that the results of the interdisciplinary workshop which included geologists, biologists and physical oceanographers have been published in document ISBA/11/LTC/2. He also informed participants that in March 2006, the Authority also convened another workshop on environmental issues, on cobalt-rich crusts and the diversity and distribution patterns of seamount fauna.

Dr. Parson outlined the relevant provisions of the draft Regulations for environmental protection and preservation during cobalt-rich ferromanganese crusts and polymetallic sulphides development. He stated that these provisions contained significant changes to the environmental regulations for polymetallic nodules. In particular, he identified regulations 5, 7, and 33-38 of the code on polymetallic nodules as those most affected, and pointed out that the other regulations concerning environmental aspects were to be found in regulations 33-38.

Dr. Parson quoted the provisions of regulation 5 of the draft Regulations that was relevant to the prospecting phase, and which reads as follows:

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:

   (a) adverse environmental impacts from prospecting; and

   (b) 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.

Dr. Parson stated that the regulation gave some leeway to prospectors by the statement that "the prospector shall minimise or eliminate adverse environmental impacts from prospecting …" However, he said that the work to be undertaken by prospectors were demanding, as prospectors were required to "… cooperate with the Authority in the establishment and implementation of programmes for monitoring and evaluating the potential impacts of exploration and exploitation …".

With regard to regulation 7, Dr. Parson said it concerned the confidentiality of data and recognized that the Authority would ensure such confidentiality, except for data relating to the environmental monitoring programme, that were not considered to be necessarily confidential. He quoted the regulation as follows:

Regulation 7
Confidentiality of data and information from prospecting contained in the annual report

1. The Secretary-General shall ensure the confidentiality of all data and information contained in the reports submitted under regulation 6 applying mutatis mutandis the provisions of regulations 38 and 39, provided that data and information relating exclusively to environmental monitoring programmes shall not be considered confidential.

In comparing the regulation to the corresponding regulation for polymetallic nodules regulation 33 of the draft Regulations, Dr. Parson said it also contained some modifications in terms of monitoring the impact of deep sea mining on the marine environment. He said that in addition, regulation 33 referred to proposals for establishing impact reference zones and preservation reference zones, and quoted the regulation as follows:

Regulation 33
Protection and preservation of the marine environment

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.

He said that regulation 36 was included in the draft Regulations to ensure that mining activities did not pollute the marine environment of coastal States, and quoted the regulation as follows:

Regulation 36
Rights of coastal States

4. Contractors shall take all measures necessary to ensure that their activities are conducted so as not to cause damage by pollution to the marine environment under the jurisdiction or sovereignty of other States, and that pollution arising from incidents or activities in its exploration area does not spread beyond such area.

Dr. Parson continued to regulation 38 where it specified that data and information regarding the marine environment was deliverable to the Authority and should not be deemed proprietary:

Regulation 38
Proprietary data and information and confidentiality

2. Data and information that is necessary for the formulation by the Authority of rules, regulations and procedures concerning protection of the marine environment and safety, other than equipment design data, shall not be deemed proprietary.

In summarising the changes to the regulations on polymetallic nodules in the draft Regulations on cobalt-rich ferromanganese crusts and polymetallic sulphides, Dr. Parson stated that the objective of these changes was to strengthen the environmental aspects of the draft Regulations. With regard to the contractor's obligation to prevent harm to the environment, Dr. Parson said that the term "*harmful effects*" was changed to "*threat of serious harm*". According to Dr. Parson the understanding of harmful effects has shifted from a physical activity into an abstract and generalized interpretation. He said that this reflected what the LTC was distilling from the awareness of the marine environment in a way that perhaps had not been quite so acute in 1998 when the Regulations on polymetallic nodules were drawn up. He also said that the draft Regulations took into account the perceived difference in the type of marine ecosystem associated with these new deposits as opposed to that for polymetallic nodules.

Dr. Parson said that the objectives of the March 2006 workshop on "Cobalt-Rich Crusts and the Diversity and Distribution Patterns of Seamount Fauna" were to:

- Assess patterns of diversity and endemism of seamount fauna including the factors that drive these patterns;
- Examine gaps in current knowledge of these patterns with a view to encouraging collaborative research to address them; and
- Provide the Legal and Technical Commission with recommendations to assist it to develop environmental guidelines for future contractors.

He said that the results of the workshop would be very useful to the LTC in making recommendations to the Council of the Authority and for the Council to absorb the information in due time.

Dr Parson said that there was limited knowledge of seamount fauna associated with cobalt-rich ferromanganese crusts deposits. He said that data available for the region which had been identified as the area with the highest potential was sparse. Consequently, he said that more sampling was needed in this region, in particular on seamounts that were likely to be mined. He noted that many of the seamounts that had been sampled at the time of the workshop were of the conical type; with very few of the guyot type.

He said that it was uncertain how many of the seamounts sampled were covered by cobalt-rich ferromanganese crusts. In particular, he stressed that the concerned seamounts needed further sampling at the relevant depths for crust formation, which was close to the oxygen minimum zone.

Dr. Parson said that the present workshop would provide the upcoming LTC session with significant assistance in terms of perspectives from current operations e.g. including a comparison of environmental damage that land-based mines, in particular copper mines, inflict on the environment compared to the damage that mining could cause in a localised sense on the seabed. He stressed that although impacts could be controlled on land, it would be difficult to control the impacts in the marine environment.

As to the state of the draft Regulations, Dr. Parson noted that the draft regulations might not be finalised for a while, but that positions would be reviewed particularly in light of the report of the workshop in March 2006 and as well as the outcomes of the present workshop.

Summary of the discussions

A participant said that most of the seamounts that had been studied in detail were of two types; either hydrothermally-active seamounts like in the Marianna Arc, and those associated with spreading centres or seamounts at continental margins that were studied for fisheries e.g. off the continental margin of New Zealand. He said none of these seamounts would have a potential for cobalt-rich ferromanganese crusts deposits. The participant said that only very few seamounts in the Central Pacific within the areas of particular interest for mining cobalt-rich crusts have been sampled in terms of biology.

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Part II

THE RESOURCES:

Cobalt-rich Ferromanganese Crusts Deposits

Polymetallic Sulphides Deposits

Chapter 4: Geologic characteristics and geographic distribution of potential cobalt-rich ferromanganese crusts deposits in the Area

Dr. James R. Hein, U.S. Geological Survey, Menlo Park, Ca, USA

Abstract

Cobalt-rich ferromanganese (Fe-Mn) crusts occur throughout the global ocean on seamounts, ridges, and plateaus where currents have kept the rocks swept clean of sediments for millions of years. Crusts precipitate from cold ambient seawater onto rock substrates thereby forming pavements up to 25 centimetres thick. Crusts are important as a potential resource for primarily cobalt, but also for titanium, nickel, cerium, copper, platinum, manganese, and others. Crusts form at water depths of about 400-4000 metres, with the thickest and most cobalt-rich crusts occurring at depths of about 800-2500 metres. Bulk crusts contain cobalt contents up to 1.7 per cent, nickel to 1.1 per cent, copper to 0.4 per cent, and platinum to 3.0 parts per million. Crust compositions vary on an ocean-wide basis. Iron/manganese ratios are lowest for crusts from the central and west parts of the North and South Pacific (hereafter called the open Pacific Ocean) and highest for crusts collected in the Atlantic and Indian Oceans, and in the eastern Pacific along the continental margin. Elements derived from the continents are highest in crusts with proximity to continental margins (off western North and South America) and in all areas of the Atlantic and Indian Oceans; and lowest in the open Pacific Ocean. Barium content can be used as a proxy for primary bio-productivity in surface waters. Barium contents are much higher in northeast Pacific continental-margin crusts than anywhere else in the global ocean. Intermediate barium contents occur in crusts from the open Pacific Ocean and reflect regional upwelling and primary productivity along the equatorial zone of convergence and local upwelling around seamounts elsewhere in the Pacific. The combined cobalt, nickel, and copper contents are highest in the open Pacific Ocean crusts, intermediate in the Indian and Atlantic Ocean crusts, and lowest in crusts from along the continental margins in the Pacific Ocean. Platinum contents are highest in the Atlantic and open South Pacific Ocean, intermediate in the open North Pacific and Indian Oceans, and lowest in crusts from continental margins. Based on the global distribution and composition of Fe-Mn crusts, it is proposed that future mine sites will likely be situated as follows:

- Mining operations will be established around the summit region of guyots (flat-topped seamounts) on flat or shallowly inclined terraces and saddles.
- The summit of the guyots will not be deeper than about 2200 metres, the terraces not deeper than about 2500 metres.
- Little or no sediment will occur in the summit region.
- The summit region will be large, more than 600 square kilometres.
- The guyots will be Cretaceous in age.
- Areas where there are clusters of large guyots will be favoured.
- Guyots with thick crusts and high grades (cobalt, nickel, copper) will be chosen.
- The central Pacific Ocean region best fulfils all the above criteria.

The surface areas of 34 typical equatorial Pacific Ocean guyots and conical seamounts vary from 4,776 to 313 square kilometres, with an average surface area of 1,850 square

kilometres. The amount of surface area above 2500 metres water depth averages 515 square kilometres. The surface area likely to be mined is less than the area that exists above 2500 metres water depth, because of sediment cover. As a worst-case scenario, about 210 square kilometres (range ~210-410) of the average seamount would have crusts exposed that could potentially be mined; and about 530 square kilometres (range ~530-1060) of the largest seamount measured would be available for mining. Those areas would likely be further reduced because of prohibitive small-scale topography, un-mined biological corridors, and other impediments. Based on a conservative estimate of 26 kilograms of crusts per square meter, it would require the mining of 77 square kilometres per year to satisfy a rate of production of 2 million tonnes of crusts per year. This would translate to 1,540 square kilometres of crusts removal for a 20 year mining operation, requiring about 3-12 large seamounts, or 10-31 average-size seamounts based on an average crust thickness of two centimetres.

Seamounts obstruct the flow of oceanic water masses, thereby creating a wide array of seamount-generated currents of enhanced energy relative to flow away from the seamounts. The effects of these currents are strongest at the outer rim of the summit of seamounts, the area with the thickest crusts. Those seamount-specific currents enhance turbulent mixing and produce upwelling, which increases primary productivity. These physical processes also affect seamount biological communities, which vary among seamounts. The rate of endemism on seamounts varies widely and seamount communities show relatively low density and low diversity where the Fe-Mn crusts are thickest and cobalt-rich. Mariana arc seamount taxa appear to produce larvae with limited dispersal potential, the dominant mode for colonization of adjacent areas. This, in combination with closed circulation cells around the seamounts, may enhance larval retention and retard colonization. The make-up of seamount communities, and population density and diversity, are determined by current patterns, topography, bottom sediment and rock types and coverage, seamount size, water depth, and size and magnitude of the oxygen-minimum zone.

The greatest potential economic value of Fe-Mn crusts has always been their unprecedented high content of cobalt. However, Fe-Mn crusts contain high concentrations of a great variety of metals that could become important by products of cobalt recovery. Recently, significant increase in the demand for metals in the rapidly growing economies of China and India have pushed up the metal prices, notably copper, nickel, and cobalt. This upward trend in prices will fluctuate, but should not be ameliorated anytime soon. Nickel consumption in China has increased five fold in the decade of the 1990s and continues to grow. The projected annual rate of growth of world consumption is expected to range from 4-6 per cent for cobalt, copper, and nickel. Shortages of copper supplies have been projected to occur within the next decade. The price of copper has more than tripled since 2001, and the price of nickel has likewise increased significantly, although with large fluctuations. These increased metal demands may have an impact on the three main deep-seabed mineral-deposit types in that nodules and crusts have high copper, nickel, and cobalt contents, and polymetallic sulphides have high copper contents. Increased metal demand and higher prices make the potential for marine mining more likely.

Introduction

Cobalt-rich iron-manganese (ferromanganese) oxide crusts, hereafter called Fe-Mn crusts, are ubiquitous on hard-rock substrates throughout the ocean basins. They form at the seafloor on the flanks and summits of seamounts, ridges, plateaus, and abyssal hills where the rocks have been swept clean of sediments at least intermittently for millions of years. Fe-Mn crusts form pavements up to 25 centimetres thick on rock outcrops, or completely coat talus debris. Fe-Mn crusts form by precipitation from cold ambient bottom waters (hydrogenetic), or by a combination of hydrogenetic and hydrothermal precipitation in regions where hydrothermal venting occurs, such as near oceanic spreading axes, volcanic arcs, and hotspot volcanoes. The metals of economic interest are significantly diluted when the hydrothermal contribution is large. Fe-Mn crusts contain sub-equal amounts of iron and manganese and are strongly enriched in a wide variety of metals relative to their abundances in the Earth's crust, especially tellurium, mercury, manganese, arsenic, cobalt, molybdenum, bismuth, thallium, platinum, tungsten, antimony, and nickel (*Figure 1*). There are two practical interests in Fe-Mn crusts, the first being their economic potential for cobalt, but also for manganese, nickel, copper, platinum, possibly also titanium, the rare earth elements (REEs), tellurium, thallium, phosphorus, and others. The second interest is the use of crusts as recorders of the past 70 million years of oceanic and climatic history. Compared to abyssal polumetallic (Fe-Mn) nodules, exploitation of crusts has been viewed as advantageous because of their high cobalt content, the large tonnage per square meter of seafloor, the shallower water depths of occurrence of high-quality Fe-Mn crusts, their extensive distribution within the Exclusive Economic Zones of island nations, as well as within international waters (The Area).

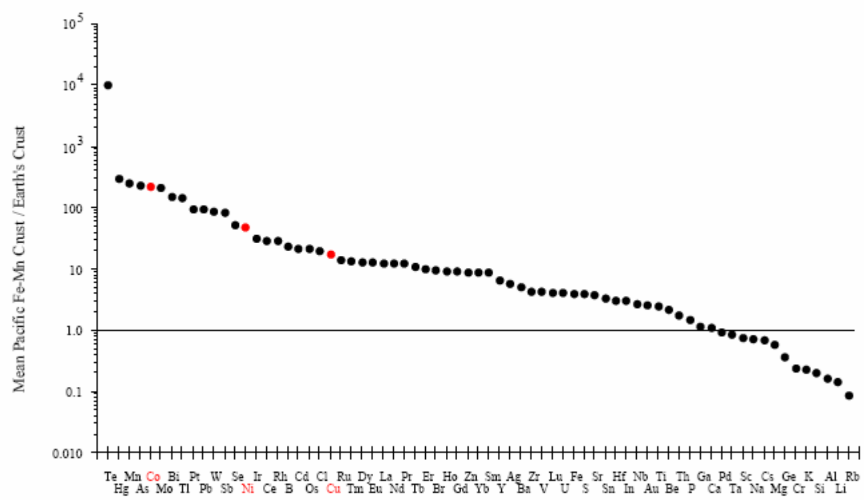

Figure 1. Comparison of mean composition of Pacific Fe-Mn crusts with the composition of the Earth's crust.

Distribution and Composition of Fe-Mn Crusts

Global Distribution

Fe-Mn crusts have been recovered from seamounts and ridges as far north as the Aleutian Trench in the Pacific Ocean, Iceland in the Atlantic Ocean and as far south as the Circum-Antarctic Ridge in the Pacific, Atlantic, and Indian Oceans. However, the most detailed studies have concerned seamounts in the equatorial Pacific, mostly from the Exclusive Economic Zones (EEZ; 370 kilometres) of island nations including the Federated States of Micronesia, Marshall Islands, Kiribati, Tuvalu, Tokelau, and French Polynesia, as well as in the EEZ of the USA (Mariana Islands, Hawaii and Johnston Island); but also from international waters, primarily in the Mid-Pacific-Ocean Mountains. Compared to the estimated 50,000 or so seamounts that occur in the Pacific Ocean, the Atlantic and Indian oceans contain fewer seamounts, and most Fe-Mn crusts are associated with the spreading ridges. Crusts associated with those spreading ridges usually have a hydrothermal component that may be large near active venting, but which is regionally generally a small (less than 30 per cent) component of the crusts formed along most of the ridges (Bury, 1989).

Those types of hydrogenetic-hydrothermal crusts are also common along the active volcanic arcs in the west Pacific Ocean (Hein et al., 1987; Usui and Someya, 1997), the spreading ridges in back-arc basins of the west and southwest Pacific Ocean, spreading centers in the south and east Pacific, and active hotspots in the central (Hawaii) and south (Pitcairn; Samoa) Pacific. Very few (less than 1 per cent) of the approximate 50,000 seamounts in the Pacific have been mapped and sampled in detail, and none of the larger ones have been so studied, some of which are comparable in size to continental mountain ranges.

Fe-Mn crusts occur at water depths of about 400-4000 metres, but most commonly occur at depths from about 1000-3000 metres. The most cobalt-rich crusts occur at water depths from 800-2200 metres, which mostly encompasses the oxygen-minimum zone (OMZ; *Figure 2*). The OMZ is produced by the oxidation of organic matter that falls through the water column, and thereby depletes the seawater of oxygen. The width of the OMZ and degree of oxygen depletion depends on the magnitude of primary biological productivity in surface waters, the source of the sinking organic particles. In the Pacific Ocean, the thickest crusts occur at water depths of 1500-2500 metres, which corresponds to the depths of the outer summit area and upper flanks of most Cretaceous seamounts. The water depths of thick, high-cobalt content crusts vary regionally and are generally shallower in the South Pacific Ocean where the OMZ is less well developed; there, the maximum cobalt contents and thickest crusts occur at about 1000-1500 metres (Cronan, 1984). Crusts become thinner with increasing water depth because of mass movements and reworking of the deposits on the seamount flanks. Most Fe-Mn crusts on the middle and lower seamount flanks consist of completely encrusted talus rather than encrusted rock outcrop, the latter, however, typically has thicker crusts (Hein et al., 1985).

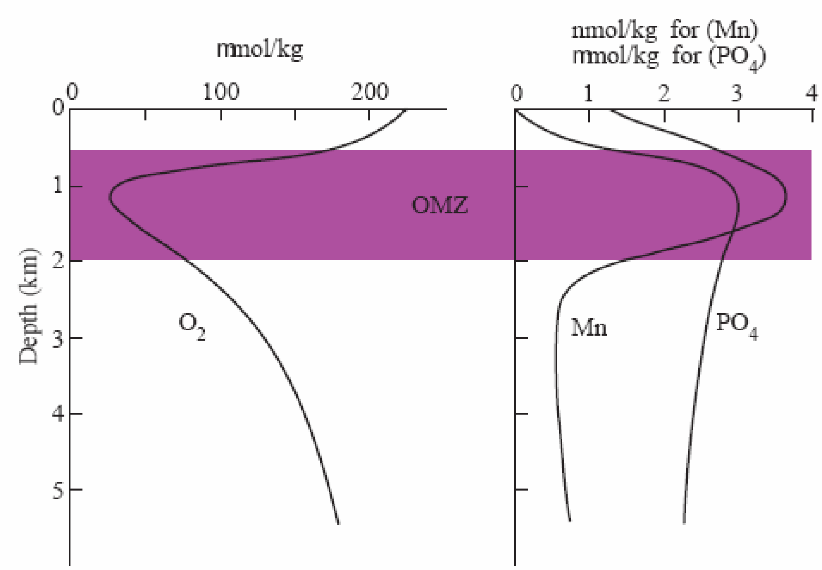

Figure 2. Manganese, manganophile elements e.g. cobalt, and oxyanions e.g. phosphorus (PO_4), concentrate in the oxygen-minimum zone (OMZ).

Many seamounts and ridges are capped by pelagic sediments and therefore do not support the growth of crusts on the summit. Other volcanic edifices are capped by limestone (drowned reefs), which commonly supports thinner crusts than those found in deeper-water or laterally adjacent volcanic and volcaniclastic rocks (Frank et al., 1976; Hein et al., 1985, 1988; Usui et al., 1993); this variation occurs because of the younger age of the limestones and therefore shorter time for crusts growth coupled with the instability and mass wasting of the limestone. Fe-Mn crusts are usually thin down to as deep as 3000 metres water depth on the submarine flanks of islands and atolls because of the large amounts of debris that are shed down the flanks by gravity-flow processes (Moore et al., 1994). Reworked crusts fragments occur as clasts in breccia, which is one of the most common rock types on seamount flanks (Hein et al., 1985).

Regional mean crust thicknesses mostly fall between 0.5 and 4 centimetres. Only rarely are very thick crusts (greater than 10 centimetres) found, most being from the central Pacific Ocean, for which initial growth may approach the age of the Cretaceous volcanic substrate rock. Clearly, while most Pacific Ocean seamounts are 65-95 million years old, most crusts collected on those seamounts represent less than 25 million years of growth because of reworking and episodic sediment cover. Thick crusts are rarely found in the Atlantic and Indian Oceans, with the thickest (up to 12.5 centimetres) being recovered from the New England seamount chain (NW Atlantic), and a 7.2 centimetre-thick crust being recovered from a seamount in the Central Indian Ocean Basin (Banakar and Hein, 2000).

Local Distribution

The distribution of crusts on individual seamounts and ridges is poorly known. Seamounts generally have either a rugged summit with moderately thick to no sediment cover (0-150 metres) or a flat summit (guyot) with thick to no sediment cover (0-500 metres). The outer summit margin and the flanks may be terraced with shallowly sloping surfaces headed by steep slopes metres to tens of metres high. Talus piles commonly accumulate at the base of the steep slopes and at the foot of the seamounts; thin sediment layers may blanket the terraces alternately covering and exhuming Fe-Mn crusts. Other seamount flanks may be uniformly steep up to 20^{o}, but most seamount flanks average about 14^{o} (e.g., Halbach et al., 1982; Hein et al., 1985). The thickest Fe-Mn crusts occur on summit outer-rim terraces and on broad saddles on the summits. Estimates of sediment cover on various seamounts range from 15 per cent to 75 per cent, with averages likely varying between 40 per cent and 60 per cent for different regions of the global ocean. Crusts may be commonly covered by a thin blanket of sediment in the summit region and on flank terraces. It is not known how much sediment can accumulate before crusts stop growing. Crusts have been recovered from under as much as 2 metres of sediment without apparent dissolution (Morgenstein, 1972; Bolton et al., 1988, 1990; Yamazaki et al., 1993). Based on coring results, Yamazaki (1993) estimated that there are two-to-five times more Fe-Mn crust deposits on seamounts than estimated from exposed crust outcrops because of being covered by a thin blanket of sediment. Those thinly veiled crusts would be within reach of mining.

Global Variations in Fe-Mn Crusts Composition

The iron/manganese (Fe/Mn) ratios are lowest for crusts from the central and west parts of the North and South Pacific Ocean (hereafter called the open Pacific Ocean) and highest for crusts collected in the Atlantic and Indian Oceans, and in the east Pacific, along the continental margin (*Figures 3, 4; Table 1*).

TABLE 1. MEAN VALUES FOR CHEMICAL COMPOSITION OF FE-MN CRUSTS FROM THE PACIFIC, ATLANTIC, AND INDIAN OCEANS; AVERAGE OF FE-MN NODULES FOR COMPARISON[1].

	C+W North Pacific	East North Pacific	C+W South Pacific	East South Pacific	Atlantic Ocean	Indian Ocean	Avg. Nodules
Fe wt. %	17.1	22.6	14.4	29.2	21.6	21.3	12.7
Mn	20.8	17.2	18.9	23.5	14.0	16.2	18.5
Fe/Mn	0.82	1.31	0.76	1.24	1.54	1.31	0.69
Si	4.14	11.3	3.47	6.95	5.50	7.71	8.80
Al	0.95	1.85	1.12	1.62	2.16	2.17	3.00
Si/Al	2.69	6.12	3.10	4.29	2.55	3.55	2.93
Mg	1.05	1.20	1.24	1.34	1.54	1.30	1.40
Ca	3.29	2.01	3.41	2.68	4.39	2.67	1.80
Na	1.54	1.89	1.01	2.05	1.32	1.71	2.10
K	0.52	0.79	0.53	0.70	0.53	0.75	0.93
Ti	1.11	0.64	1.06	0.85	0.95	0.98	0.78
P	0.74	0.54	0.79	0.58	0.78	0.44	0.25
S	0.21	0.13	0.16	0.18	0.19	0.15	0.50
Cl	0.975	1.03	0.981	2.28	0.935	1.27	0.500
LOI	32.3	17.4	21.1	19.4	28.3	26.0	16.0
H_2O^-	18.0	16.9	18.7	15.8	11.2	12.8	--
H_2O^+	6.90	9.20	10.2	--	--	--	7.50
CO_2	0.62	0.40	0.83	--	--	--	0.20
Ag ppm	~0.3	1.3	~0.3	~0.1	2.0	1.4	0.10
As	291	249	183	260	289	180	159
B	209	328	300	298	257	287	273
Ba	1895	2356	1796	2271	1716	1637	2000
Be	6.6	4.2	6.8	11	8.4	7.5	4.0
Bi	31.9	16.9	27.9	10.8	14.2	16.4	21.0
Br	31.6	27.0	22.1	--	30.5	54.0	5.0
Cd	3.4	3.2	4.3	1.8	3.0	2.5	11
Co	5109	2819	5731	1739	3574	3171	2400
Cr	22.9	46.2	23.0	~36	29.1	29.6	25.0
Cs	1.06	0.80	~1.77	--	1.17	1.80	1.00
Cu	973	461	939	862	774	1354	4200
Ga	18.3	10.5	17.5	46.9	14.4	18.2	11.0
Ge	1.4	3.7	~11	~12	5.0	5.0	0.80
Hf	10.5	6.2	7.0	8.7	14.1	12.1	6.0
In	0.31	~0.18	~0.36	0.59	0.32	0.30	0.25
Li	3.6	8.5	3.2	5.9	34	9.8	80
Mo	402	367	502	436	429	333	360
Nb	60.6	29.9	55.7	42.3	54.0	76.0	74.0
Ni	3473	2349	4364	2618	2685	2727	6300
Pb	1265	1486	798	734	1108	1082	820
Rb	6.2	13.3	~2.7	16.6	14.5	22.9	15.0
Sb	42.6	33.3	38.2	27.4	57.2	43.1	37.0

Sc	9.6	9.4	7.5	12.2	17.3	12.3	10.0
Se	2.4	1.6	~7	--	3.0	3.8	0.6
Sn	11	6.1	15	5.9	16	12	2.0
Sr	1413	1239	1508	1202	1341	1124	700
Ta	1.4	2.8	~1.4	--	1.0	1.3	10
Te	48.3	9.9	27.7	23.5	39.1	32.8	10.0
Th	38.7	49.7	8.96	--	51.9	45.8	30
Tl	136	41	161	80	95	89	150
U	13.0	17.3	11.1	--	9.2	9.1	6.8
V	568	597	675	739	825	616	480
W	114	62	66	~33	69	78	76
Y	190	169	190	305	184	164	133
Zn	565	554	631	583	598	553	900
Zr	793	463	885	607	564	696	620
La	266	272	199	293	277	281	122
Ce	1022	1436	761	239	1430	1483	665
Pr	49.0	60.9	53.4	44.5	74.6	68.8	70.0
Nd	209	257	169	200	251	248	160
Sm	42.3	53.7	36.0	37.4	61.4	60.2	30.0
Eu	10.4	13.6	9.2	10.4	10.4	10.8	9.0
Gd	47.8	55.1	56.6	57.8	62.4	62.0	35.0
Tb	8.9	8.8	5.4	9.0	10.0	9.0	5.3
Dy	46.9	49.0	49.8	54.8	52.9	49.4	30.0
Ho	10.8	9.7	11.1	12.0	9.0	6.9	6.4
Er	25.2	27.4	30.5	36.7	31.0	26.0	18.0
Tm	4.4	3.9	4.6	5.2	3.6	3.0	1.8
Yb	23.2	25.2	19.2	34.3	23.8	22.7	18.0
Lu	3.1	3.8	3.0	6.0	4.3	3.5	2.2
Hg ppb	9.2	~94	~10	67	134	48	20
Au	~10	~16	28	6	7	8	2
Ir	9	3	6	2	5	8	2
Os	2	--	--	--	2	--	1
Pd	3	4	5	12	6	7	2
Pt	348	75	522	116	567	348	130
Rh	19	9	37	11	37	24	13
Ru	19	10	18	14	18	13	8
	n=627	**n=138**	**n=297**	**n=18**	**n=25**	**n=19**	

~ Means that more than 25% of values were less than the detection limit; less than values were halved and means calculated. Dash means no data. N values are maxima; some elements have fewer analyses, especially the platinum group elements, gold, and rare-earth elements. LOI is loss on ignition, CO_2 is carbon dioxide; H_2O^+ is structural water; H_2O^- is adsorbed water; see appendix 1 for a key to the elements

1 Appendix 1 provides the key to the symbols in this table

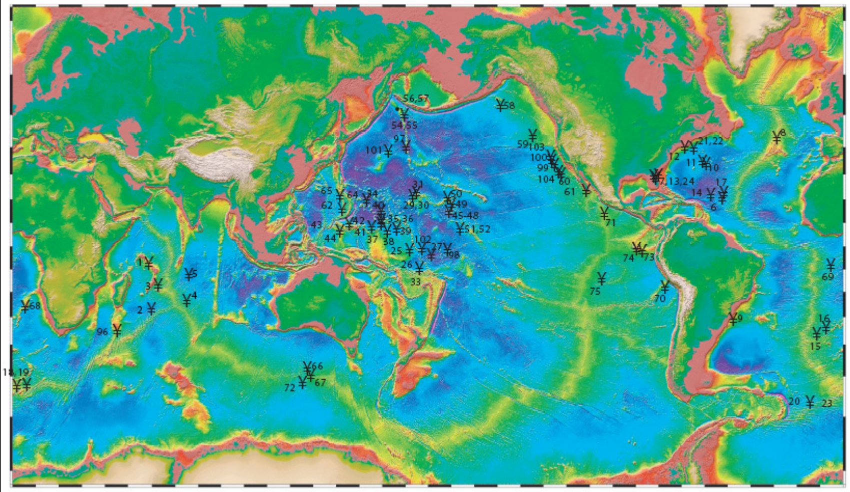

Figure 3. Location of samples compiled in Table 1; many samples were analyzed from each location.

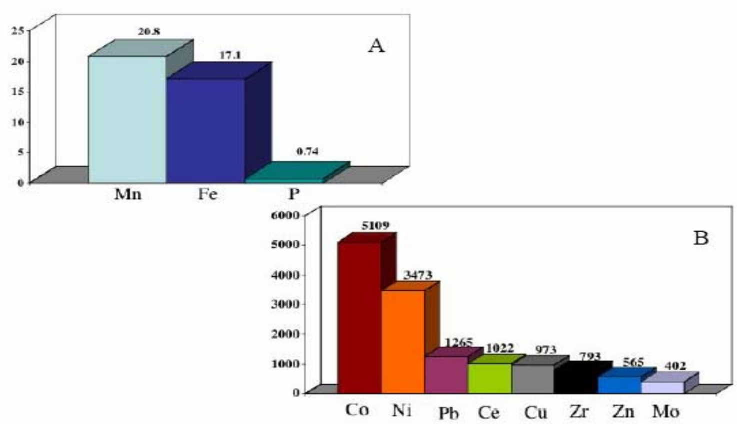

Figure 4. Histogram of mean content of major elements in weight percent (A) and select minor elements in ppm (B); open North Pacific Ocean samples, based on analysis of 627 samples.

The detrital (continent derived) element contents (e.g., silicon [Si], aluminium [Al]) are highest in crusts with proximity to continental margins (off Western North and South America) and in all areas of the Atlantic and Indian Oceans; and lowest in the open Pacific Ocean (*Table 2*). Barium (Ba) content can be used as a proxy for the magnitude of primary bioproductivity in surface waters. Mean barium content is much higher in northeast Pacific Ocean continental-margin crusts than anywhere else in the global ocean. Mean Ba contents are also high along the continental margin of South and Central America. Intermediate mean Ba contents occur in crusts from the open Pacific Ocean and reflect regional upwelling and primary productivity along the equatorial zone of convergence, and local upwelling around seamounts elsewhere in the Pacific Ocean. The Atlantic and Indian Ocean crusts show lower concentrations of this productivity proxy. This same trend is reflected in uranium (U) concentrations in crusts, which is a proxy for the oxygen content of seawater, a direct consequent of primary bioproductivity in surface waters. Another interesting distribution is seen with phosphorus (P) because it is not enriched in areas where upwelling and bioproductivity are greatest, as expected, but rather is highest in crusts from the open Pacific and Atlantic Oceans (*Table 2*). This distribution may reflect the diagenetic input of phosphorus to the crusts long after their formation (Hein et al., 1993).

TABLE 2. STATISTICS FOR THE SURFACE AREA OF SEAMOUNTS AND GUYOTS AVERAGE SEAMOUNT (SURFACE AREA STATISTICS FOR 34 SEAMOUNTS)

	Total surface area (km^2)	Surface area above 2500 m water depth (km^2)
Mean	1,850	515
Median	1,450	325
SD[1]	1,150	470
Min	310	0
Max	4,776	1,843

[1] Standard Deviation

The combined cobalt (Co), nickel (Ni), and copper (Cu) contents are highest in the open Pacific Ocean, intermediate in the Indian and Atlantic Oceans, and lowest along the continental margins in the Pacific Ocean (*Table 1*). The highest copper contents occur in Indian Ocean crusts because they are generally from deeper water areas and copper contents increase with increasing water depth of crusts occurrence. The Shatsky Rise Fe-Mn crusts and mid-latitudes of the northwest Pacific Ocean, have a surprisingly high mean copper content, as well as the highest copper value yet measured in a bulk crust, 0.4 per cent (4000 ppm). Platinum (Pt) contents are highest in the Atlantic and open South Pacific Ocean crusts, intermediate in the open North Pacific and Indian Ocean crusts, and lowest in crusts from continental margins (*Table 2*). Cerium (Ce) and the other rare-earth elements are generally highest in Indian and Atlantic Ocean crusts.

<u>Implications for Mine Site Characteristics</u>

Based on the above data on distribution and composition of Fe-Mn Crusts, it is proposed that a future mine site will have the following characteristics.

- Mining operations will take place around the summit region of guyots on flat or shallowly inclined surfaces, such as summit terraces and saddles, which may have either relatively smooth or rough small-scale topography. These are the areas with the thickest and most cobalt-rich crusts; much thinner crusts occur on steep slopes;
- The summit of the guyots will not be deeper than about 2200 metres, the terraces not deeper than about 2500 metres;
- Little or no sediment will occur in the summit region, which implies strong and persistent bottom currents;
- The summit region will be large, more than 600 square kilometres (see next section);
- The guyots will be Cretaceous in age;

- Areas with clusters of large guyots will be favoured;
- Guyots with thick crusts and high grades (cobalt, nickel, copper) will be chosen;
- The central Pacific Ocean best fulfils all the above criteria.

Within the central Pacific Ocean, a great many seamounts occur within the Area (international waters), and promising locations for potential mining occur within the Mid-Pacific-Ocean Mountains, such as between Wake and Minami Torishima (Marcus) Islands, the Magellan Seamounts, seamounts between the EEZs of Johnston Island and the Marshall Islands, Johnston Island and Howland and Baker Islands, and the Shatsky Rise farther to the north might also be promising.

The basic mine-site characteristics listed above can be utilised in the design of mining equipment, and in considering biological and environmental issues. For example, sessile biota and fish may be more important concerns than sediment infauna. Mining equipment will probably not have to be designed to operate on steep slopes, although that capability would offer greater flexibility.

Seamounts

<u>Surface Area of Seamounts</u>

The surface areas of 34 typical equatorial Pacific Ocean guyots (*Figure 5*) and conical seamounts (*Figure 6*) were measured.

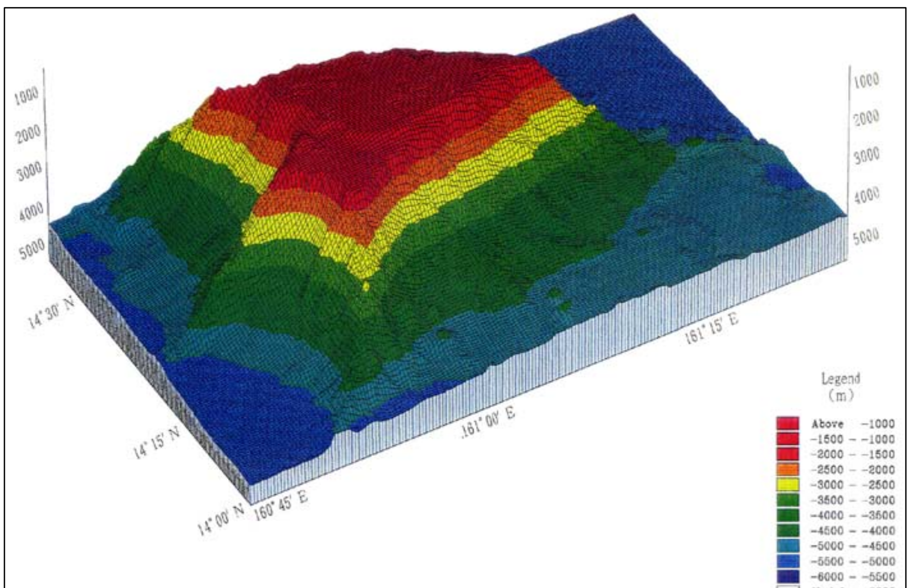

Figure 5. Typical central Pacific guyot (flat-topped seamount).

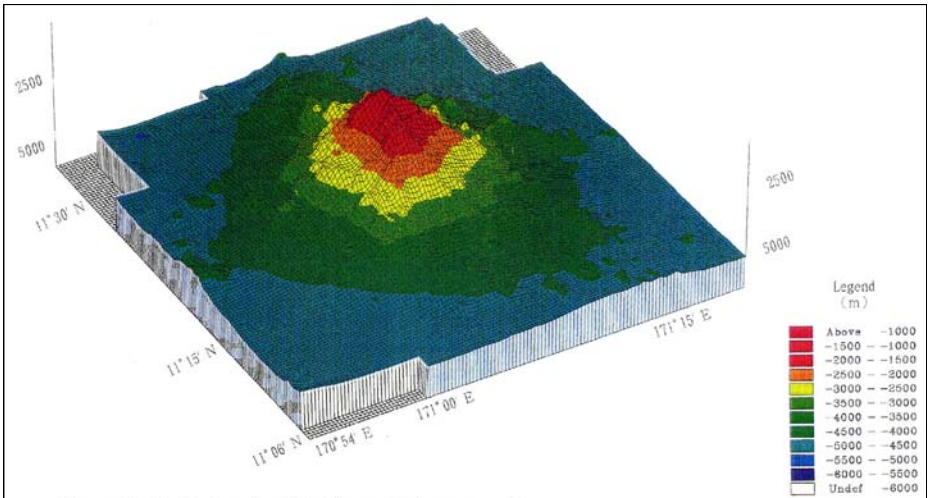

Figure 6. Typical central Pacific conical seamount.

Surface areas were determined using Arc Map's 3-D analyst and the amount of sediment versus hard-rock areas were calculated from side-scan sonar back-scatter images. The surface areas of 19 guyots and 15 conical seamounts varied from 4,776 to 313 square kilometres (*Figure 7*). The total area of the 34 seamounts is 62,250 square kilometres, which cover a geographic region of 506,000 square kilometres.

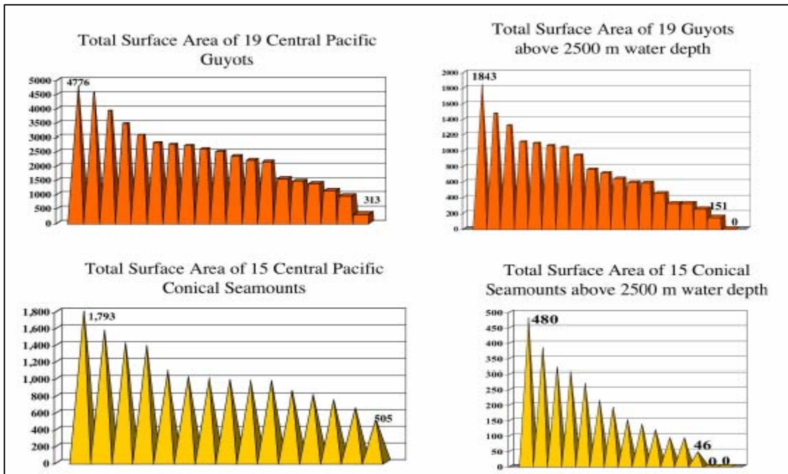

Figure 7. Surface area of 34 central Pacific seamounts in square kilometres.

The average surface area of the 34 seamounts is 1,850 square kilometres (*Figure 8; Table 2*). The amount of surface area above 2500 m water depth, where mining is likely to occur, averages 515 square kilometres (range 0-1,850 square kilometres). Guyots are bigger than conical seamounts (*Figure 7*) because guyots at one time grew large enough to be islands before erosion and subsidence took place. The conical seamounts never grew large enough to breach the sea surface.

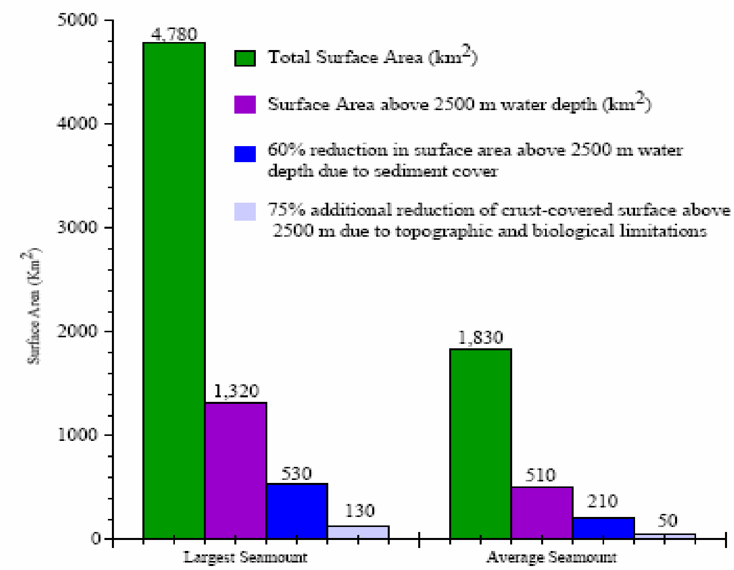

Figure 8. Surface area available for potential mine site considering a worst-case scenario.

For many guyots and seamounts, the surface area that is likely to be mined is less than the area that exists above 2500 m water depth, because of sediment cover. As a worst-case scenario, about 210 square kilometres (range 210-410 square kilometres) of the average seamount would have crust exposed (not covered by sediment) that could potentially be mined; and about 530 square kilometres (range 530-1060 square kilometres) of the largest seamount measured would be available for mining (*Figure 8*). Those areas would likely be further reduced because of prohibitive small-scale topography, un-mined biological corridors, and other impediments to mining. Consequently, for the largest seamount measured, as little as 130 square kilometres (range 130-265 square kilometres) might be available for mining; and for the average seamount, as little as 50 square kilometres (range 50-105 square kilometres) might be available for mining. Seamounts and guyots that have little sediment cover and relatively subdued topography do exist; and those are the ones that are likely to be mined.

Implications for mine sites

Based on a conservative estimate of 26 kilograms of crust per square meter of seafloor (range 25-78 kilograms per square meter based on dry bulk density of 1.3 grams per cubic centimetre and mean range of crust thicknesses of 2-6 centimetres), it would require the mining of 77 square kilometres (range ~26-77) per year to satisfy a rate of production of 2 million metric tons of crust per year. This would translate to 1,540 square kilometres (range ~520-1,540) of crust removal for a 20 year mining operation. From the data on seamount sizes and likely areas available for mining presented above (*Figures 7, 8*), it can be concluded that about 3-12 large guyots would be needed for a 20 year mining operation, or about 10-31 average size seamounts based on an average crust thickness of two centimetres. However, it is likely that large areas can be found with twice that average crust thickness.

Currents around Seamounts

It is essential to understand the movement of water masses around seamounts so that appropriate mining equipment and techniques can be developed and dispersal routes of suspended and re-suspended particles and wastes can be determined. Very few studies have addressed seamount currents and biology. Fe-Mn crusts occur on many different kinds of topographic features throughout the global ocean, but in this section, we concentrate on seamounts of the type that occur in the equatorial Pacific Ocean, where the most economically promising Fe-Mn crust deposits occur.

Seamounts obstruct the flow of oceanic water masses, thereby creating a wide array of seamount-generated currents of generally enhanced energy relative to flow away from the seamounts. Seamounts interact simultaneously with large-scale currents, mesoscale jets and eddies, and tidal flows (Roden, 1994), the combined effect of which produces seamount-specific currents. Those seamount-generated currents can include anticyclonic currents (Taylor column), internal waves, trapped waves, vertically propagating vortex-trapped waves, Taylor caps (regions of closed circulation or stagnant water above a seamount), attached counter-rotating mesoscale eddies, and others (e.g., Noble et al., 1988; Brink, 1995; Bograd et al., 1997). The effects of these currents are strongest at the outer rim of the summit region of seamounts, the area where the thickest crusts are found. However, the seamount-generated currents can be traced for at least several hundred metres above the summit of seamounts. Other water-column features produced by the interaction of seamounts and currents are density inversions, isotherm displacement, enhanced turbulent mixing, and upwelling; the latter process moves cold, nutrient-rich waters to shallower depths. Upwelling increases primary productivity, which in turn increases the size and magnitude of the OMZ (*Figure 2*), and makes seamounts ideal fishing grounds. Seamount-generated currents also cause erosion of the seamounts (and Fe-Mn crusts) and move surface sediments, which produce sand waves and ripples.

Seamount height, summit size, types of ambient currents, and energy of the tidal currents determine which seamount-specific currents will be generated and their longevity. It is clear that some seamounts in the equatorial Pacific have been swept clean of sediment for most of 70 million years, because that is the duration of growth of the thickest crusts in that area, whereas other seamounts may be capped by as much as 500 m of carbonate sediment and therefore lack development of Fe-Mn crusts on the summit.

Seamount Biology

It is also essential to understand the nature and composition of seamount biological communities so that the impact of mining on these unique communities can be determined and the information incorporated into environmental impact recommendations. The physical processes described in the above section also affect seamount biology and may have a controlling influence on larval dispersal. Seamount communities vary from seamount to seamount; even communities from the same water depths on adjacent seamounts may differ. Most studies of seamount biology have concentrated on seamounts with a sediment cap and on the biological communities living on (epifauna) and in (infauna) that sediment (e.g., Levin and Thomas, 1989; Smith et al., 1989). Fewer studies have addressed communities dwelling on the rock outcrops, which consist of mostly attached (sessile) organisms. These sessile biota may grow to impressive sizes, with glass sponges ranging up to three plus metres tall and solitary corals (e.g., gorgonian corals), growing even taller. Glass sponge “thickets” occur at the tops of vertical steps separating summit terraces, where strong up-flow acceleration provides abundant nutrients (personal observation aboard the Deep Submergence Research Vehicle (DSRV) Alvin on Horizon Guyot). Elsewhere on the summit, glass sponges are less densely populated. A few studies have looked at the types of organisms that live on the surface of Fe-Mn crusts, which consist predominantly of agglutinated foraminifera (e.g., Mullineaux, 1987). Archaea and bacterial microbiological processes that may mediate the growth of Fe-Mn crusts and participate in the concentration of trace metals have not been studied.

Seamount biological communities show a variable rate of endemism, which may be high on some seamounts (Stocks et al., 2004). Seamount communities are also characterized by relatively low density and low diversity where the Fe-Mn crusts are thickest and most cobalt rich. This occurs because the low-oxygen contents in the OMZ decrease the abundance of consumer populations, excludes most tolerant species from seafloor habitats, and can produce steep gradients in seafloor communities (Wishner et al., 1990). Above and below the OMZ, the populations may be greater and more diverse. Levin and Thomas (1989) found lower biological activity at the high-energy summit margin (covered by both rock and sediment) of the central Pacific Horizon Guyot than at other sediment-covered summit sites. In contrast, Genin et al. (1986) found that antipatharian and gorgonian corals are more abundant in areas of seamount summits where flow acceleration is prominent. Thus, the make-up of seamount communities and population density and diversity are determined by current patterns, topography, bottom sediment and rock types and coverage, seamount size, water depth, and the size and magnitude of the OMZ, which in turn is related to primary productivity in surface waters.

Recent research on seamounts in the Mariana volcanic arcs in the Western Pacific Ocean, has revealed some interesting biological relationships . Those seamounts generally support diffuse-flow, low-temperature hydrothermal systems at various locations around the summits, so conditions there are not entirely applicable to central Pacific seamounts. However, as with seamounts elsewhere, unique biological communities are found on adjacent seamounts. It was discovered that several snails lay egg cases on the rocks and that when veligers (larval stage) hatch from those egg cases they remain near the bottom, rather than being widely dispersed as is common during the larval stage. They quickly become protoconchs, the first stage of benthic existence. Thus, some Mariana seamount taxa appear to produce larvae with limited dispersal potential, the dominant mode for colonization of adjacent areas. This, in combination with closed circulation around the seamounts, may enhance larval retention and retard colonization.

Several recently developed programs will promote our understanding of seamount biology and habitats. The Census of Marine Life (CoML) (www.coml.org) is an international science initiative designed to fill in knowledge gaps concerning under-explored habitats in the ocean, including seamounts (Stocks et al., 2004). The Global census of marine life on seamounts, CenSeam (http://censeam.niwa.co.nz), began in 2005 and is one of 14 field programs sponsored by the CoML. CenSeam is hosted by the National Institute of Water and Atmospheric Research (NIWA) in Wellington, New Zealand. Seamounts Online is a National Science Foundation funded project designed to compile data on seamount species, which are made freely available as an online resource (http://seamounts.sdsc.edu/about_projects.html). The Seamount Biogeo-sciences Network (SBN) supports coordination of multidisciplinary studies (geosciences, biosciences, fisheries, physical oceanography) of seamounts and is administered at Scripps Institution of Oceanography, University of California at San Diego. SBN will hold its first workshop in March 2006 (http://earthref.org/events/ SBN/2006/index.html).

Recent Economic Trends

The greatest potential economic value of Fe-Mn crusts has always been their unprecedented high content of cobalt. This is still the case and is not likely to change. However, Fe-Mn crusts contain high concentrations of a great variety of metals that could become important by-products of cobalt recovery, especially copper, nickel, rare-earth elements (primarily cerium), titanium, zirconium, platinum, molybdenum, tellurium, and manganese, among others. Recent significant increased demands for metals in the rapidly growing economies of China and India has pushed up the metal prices, notably for copper, nickel, and cobalt, but increased prices for other metal will soon follow. This upward trend in prices will fluctuate, but should not be ameliorated anytime soon. This upward trend of metal prices follows closely that of petroleum, for which most of the recent dramatic increases in price can be attributed to increased demand in Asia. Nickel consumption in China has increased five fold in the decade of the 1990s and continues to grow (Antrim, 2005; *Figure 9*).

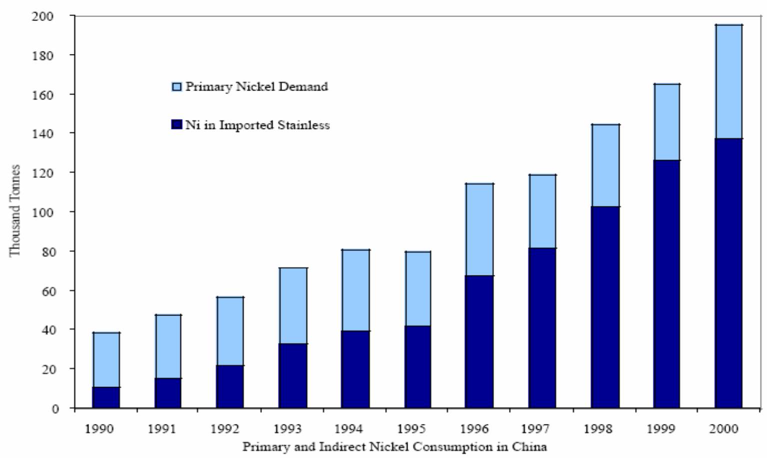

Figure 9. Nickel consumption increased five fold in China in the decade of the 1990s and continues to grow (from Antrim, 2005).

The projected annual rate of growth of world consumption of cobalt is 6 per cent, copper 4 per cent, and nickel 4.25 per cent (Antrim, 2005; *Figure 10*).

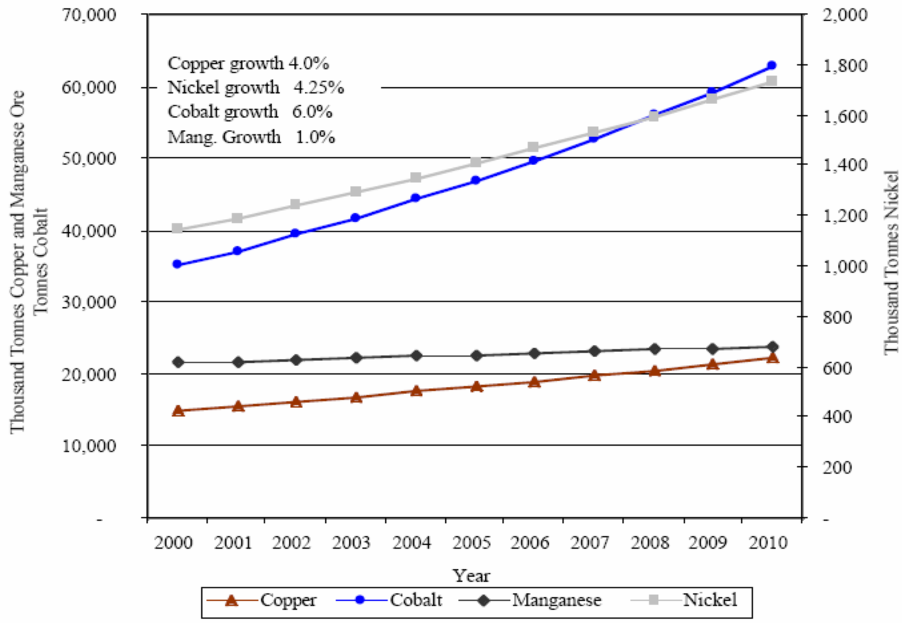

Figure 10. Projected world consumption of select metals (from Antrim, 2005).

Yamazaki (2005) considered that we are now at the beginning of a copper crisis, where shortages are projected to occur within the next decade. In support of this projection, the price of copper has more than tripled since 2001, and the price of nickel has likewise increased significantly, although with large fluctuations (*Figure 11*). These increased metal demands may have an impact on the three main deep-seabed mineral-deposit types in that nodules and crusts have high copper, nickel, and cobalt contents, and polymetallic sulphides have high copper contents. Increased demand for metals and higher prices make the potentiality for marine mining more likely.

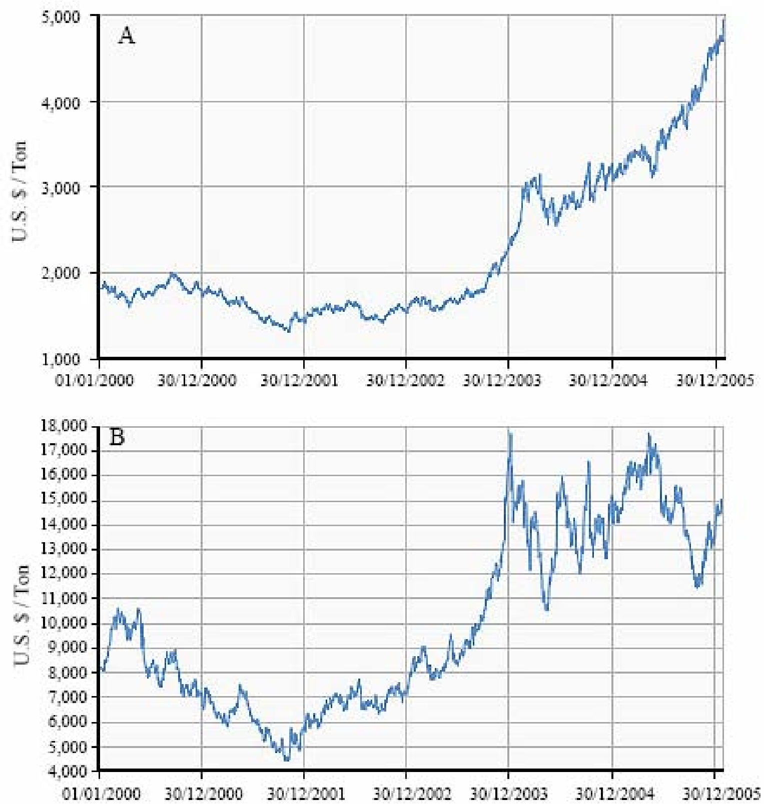

Figure 11. Price of copper (A) and nickel (B) on the London Metal Exchange for the period 1 January 2000 through 1 February 2006.

Knowledge Gaps and Opportunities

Nearly 25 years have been dedicated to studies of cobalt-rich Fe-Mn crusts. Most of that work concentrated on the crusts and did not systematically address biological and environmental issues. So, biological studies, physical oceanography, and the environmental consequences of mining are the hot issues for the 21st century. However, many questions also still remain to be answered concerning the formation of Fe-Mn crusts and the morphology of seamounts:

- Detailed mapping of selected seamounts, including analysis of small-scale topography,
- Development of better dating techniques for crusts,
- Ascertain the oceanographic and geologic conditions that produce very thick crusts,
- Determine the processes that control the concentration of platinum-group elements and other rare elements in crusts,
- Determine how much burial by sediment is required to inhibit crust growth; and to what extent crusts occur on seamounts under a thin blanket of sediment,

- Develop remote-sensing technique to measure crust thicknesses,
- Develop new mining technologies; and especially new, innovative processes of extractive metallurgy,
- Determine the role of microbiota in the formation and growth of crusts,
- Determine the extent and significance of organic complexing of metals that compose crusts,
- Determine the effects of potentially toxic metals (i.e., arsenic, thallium) that occur in Fe-Mn crusts on biota that interact with the crusts; under what conditions can the generally non-bioavailable forms of the metals that occur in the crusts be transformed into bioavailable forms,
- Provide environmental and ecological surveys of seamount communities and how they vary; the ranges of biodiversity and bioproductivity,
- Establish the range of variability of endemism,
- Determine the mechanisms and controls for the dispersal and colonization of seamount biota,
- A greater effort is needed in taxonomy and genetic fingerprinting of seamount biota,
- Determine the variability of currents, internal tides, and upwelling (physical oceanography) around seamounts; provide long-term monitoring.

During the 1980s and 1990s, hundreds of hours of seabed video and still photography were taken during Fe-Mn (ferromanganese) crusts studies, with the main purpose being geologic mapping and understanding crust distributions. Important biological information may also exist on those videos, which were taken mostly on central Pacific Ocean seamounts and ridges; those records perhaps can be used to augment ongoing and future biological studies. Most of those records are housed at the Free University of Berlin, the U.S. Geological Survey in Menlo Park, California, and the University of Hawaii in Honolulu. In addition, many other cruises dedicated to geological studies have sampled seamounts and likely have records that would be valuable to biological studies. Data from many of those earlier studies are not included in the Seamount Biogeosciences Network database. The U.S. Geological Survey sampled many central Pacific seamounts for Fe-Mn crusts during the ten-year period 1983-1993. Dredging was used to collect rock samples during those cruises and many biological specimens were recovered at the same time, which were preserved in formalin or formaldehyde and sent to Scripps Institute of Oceanography (Professor Ken Smith). Those samples were then shipped to the Smithsonian, where they should be available for study. Other such seamount biological collections likely exist in museums and oceanographic institutions elsewhere that could possibly support current studies.

Acknowledgements

Several sections of this paper were modified from Hein (2004), whereas the other sections are entirely new. I would like to thank Brandie McIntyre for invaluable technical support in the preparation of this paper.

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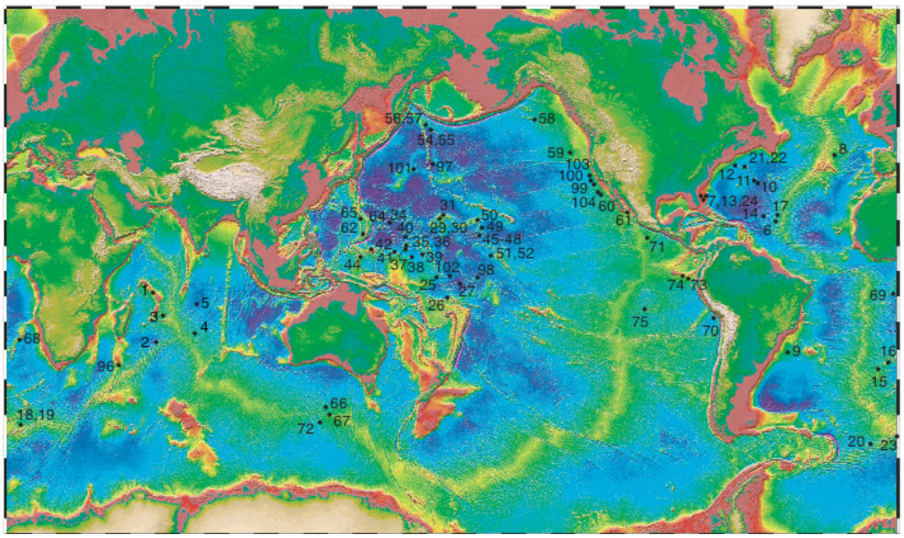
APPENDIX 1. KEY TO SYMBOLS IN TABLE 1.

Element	Name	Element	Name
Fe	Iron	Sc	Scandium
Mn	Manganese	Se	Selenium
Si	Silicon	Sn	Tin
Al	Aluminium	Sr	Strontium
Mg	Magnesium	Ta	Tantalum
Ca	Calcium	Te	Tellurium
Na	Sodium	Th	Thorium
K	Potassium	Tl	Thallium
Ti	Titanium	U	Uranium
P	Phosphorus	V	Vanadium
S	Sulphur	W	Tungsten
Cl	Chlorine	Y	Yttrium
LOI	Loss on ignition	Zn	Zinc
H_2O^-	Hygroscopic water	Zr	Zirconium
H_2O^+	Structural water	La	Lanthanum*
CO_2	Carbon dioxide	Ce	Cerium
Ag	Silver	Pr	Praseodymium
As	Arsenic	Nd	Neodymium
B	Boron	Sm	Samarium
Ba	Barium	Eu	Europium
Be	Beryllium	Gd	Gadolinium
Bi	Bismuth	Tb	Terbium
Br	Bromine	Dy	Dysprosium
Cd	Cadmium	Ho	Holmium
Co	Cobalt	Er	Erbium
Cr	Chromium	Tm	Thulium
Cs	Cesium	Yb	Ytterbium
Cu	Copper	Lu	Lutetium
Ga	Gallium	Hg	Mercury
Ge	Germanium	Au	Gold
Hf	Hafnium	Ir	Iridium
In	Indium	Os	Osmium
Li	Lithium	Pd	Palladium
Mo	Molybdenum	Pt	Platinum
Nb	Niobium	Rh	Rhodium
Ni	Nickel	Ru.	Ruthenium
Pb	Lead	Wt %	Weight percent
Rb	Rubidium	ppm	Parts per million
Sb	Antimony	ppb	Parts per billion

* La through Lu are rare-earth elements (REEs); Ir through Ru are Platinum-group elements (PGEs); ppm = grams per ton

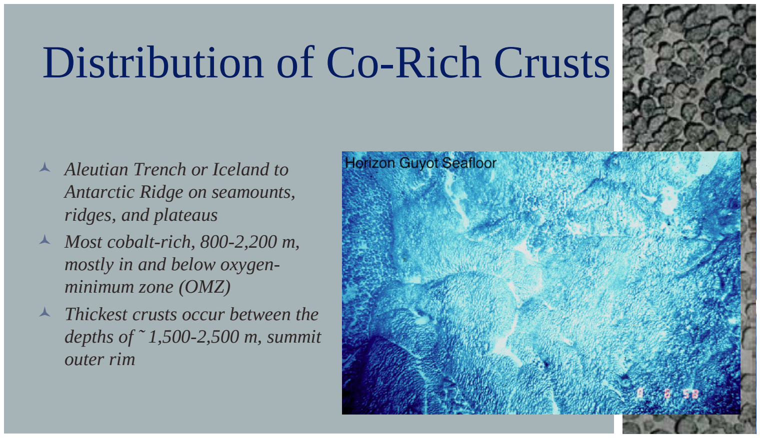
Summary of the presentation

Dr. Hein stated that in order to understand the characteristics of ferromanganese crusts it was essential to understand the characteristics of the seamounts substrate on which crusts grew. He informed participants that his presentation would be based on information on the morphology of seamounts and the distribution of ferromanganese crusts on seamounts that he and his colleagues had collected over the last 30 years. He added that the available data were nonetheless rather limited.



Dr. Hein explained that ferromanganese crusts were found on hard rock substrates throughout the entire world's ocean basins, from the northern Pacific and the northern Atlantic to the Antarctic Oceans. He said that cobalt-rich ferromanganese crusts occurred on seamounts at 800-2,000 metres water depth and overlap the oxygen minimum zone (OMZ). He also said that the oxygen minimum zone was a depth range in seawater where the oxygen content was relatively low. He noted that the relationship between the OMZ and the cobalt content of crusts was not unexpected, as low oxygen seawater created a reservoir for dissolved manganese associated with other metals such as cobalt and nickel.

According to Dr. Hein the thickness of ferromanganese crusts was also related to the surface structure and the depth of the seamount. Dr. Hein said that crusts only formed on hard rock substrates where no sedimentation occurred. He noted that these conditions usually occurred at the rims of seamounts, especially on the rims of guyot-type flat-top seamounts, where currents come up the sides of the seamount and sweep the rims of sediment. Dr. Hein further noted that the thickest crusts occurred at water depths of between 1500 metres - 2500 metres.



Along hard rock substrates on seamounts throughout the global oceans, Dr. Hein said that thickness could vary up to 25 centimetres from a patina. According to Dr. Hein these variations need to be considered when determining grid sizes for exploration areas or mine sites. He also said that it was important to be aware of the limitations of the available geochemical database. Dr. Hein added that the United States Geological Survey's (USGS) global dataset contained about 1,000 analyses of ferromanganese crusts with varying numbers of samples in different parts of the world's oceans. He said that globally, the distribution of ferromanganese crusts and their average thickness indicated that there were many areas of the world's ocean basins with manganese crusts that were 5 centimetres to 7 centimetres thick.

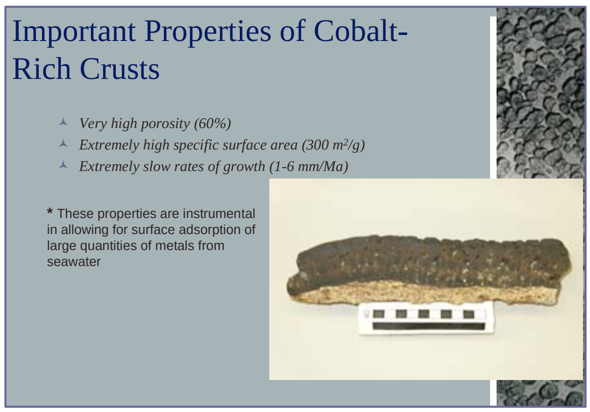
He noted, that there were several areas with no crusts occurrences because of the absence of seamounts and other topographic highs such as the abyssal plains of the North Pacific Ocean, or because no sampling had occurred in these areas e.g. in the South Pacific where seamounts can be found and ferromanganese crusts potentially occur. Dr. Hein informed the workshop that in the Atlantic Ocean, ferromanganese crusts formed along the Mid-Ocean Ridge and not on seamounts. He also said that the same was true for the Indian Ocean, which was dominated by the spreading centre ridge.

He said that the Atlantic Ocean was dominated by the mid Atlantic Ridge and the flanks of the ridge, and that the topographic high where ferromanganese crusts formed in the Atlantic Ocean were along the ridge and not on seamounts. Dr Hein said that it was the same way in the Indian Ocean, pointing out that a spreading center ridge dominated the Indian Ocean and that ferromanganese crusts formed on that ridge rather than on seamounts.

He informed participants that in the central western equatorial Pacific Ocean, seamounts dominated the area, and said that this was the only part of the world's oceans where large guyots were found. According to Dr. Hein, for a number of reasons this area of the Pacific Ocean was the most promising for future mining of ferromanganese cobalt-rich crusts deposits. He added that ferromanganese crusts also occurred along the continental margins, but that their contents of cobalt, nickel, manganese and other metals were lower because of input material from the continents, which diluted the metals in the crusts. He said that large seamounts could also be found in other parts of the world's ocean e.g. along the New England seamount chain, but that their surface structures were usually very rugged and therefore difficult to mine. Stating that a lot of isolated seamounts existed in the oceans, Dr. Hein said that some of them were very large (tens of thousand of square kilometres in size) and contained potentially interesting deposits.

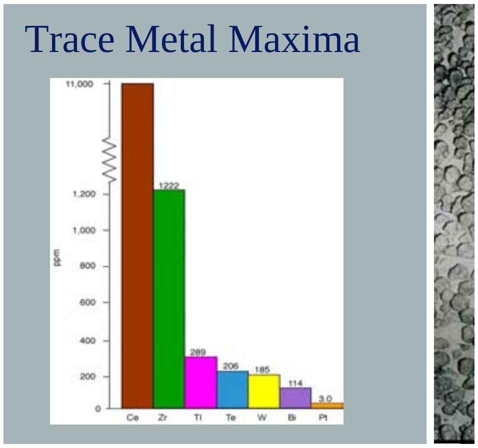
Dr. Hein listed the major properties of ferromanganese cobalt-rich crusts as follows:

1. Very high porosity (60 per cent);
2. An extremely high specific surface area – every gram or cubic centimetre of crusts has about 300 m² of surface area; and
3. Extremely slow growth rates in a range of 1 millimetre to 6 millimetres per million years. Ferromanganese crusts can therefore be considered as non-renewable resources.

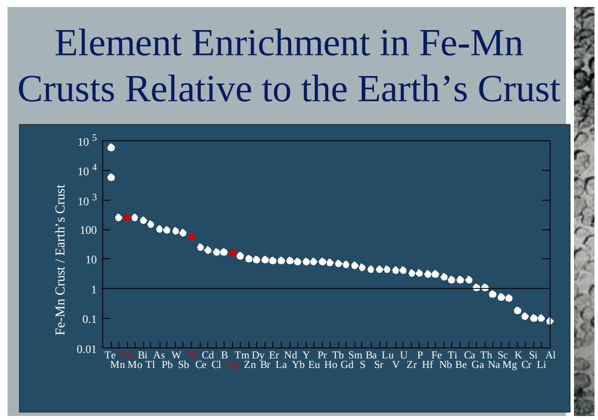


He said that all of these properties were significant, as they resulted in absorption of metals in great quantities from seawater. Dr. Hein noted that dating ferromanganese crusts had been difficult in the past, but a number of techniques have been developed, particularly for dating old crusts. He said that the methods used were mostly radiometric, and based on beryllium 9:10 ratios. He added that the United States Geological Survey had developed a technique for using osmium isotope ratios allowing for the dating of crusts as old as 70 million years. He explained that this meant that currents were persistent enough and sedimentation low enough to keep the area clean of sediment for 70 million years. He added that 70 million years of oceanic history was recorded in ferromanganese crusts and that these would be useful in indicating climate change, providing useful information on, *inter alia*, deep ocean circulation, the erosion rates of continents and other aspects such as the pH of seawater.

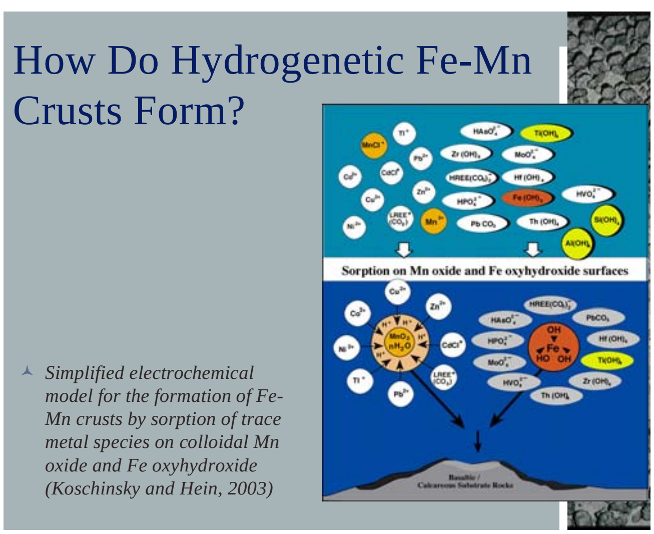
Dr. Hein said that based on the data available to him, the metal content of ferromanganese crusts varied significantly in the different parts of the oceans, and he presented data for the Central and Western North Pacific Oceans, which he said had the highest potential for future ferromanganese crusts mining. With regard to base metals in this area, he said that the average value for iron was about 17 per cent, manganese 21 per cent, phosphorous 7 per cent, cobalt 0.5 per cent, nickel 0.3 per cent and lead, cerium and copper about 0.1 per cent each. For trace metals, Dr. Hein presented a plot showing high metal contents for cerium, zirconium, tellurium, tungsten, platinum and other rare earth metals.



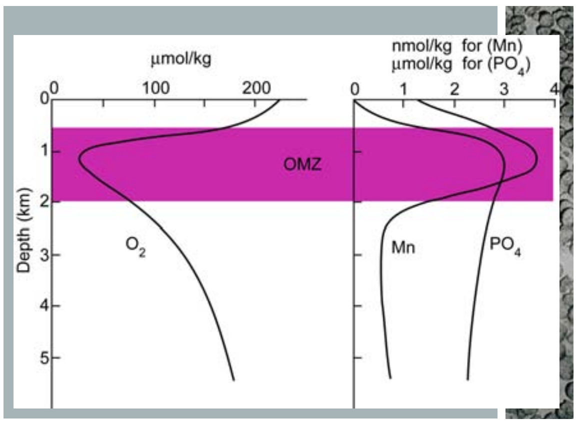
Through a figure showing that tellurium and cobalt were the most enriched metals in ferromanganese crusts, Dr. Hein said that almost every element in the Periodic Table was enriched in ferromanganese crusts when compared with their concentrations in the Earth's crust. He said that it was believed that metals were adsorbed from seawater into ferromanganese crusts, oxidized into a more stable state and accumulated in high quantities within the crusts. He also said that the chemistry of how metals were incorporated into ferromanganese crusts was complex and became important in extractive metallurgy.



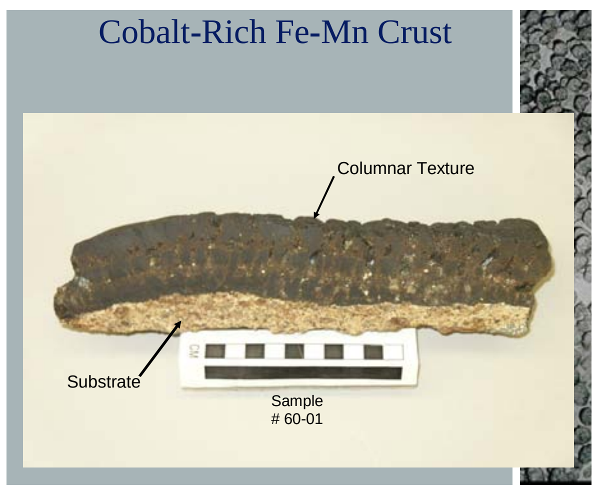
Dr. Hein presented a simplified electrochemical model for the formation of ferromanganese crusts by adsorption of trace metals on colloidal manganese oxide and iron oxyhydroxide. Dr. Hein explained that manganese oxide had a negatively-charged surface so it attracted positively-charged ions of cobalt, nickel, thallium, lead, zinc, copper and other metals in seawater. He said that the metals were either attached by the difference in charge, or attracted and then oxidized, which made them stable. He said that iron had a positively-charged surface and therefore attracted a different group of metals. Dr. Hein noted that the electrostatic model for the formation of crusts worked well in practice and had been successfully applied to assess complexing phases in seawater.



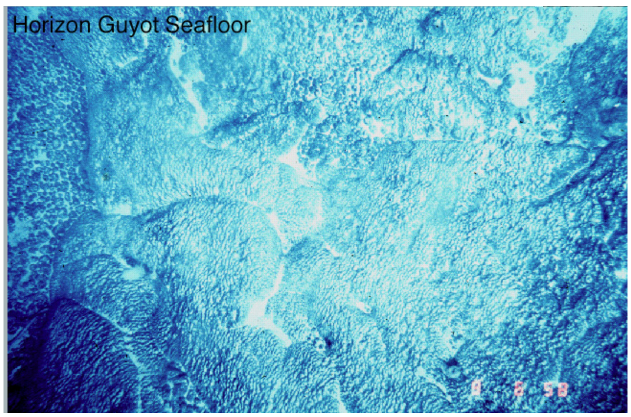
He turned his attention to the depth range where ferromanganese crusts were formed and showed a slide depicting the oxygen minimum zone in relation to the concentration of phosphorous and manganese, which were associated with a number of metals. In the range where the oxygen concentration was low, manganese and phosphorous concentrations were generally high. He said that the oxygen minimum zone was created by the oxidation of sinking organic matter where it becomes a reservoir for manganese and associated metals, and he further explained that the oxygen in this range of the water column was used up in degrading organic matter. He said that as a result, the seawater in this zone had low oxygen content. Dr. Hein noted that there were certain parts of the world's oceans where the oxygen minimum zone is well developed with a strong reservoir of metals. He explained that if the milieu gets anoxic (no oxygen) ferromanganese crusts do not form, since the metals are dissolved, and added that in his opinion the oxygen content was what controls the rate of growth of ferromanganese crusts. He noted that at a slow rate of growth the accumulation of metals associated with iron and manganese is relatively high, but that at a certain point with decreasing oxygen content, crusts stop growing. In order to understand ferromanganese crusts, Dr. Hein said that it was essential to understand seawater chemistry, the structure of seamounts and the global distribution of elements.



Dr. Hein said that ferromanganese crusts grew on hard rock substrates. He provided an example of a substrate called hyaloclastite, an altered volcanic, glassy debris. He said that this was a typical ferromanganese crust and that this sample may be 20 million years. Dr. Hein said that the chemistry of ferromanganese crusts changes from the top to the bottom because the chemistry of seawater changed during the 20 million years of growth of this ferromanganese crust. He informed participants that cobalt was always higher in the upper surface whereas platinum was higher in the lower part. He noted that changes occur in the chemistry of individual ferromanganese crust, at individual locations, and over larger regional areas.



Dr. Hein said that he was part of a team that collected ferromanganese crusts on a NW/SE transect across the Equator in the Central Pacific Ocean, where very strong geographic control on the chemistry of ferromanganese crusts is found. He informed participants that there were certain elements that increased both north and south toward the Equator in ferromanganese crusts. He said that ferromanganese crusts along the Equator will have higher concentrations of these metals than crusts forming away from the Equator, because at the Equator upwelling occurs. In this regard, Dr. Hein pointed out that upwelling increases going north and south towards the Equator and towards the east in the Pacific Ocean. He further pointed out that these sort of regional oceanographic trends have a lot to do with the composition of ferromanganese crusts. Dr. Hein said that the end result meant complicated regional trends in the composition of ferromanganese crusts, which all depend on the composition of ocean water, the regional upwelling, and current and wind patterns. He said that some of the factors were controlled by the blowing of debris in aeolian patterns (blowing into the area from winds coming from Asia). He observed that normally one would think that silica and aluminium would increase together because they both came from the continents, but in this instance, one increases to the east and the other one to the west. He said that the reason was because a lot of the silica comes from biogenic silica in little shelves of plankton that increase to the east, whereas aluminium increases to the west from terrigenous materials that come off the Asian continent. Dr. Hein said that from an unpublished equatorial study that the United States Geological Survey completed recently, it has been determined that many of the elements in crusts increase with increasing water depth and that another group of elements decrease with water depth. In this regard, he said that cobalt is higher up in the water column and that is because the oxygen minimum zone is also up there. He said that copper and other elements also increase in crusts at deeper water levels.

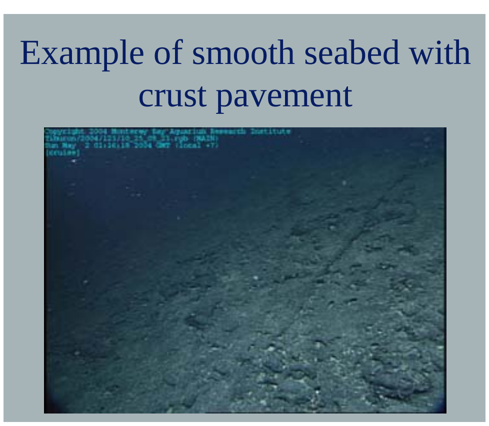


Dr. Hein reiterated the need to understand seamounts in general. He said that a flat-top seamount was once an island and then as it subsided it was planed off to create a flat-top guyot. For mining, Dr. Hein said that potential applicants would only be interested in the parts of the seamounts that were above 2,500 m water depth. He described such guyots as very large, with some tens of thousands of square kilometres in size.

Dr. Hein said that the other type of seamount in the Pacific Ocean was the conical seamount. He said that conical seamounts are always smaller overall on an average basis because they never grow long enough to reach the sea surface, so were never planed flat. He also said that the upper parts of conical seamounts were always more rugged than they are in guyots.

Dr. Hein said that some seamounts are the size of the Sierra Nevada and he described one or two samples from a large seamount. He also said that the USGS has swath bathymetry maps of approximately 200 seamounts. He said that the Pacific Ocean is estimated to contain about 50,000 seamounts. He remarked that there are a lot of seamounts and that very little is known about almost all of them. He said that none of the seamounts that he knew have been sampled and mapped in any great detail.

With slides, Dr. Hein showed pavements of ferromanganese crusts on the seafloor.



He suggested that for some of the occurrences it should be relatively easy to mine. For others including those with coatings of iron manganese crusts, he said it would be almost impossible to mine these occurrences. With regard to the extent of these areas, he indicated that not much was known but he suggested that in many cases using a bottom camera it has been found out that they are continuous for many kilometres along a line. He said however that their extent in the other directions was unknown.

Dr. Hein said that seamounts were unique because they stuck up from the bottom of the ocean impinging on major ocean circulation. Dr. Hein informed participants that there were huge water masses that circulated around the bottom of the ocean creating seamount-generated currents and anti-cyclonic Taylor columns every time they hit a seamount. He added that the spinning currents which came off the top seamounts were extremely important to the biological development on seamounts. He described a result of these phenomena as a turbulent mixing along the flanks of seamounts where the seamounts were swept clean of sediments. Dr. Hein also said that the upwelling associated with the phenomena was important because it brought nutrients from deeper water to the surface water accompanied by a lot of planktonic activity. He further added that one needed to understand biology, currents, structure of volcanic edifices and the global and regional chemistry in order to understand ferromanganese crusts.

According to Dr. Hein, not much is known about seamount biology. He said that within the last few years there had been a lot of work going on in this area. He said that in 1976 he went on a biology cruise in the Alvin submarine to the Central Pacific seamounts. He said that thereafter there was a hiatus for about 20 years because many scientists were not interested in seamount biology , but that interest in studying seamounts has since grown.

Dr. Hein said that circular currents going around seamounts, kept the biology located on the seamounts. He said that from one seamount to an adjacent seamount, the biological communities were completely different. He said that this was true even at the same water depth. Dr. Hein told participants that the real question was how many endemic species (they occur there and nowhere else) occurred on seamounts. He said that present knowledge suggests that some seamounts have large endemic species and other seamounts have almost no endemic species. He also suggested this field of study as one that needed to be looked at by biologists.

According to Dr. Hein, the most cobalt-rich crusts are found in the oxygen minimum zone because oxygen, biological density and diversity were low. He said that the outer rim of the seamount is swept clean of sediment because of the high energy currents coming up along them. He also said that the high energy current was good for the productivity of some organisms (corals and sponges) although inhibiting productivity of others. He noted that it was unknown if there is biological input to precipitation of metals on ferromanganese crusts and suggested the question as useful for scientific study.

Referring to the Authority's workshop on "Cobalt-Rich Crusts and the Diversity and Distribution Patterns of Seamount Fauna" in March 2006, Dr. Hein informed participants that he was the only geologist present among biologists. He said that prior to that workshop there was a meeting in San Diego about oceanography and seamounts, with five biologists in attendance. He therefore concluded that there were a lot of biologists now looking at seamounts. He noted that there are also websites - Census of Marine Life, Seamounts on Line, Global Census of Marine Life on Seamounts, Biogeosciences Network, etc. – and further noted that there was a global network of scientists looking at seamount biology and global deep water biology.

On the economics of cobalt-rich ferromanganese crusts, Dr. Hein said that USGS started studying ferromanganese crusts in detail in the early 1980s because the price of cobalt increased then, due to the Zaire/Zambian war where much of the world's cobalt was produced as a by-product of copper mining. He said that when the countries went to war their production decreased significantly, affecting supply and cobalt prices. Dr. Hein said that the first cobalt crust cruise was in 1981. He said that subsequently there was 20 years of intense study of cobalt crusts. According to Dr. Hein, with the price of cobalt decreasing and remaining that way for a protracted period of time, much interest was lost in crusts. He noted however that the latest thing to happen was the increase in the price of metals. He said that this gave incentive, not only for cobalt crusts and manganese nodules, but also for polymetallic sulphides. He said that all deep sea deposit types were going to benefit from things like the doubling and tripling of the prices of copper, nickel and platinum.

Dr. Hein informed participants that in 2003, the USGS published a paper on ferromanganese crusts as being one of the richest sources of tellurium on earth. He read a quote in an email that he had received from a company, National Renewable Energy Laboratory, which said "finding enough tellurium for cadmium tellurium is the largest barrier to the multi-terawatt use of cadmium tellurium for electricity. It is widely regarded as the lowest cost photovoltaic technology with the greatest potential." Dr. Hein said that the email went on to say that the company needed lots of tellurium.

Through the use of a slide, Dr. Hein illustrated the values of some of the metals in ferromanganese crust.

Value of Metals in 1 Metric Ton of Fe-Mn Crust from the Central-Equatorial Pacific

	Mean Price of Metal (2006 $/kg)	Mean Content in Crusts (g/ton)	Value per Metric Ton of Ore ($)
Cobalt	$32.41	6899	$223.60
Titanium	$18.03	12,035	$216.99
Cerium	$85.00	1605	$136.43
Zirconium	$22.00	618	$13.60
Nickel	$17.36	4125	$71.61
Platinum	$33,919.41	0.5	$16.96
Molybdenum	$51.47	445	$22.90
Tellurium	$100.00	60	$6.00
Copper	$5.93	896	$5.31
Tungsten	$17.40	90.5	$1.57
Total	--	--	$714.97

Dr. Hein concluded this part of his presentation informing participants that from his calculations, ferromanganese crusts in the world's oceans amounted to 6.35 million km^2.

Turning to technology, Dr. Hein informed participants that the real problem in the development of crusts deposits was with the processing of ore because the substrate rock collected tended to dilute it. He said that a mining technique that does not collect substrate rock has to be developed, or alternatively, a method to get rid of the substrate rock onboard ship cheaply. He described bubble floatation as a method for doing that. He said that even if substrate rock was collected with ore, the rock can be isolated from the ore using this method onboard the ship and fairly cheaply.

He said that there were a lot of technologies being talked about: - vibration to loosen the crusts, rip off, water jets, and in-situ leaching etc. Recalling the Authority's March 2006 workshop, he said that there was a technologist from China, Professor Li Li, who has been doing a lot of experimentation and mining process development for ferromanganese crusts.

He said that in the USA, scientists have been studying crusts since 1981/82, but there was so much more to learn. He described the first 20 years of effort in the USA as trying to understand how crusts were distributed globally; where to find them and what controls their chemistry. He said that American scientists have a pretty good idea of that now, but without detailed sampling and mapping. While there were swaths of bathymetric mapping, these had a resolution of tens of metres indicating that more technology needed to be developed.

Dr. Hein concluded his presentation by pointing out that the largest impediment to exploration was the inability to measure the thickness of crusts in real time. He suggested such technology could comprise towing an instrument behind the ship to give real time measurement of crust thickness. He further suggested the use of gamma radiation because it was the only property of ferromanganese crusts that differs significantly from the properties of the substrate rocks on which they occur. He noted that ferromanganese crusts can occur on limestone, phosphorite, lead, stone and all kinds of different substrate rocks. He further noted that any other technique would encounter an overlap between the properties of the ferromanganese crusts and the properties of the substrate rock. He said that using some kind of a multi spectral sonic technique could be developed, but that surmounting the overlapping velocities of the crusts and the substrate rock would not be technologically easy. Dr. Hein said that for exploration for ferromanganese crusts, this was the technology that needed to be developed.

Summary of the discussions

The discussions following Dr. Hein's presentation focused on the global distribution of cobalt in the world's oceans, on his proposed techniques for exploration, how the growth rates of ferromanganese crusts can be determined, whether or not there was a correlation between the type of seamount (conical or flat) and metal content, whether or not there was a correlation between biological communities and the shape and size of seamounts, and the variation in metal content in crusts on a single seamount.

Asked about the statistical distribution of the cobalt content of ferromanganese crusts, Dr. Hein replied that content is highest in the Western Equatorial Pacific Ocean decreasing to the west and east as well as to the north and south. Dr. Hein said that cobalt content was intermediate between the central Pacific and the margins of the Pacific Oceans. In the Atlantic and the Indian Oceans it is intermediate compared to the overall Pacific Ocean.

On the problem of developing mining techniques and overlap of the densities of crusts and underlying substrate, a participant asked whether the high porosity of crusts would provide a contrast to the hard substrate. Dr. Hein said that this depended on the type of crust as well as on the type of substrate rock. He pointed out that a thin crust had the upper high porosity part and not the older compact part. He further pointed out that a thicker crust usually has an upper high porosity part and a more dense lower part. Additionally, he said that the porosity of the substrate depended on the type of rock, e.g. the physical properties of fresh basalt may be significantly different from highly-altered basalt.

A participant wanted to know how growth rates of ferromanganese crusts could be determined and if crusts were growing at all times. Dr. Hein replied that in some crusts, big hiatuses can be observed giving as an example, a recently examined 70 million year old crust with 3 hiatuses, one of them a hiatus of 20 million years. After this period of time the crust started growing again. Another 70 million year old crust in the same area had no hiatuses at all. He informed participants that there were three types of hiatuses: a period of time with no growth; a period when erosion takes place and dissolution hiatuses in anoxic environments.

Another participant asked whether a direct correlation between the type of seamount – conical or flat – and metal content had been established. Dr. Hein said that all thick cobalt-rich crusts have been found on guyots, but never on conical seamounts, partly because seamounts were deeper and closer to the calcium carbonate compensation depth and partly because more gravity processes occur on the slopes of seamounts. He said that in the same area and at the same water depth, a crust is likely to be thicker on a guyot than on a conical seamount. The same participant asked if this meant that conical seamounts could be eliminated as potential sites for exploitation. Dr. Hein answered in the affirmative and referred to his next talk regarding this particular question. The participant also asked if there was a relationship between biological communities and the shape and size of seamounts. Dr. Hein said that some organisms relate to the surface structure and sediment conditions but that knowledge in this regard was very limited. Dr. Hein noted that marine life on guyots has been studied more intensively than on conical seamounts although the range of endemism and regional patterns of species distribution remain unknown.

On the question of variations in metal contents on a single seamount, Dr. Hein replied that this was a difficult question, since no seamount had been sampled in enough detail to determine the variability in its metal content. He said, however, that variations were significant, for instance cobalt content varies tremendously with water depth.

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Chapter 5: Technological Issues Associated with Commercializing Cobalt-rich Ferromanganese Crusts Deposits in the Area.

Mr. Tetsuo Yamazaki, Senior Researcher, National Institute of Advanced Industrial Science & Technology, Japan

Abstract

Both cobalt-rich ferromanganese crusts on ocean seamounts and manganese nodules on deep ocean floors have received attention as potential deep-sea mineral resources for strategic metals such as cobalt (Co), nickel (Ni), copper (Cu) and manganese (Mn), due to their vast distribution and relatively higher metal concentrations. Because similar metals are contained in the two, however, future needs may require that we select one of them.

A preliminary economic evaluation and some sensitivity analyses are conducted using special models for examining and comparing the economic potential of cobalt-rich ferromanganese crusts and manganese nodules in the Area. Though less information is available for the deposition aspects based on geotechnical properties and the mining methods of the crusts, some advantages and disadvantages in the development of crusts have been clarified from the evaluation and analyses. The results and technological issues induced from the discussions are introduced.

Technical and economic evaluation models, which are for examining and comparing the economic potential of cobalt-rich ferromanganese crusts and manganese nodules, were developed by the author [2] on the basis of previous feasibility reports for the two deep-sea mineral resources [3,4,5]. In addition to considering the geological and geophysical differences between the two deep-sea mineral resources, a mineral dressing subsystem for the crusts was installed in the model. The other subsystems and the components were assumed to be almost similar; for example, the same metallurgical processing method was selected in the two models. The production scales were equivalent, set at 2,500 t/y of cobalt metal. The production of cobalt, nickel and copper were considered in the metallurgical processing. Outlines of the models and the flowchart of mined ore are introduced in Figure 1. The locations of mining sites were assumed in the Clarion Clipperton Fracture Zone for nodule mining and a representative site to be the southeast region of the Minami-Tori-shima (Marcus) Island for crusts mining. Both are located in the international seabed area (the Area). The locations of metallurgy sites were assumed to be near Tokyo for both mining operations.

Both the preliminary economic evaluation and the sensitivity analyses were conducted and reported using the models [2, 6]. Through the evaluation and analyses, some advantages and disadvantages in the development of cobalt-rich ferromanganese crusts have been clarified. For example, as shown in Figure 2, because of the degradation with substrate bedrock recovery during the seafloor excavation, the economics of crusts mining is seriously impacted. In the figure, the vertical axis shows the internal rate of return (IRR). The increasing investment and operational costs of the mineral dressing subsystem for crusts mining are the main reasons for the diseconomy. When degradation is less, a mining model without the mineral dressing subsystem is more economic than the one with the subsystem. Summarising the results of the sensitivity analyses, the advantages and disadvantages of crusts mining and mineral dressing are presented in Figure 3 in comparison with nodule mining and in conjunction with the percentage of substrate bedrock and cobalt price.

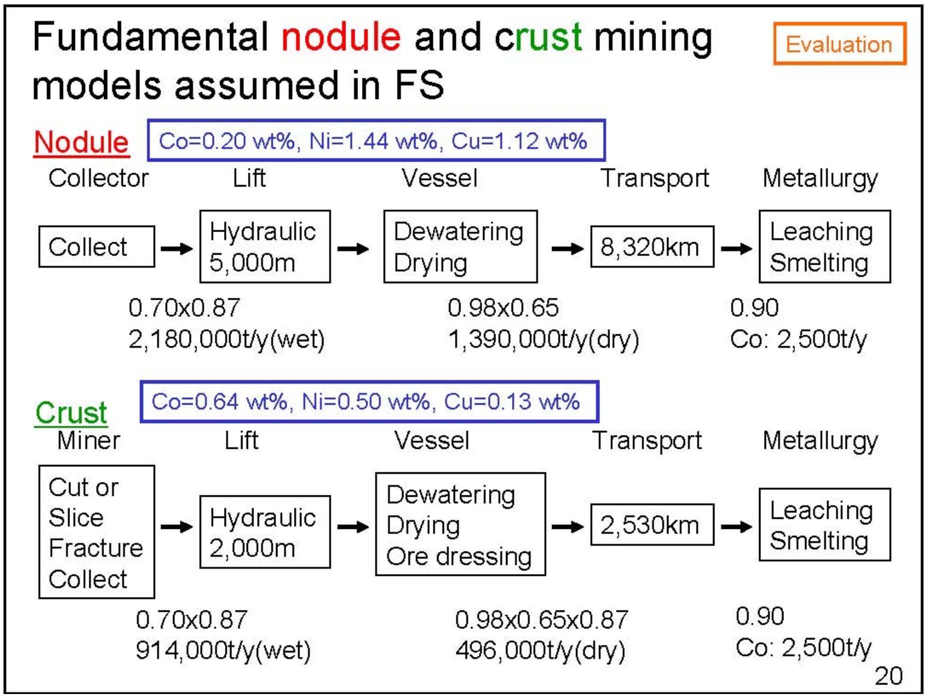

Figure 1: Outline of crusts and nodule mining models and ore flowcharts

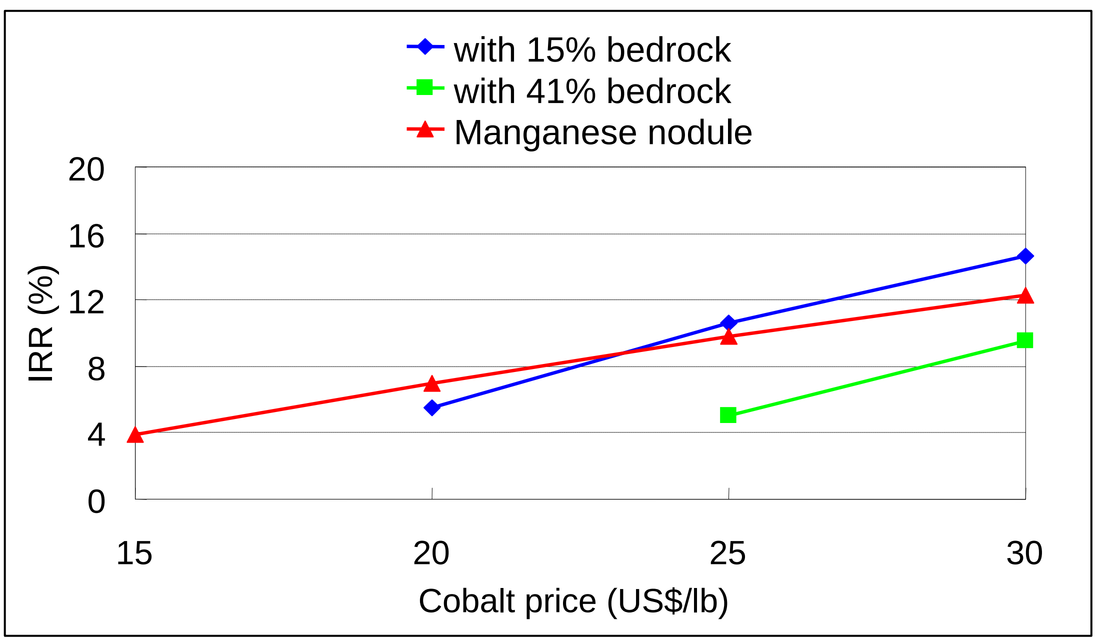

Figure 2: Effect of degradation with substrate bedrock recovery on economy in crusts mining

Though the turning margin between nodules and crusts mining is affected with cobalt price, there is very little chance for crusts mining in the Area except in the case of very low degradation with substrate bedrock. The advantage zone of mineral dressing in the figure is totally included in the one of nodules mining. Selecting flat and less microtopographic undulation sites for crusts mining is the most important requirement in order to keep degradation low. Platinum recovery from cobalt-rich ferromanganese crusts, the other metal contents in nodules and crusts, and some other factors may improve this situation. Among these possibilities, platinum recovery is possible and is not the key one. Platinum behaviour in the metallurgy must be clarified to estimate the investment and operating costs for its recovery.

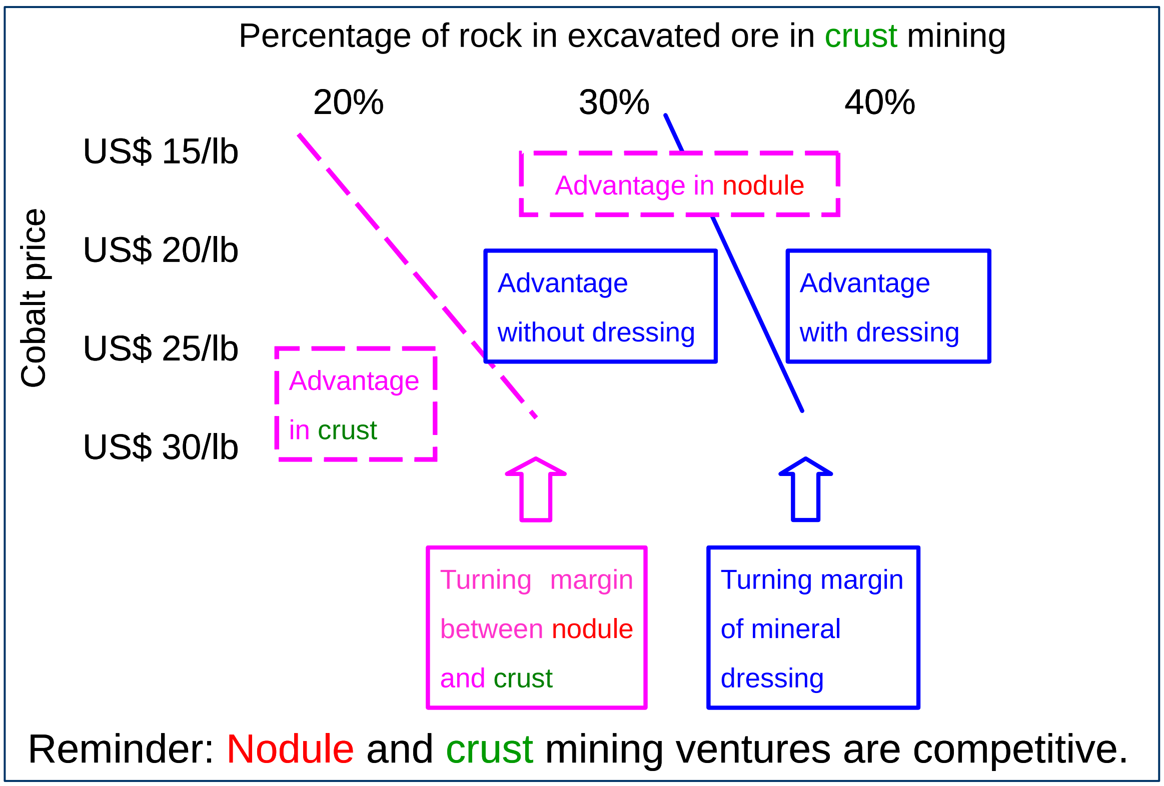

Figure 3: Advantages and disadvantages of crust mining and effect of the mineral dressing

Key words: Cobalt-rich ferromanganese crusts, Economic analysis, Manganese nodule, Microtopography, Mineral dressing, Platinum recovery, Substrate rock, Sensitivity analysis, Technological issue

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Summary of the presentation

Mr. Yamazaki said that his presentation would be a mining engineer's approach to addressing the technological issues associated with commercializing cobalt-rich ferromanganese crusts deposits in the area, and would address the economics of developing these resources. Mr. Yamazaki cited four published studies on deep seabed polymetallic nodule mining that he used in this study. These were by Texas A&M University, USA; the United States Bureau of Mines; a study by IFREMER/GEMONOD of France and the fourth by a Norwegian group, which undertook an evaluation of the Cook Islands EEZ nodules. Mr. Yamazaki noted that the metal content of polymetallic nodules and cobalt-rich crusts are significantly different, but that the metallurgical processing methods are expected to be similar since both are ferromanganese oxide ores. He also noted that mineral dressing would be necessary for cobalt-rich crusts. He further stated that the mining methods, especially seafloor excavation methods will be different, but that other parts of the mining system e.g. the ore lifting system and the mining vessel may be similar. He said that since less technical information is available on mining cobalt-rich crusts, an economic evaluation is more difficult. He said, however, that it is possible to evaluate the economics of mining cobalt-rich crusts through a comparison with polymetallic nodule mining in the Area.

Mr. Yamazaki provided participants with illustrations of the general aspects of cobalt-rich crusts distribution on seamounts and outlined the geotechnical properties of crusts, the substrates on which they grow and sediments that may cover crusts deposits. He showed a figure containing the typical distribution of crusts, substrates and sediments along the slope of a seamount.

Mr. Yamazaki said that the geotechnical properties of crusts and substrates, that is, the density, compressive strength and the tensile strength are important parameters for the separation of crusts and substrates, and are therefore crucial for the design of crusts mining systems. In this regard, he pointed out that studies show the tensile strength of crusts to be low whereas this parameter varies widely in the case of substrate rock.

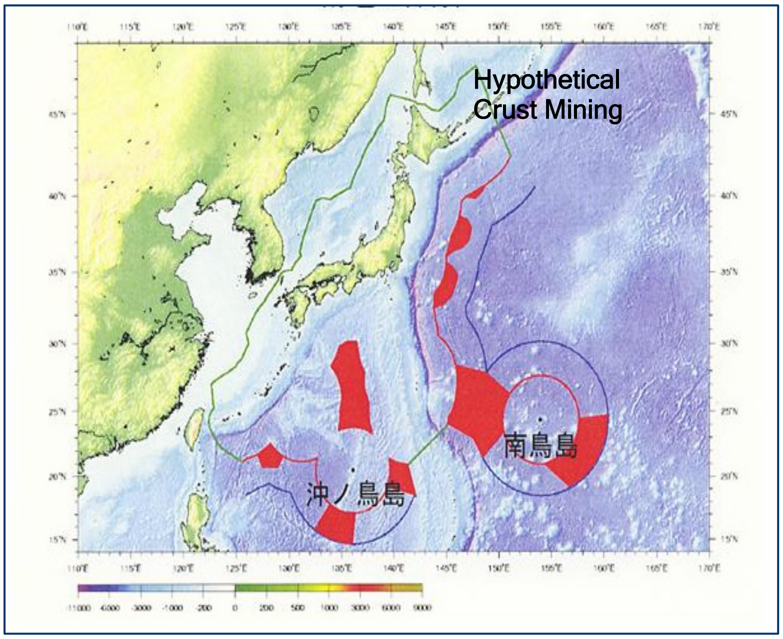
With additional slides, he showed graphs containing the frequency distribution of the density, compressive strength and tensile strength of crusts and substrates. He also illustrated the relationship between porosity and compressive strength.

With regard to seamount sediments, Mr. Yamazaki informed the workshop that other factors such as cohesion and the internal friction angle are important properties to evaluate the effort required to remove sediments on the crusts layer.

Mr. Yamazaki informed the workshop that he would present a preliminary evaluation of the economics of mining polymetallic nodules and cobalt-rich ferromanganese crusts.

Starting with polymetallic nodules, Mr. Yamazaki presented a slide indicating the location of a nodule deposit in the CCZ.

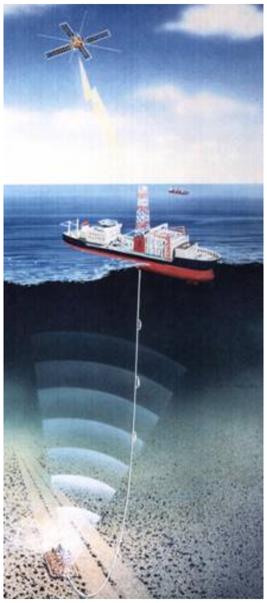
He presented a map showing the location of an assumed crusts mining site in the international seabed area, near the Marcos Islands.

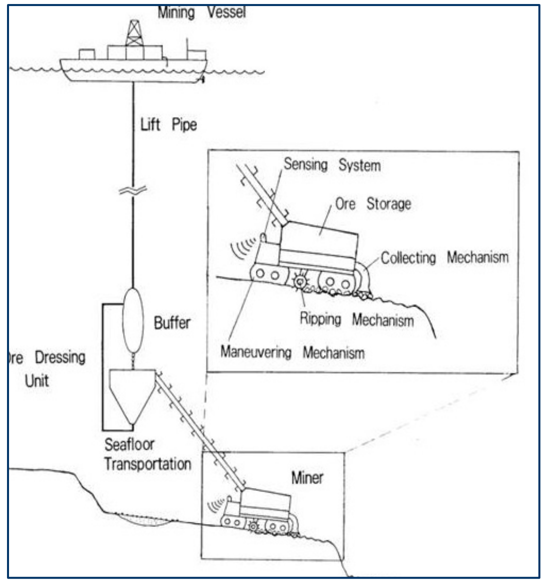


Mr. Yamazaki introduced a model for crusts mining with the following parameters:

- Seamount location: N17º, E157º
- Seamount depth: 2,000 m
- Crust abundance: 100 kg/m^2 in wet weight
- Crust thickness: 50 mm
- Metal content in crust: 0.64 % in Co, 0.50 % in Ni, 0.13 % in Cu in dry weight
- Crust density: 2.0 in wet bulk
- Crust water content: 0.35 in weight
- Substrate density: 2.5 in wet bulk
- Substrate water content: 0.1 in weight
- Substrate weight ratio in excavated wet ore: 0.194
- Content in substrate: 0.6 limestone vs. 0.4 basalt

He also utilized the images below to highlight the nodules (left) and crusts mining systems that he used in his study. He said that in the case of a crusts mining system, he assumed that a self-propelled miner would be used.





Mr. Yamazaki said that the crusts mining subsystem would comprise a seafloor collector or a miner, a pipe string with submersible hydraulic pumps and a mining vessel.

He also said that mechanical slicing and crushing, along with hydraulic pick-up devices are assumed to be functions of the miner. From the geotechnical properties of cobalt-rich crusts Mr. Yamazaki said that a mechanical excavation system is applicable. In both cases, he said that sediment separators are necessary. He said that in his model, the pipe string is composed of a steel pipe and a flexible hose.

Other components of Mr. Yamazaki's model include the depth from which crusts would be lifted to the sea surface and the transport distance to the metallurgical processing plant. He noted that both parameters would be different for polymetallic nodules and the cobalt-rich crusts ventures. In Mr. Yamazaki's model the metallurgical plant is situated near Tokyo. For metal recovery, the method he selected was metallurgical processing; including smelting and chlorine leach for 3-metal recovery (cobalt, nickel and copper).

Another important factor mentioned by Mr. Yamazaki was the production rate. Since the market size for cobalt is the smallest of the 3 targeted metals, he said that cobalt is assumed to be the limiting factor for total production. Mr. Yamazaki assumed a production limit of 2,500 tons of cobalt per year which represented approximately 10 per cent of world demand in the late 1990s.

Utilizing the table below, Mr. Yamazaki compared the capital investment and the operating costs for nodules and crusts mining operations. He said that because of its lower cobalt content the production rate for a polymetallic nodule operation is about 2 times higher than that for a crusts mining operation, resulting in higher investments for nodule mining operations.

Subsystem	Cobalt-rich crusts		Polymetallic nodules	
	Capital costs	Operating costs	Capital costs	Operating costs
Mining system	107.1	16.8	202	45.0
Ore dressing	28.1	4.3		
Transportation	48.9	10.3	142.7	27.1
Metallurgical processing	239.4	21.5	417	53.5
Sub-total	423.5 M$	52.9 M$	761.7 M$	125.6 M$
Continuing expenses	129.8		177.1	
Working capital	92.5		219.8	
Total investments	645.8 M$		1158.6 M$	

For economic evaluation, Mr. Yamazaki said that he used the average prices in the late 1990s for the three metals. He noted that cobalt is the most expensive and the most unstable metal in terms of market prices. Mr. Yamazaki said that he used cobalt as the main parameter in his economic calculations. Mr. Yamazaki presented the preliminary results of his economic evaluation of a nodules mining operation. (Case 1) and a crusts mining operation (Case 2).

Evaluation

Result of economic evaluation: Case 1

Item	Production scale: 300,000 t/y	
	Capital costs	Operating costs
Mining system	55.0	6.6
Mineral processing	19.5	2.2
Transportation	9.6	3.4
Sub-total	84.1 M$	12.2 M$
Continuing expenses	18.9	
Working capital	9.1	
Total investments	112.1 M$	

Sensitivity factor	Production scale: 300,000 t/y		
Purchased price	Payback periods (year)	NPV($)	IRR(%)
Metal sales in 75%	9.4	23M	13.2
Metal sales in 70%	10.5	13M	11.1

with economic factors in 1999

Evaluation

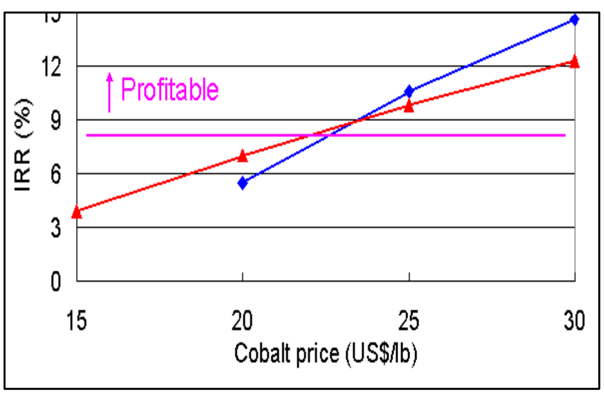
Result of economic evaluation: Case 2

Item	Production scale: 50,000 t/y	
	Capital costs	Operating Costs
Mining system Mineral processing Transportation	15.3 6.6 4.5	2.05 0.35 0.91
Sub-total	26.5 M$	3.31 M$
Continuing expenses Working capital	4.60 2.48	
Total investments	33.6 M$	

Sensitivity factor	Production scale: 50,000 t/y		
Purchased price	Payback periods (year)	NPV($)	IRR(%)
Metal sales 75% Metal sales 70%	7.3 8.0	17M 14M	20.4 18.1

with economic factors in 1999

Mr. Yamazaki said that he assumed an 8 per cent of Internal Rate of Return (IRR) as the limit for profitability. He said with a cobalt price of US$20/lb, both ventures are not profitable. He said that with a cobalt price of US$25/lb both ventures are profitable, and that with increasing cobalt prices, crusts mining becomes more profitable. The figure below represents his findings.



Mr. Yamazaki presented the results of adjustments to his model's parameters. He said that by altering the percentage of substrate rock recovered in crusts mining, profitability rises significantly. In this regard, he said that in the case where the recovered material consists of 15 per cent substrate rock, the crusts mining operation is generally more profitable than the nodules mining operation. Where the substrate rock comprises 41 per cent of the recovered material, he said that the crusts mining venture is uneconomical because of the large amount of substrate rock that needs to be handled by the ore dressing subsystem.

Mr. Yamazaki disclosed that he tried a "radical" modification to the model by assuming that no ore dressing is done at the mine site. He said that as a result, the costs for transportation and metallurgical processing increase, but capital and operating costs for ore dressing decrease. He informed participants that it turns out that in the case of a low percentage of substrate rock the Internal rate of return increases slightly.

Mr. Yamazaki computed the economic returns from nodules and crusts mining with his model using 1999 and 2004 values for metal prices, operating costs and working capital. He presented the results in the table below.

Comparison of economic factors and metal prices used in validation analyses

Evaluation

Prices of main cost elements in 1999 and 2004

Items	1999	2004	Changing ratio	Application
Heavy oil (3%C)	113 US$/kl	238 US$/kl	▲2.11	Whole system
Coal	30.0 US$/t	35.9 US$/t	▲1.20	Processing
Electricity	0.086 US$/kWh	0.11 US$/kWh	▲1.28	Whole system
Calcined lime	66.6 US$/t	85.5 US$/t	▲1.28	Processing
Material (Others)			▲avg. 1.25	Processing
Foreign exchange	1 US$= 121 Yen	1 US$= 112Yen	▼0.93	
Labor	2,350 US$/month	2,327 US$/month	▼0.99	
Interest	8%	3%	▼0.38	

Prices of metals in 1995-1999 and 2004

Metal	in 1995-1999	2004	Changing ratio
Cobalt	US$ 15/lb, US$ 20/lb, US$ 25/lb, US$ 30/lb	US$ 26.8/lb	
Nickel	US$ 3.3/lb	US$ 6.28/lb	▲1.90
Copper	US$ 1/lb	US$ 1.26/lb	▲1.26
Lead	US$ 0.45/lb	US$ 0.37/lb	▼0.82
Zinc	US$ 0.55/lb	US$ 0.47/lb	▼0.85
Gold	US$ 336.4/oz	US$ 407.5/oz	▲1.21
Silver	US$ 5.2/oz	US$ 6.76/oz	▲1.30

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He said that because of higher nickel and copper prices profitability was higher in 2004, especially in the case of nodules mining.

Case	Manganese nodules			Cobalt-rich manganese crusts (with 14.9% substrate)		
	Payback periods (year)	NPV ($)	IRR (%)	Payback periods (year)	NPV ($)	IRR (%)
Metal prices in 1995-1999 (Co: US$ 25/lb)	11.7	77M	9.8	11.1	62M	10.6
Metal prices in 2004	6.6	584 M	19.2	9.7	105 M	12.3

With regard to other model modifications that he investigated, Mr. Yamazaki listed the following:

1. Different metallurgical processing method.
2. Possibility of manganese recovery.
3. Locating the processing plant in Mexico.
4. The effect of changes in the cobalt content in crusts.
5. Preliminary calculation of the effect of recovering platinum, and
6. The effects of different production rates.

Mr. Yamazaki stressed that his economic evaluation was preliminary and said that more advanced analyses based on details such as the micro-topography within the mining sites, variations in crust thickness, and variations in crusts metal content need to be factored into the model. In this regard, Mr. Yamazaki provided the following details for inclusion in the evaluation:

1. Estimates of the metal content of excavated ore and of the economic reserves in the deposit(s) are required to select a potential mining site for crust mining;

2. Acoustic survey data for micro-topography with less than one metre resolution is essential for feasibility assessments;

3. Combined analysis of acoustic and photographic data is required to classify the micro-topographic characteristics of the sites and to analyse crust thickness; and,

4. The behaviour of platinum in metallurgical processing has to be clarified in order to estimate the effect of platinum recovery on profitability.

Mr. Yamazaki said that for micro topography surveys, deep-towed bathymetric side scan sonar is one solution. In his model, Mr Yamazaki said that a vertical resolution of 0.5 metres is assumed.

Concluding his remarks, Mr. Yamazaki stated that cobalt-rich crusts mining may be more profitable than polymetallic nodule mining and that the two resources would have a competitive relationship.

Summary of the discussions

A participant commented that in Mr. Yamazaki's presentation he addressed two sensitive factors; the price of cobalt and the substrate ratio. The participant said that assuming a lower substrate ratio and the current cobalt price of US$25/lb, one obtained a very good internal rate of return. His first question was whether in Mr. Yamazaki's opinion the current high price of cobalt was unusual and for how long this price could be sustained. The second question was the tax and royalty rates that Mr. Yamazaki used for the evaluation of economic feasibility. Mr. Yamazaki replied that since he was not an economist he could not provide a definitive response to the first question, but was of the opinion that cobalt prices would decrease in the near future. In response to the second question, he answered that in his model, the metallurgical processing plant was located in Mexico and that the applicable tax rate was the Mexican tax rate. He also said that he did not incorporate royalties into his model and suggested that this item could be included in a future study.

Regarding the mining system mentioned in Mr. Yamazaki's presentation, a participant said he understood that the system could mine both polymetallic nodules and cobalt-rich crusts. This participant asked Mr. Yamazaki if there had been an at-sea trial to mine crusts. Mr. Yamazaki replied that the nodules excavation recovery system was a towed-type collector, which was presently not applicable to crusts mining. He said that more functions would have to be added to the system to make it suitable for crusts mining. He said that these could include slicing, crushing and fracturing of crusts material, as well as a self-propelled miner.

Mr. Yamazaki was asked if he had calculated how many collectors would be required to carry out profitable mining. He replied that according to his model 1.5 million tons/year in dry weight is the lower limit for profitable mining and that in the case of a towed-type collector, one collector is sufficient to recover this amount per year. He added that the collector itself is not the restricting part of the mining system, but that powerful lifting pipes are the ruling factors in design.

A participant commented on the scale of a possible commercial operation and said that in order to increase the internal rate of return operators would tend to augment production. Mr. Yamazaki concluded his remarks by stating that the size of the cobalt market was one of the major uncertainties for both nodules and crusts mining.

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Chapter 6: Prospecting and exploration for cobalt-rich ferromanganese crusts deposits in the Area

Dr. James R. Hein, U.S. Geological Survey, Menlo Park, CA, USA

ISBA/14/C/3 Parts I and 2: Exploration and Mine Site Model Applied to Block Selection for Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides. Part I: Cobalt-Rich Ferromanganese Crusts and Part II Polymetallic Sulphides.

Introduction

During the eleventh session of the International Seabed Authority in 2005, the Council of the Authority completed a first reading 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 regulations”). At the conclusion of that first reading, the Council considered that further explanation and elaboration was required with respect to certain aspects of the draft Regulations.

With respect to the size of areas for exploration, the Council requested that further information be provided on the proposed system of allocating exploration blocks and the way in which it might operate in practice, as well as on the proposed schedule for relinquishment and its consistency with the provisions of the United Nations Convention on the Law of the Sea. The present paper provides a scientific basis for the selection and quantification of parameters that can be used to define a seamount mine site for cobalt-rich crusts.

The parameters that will ultimately be used to choose a cobalt-rich ferromanganese crust mine site are not yet known. However, reasonable assumptions can be made that will bracket the likely characteristics of a mine site (see Annex I, Table 1). From that range of possibilities, a set of conditions have been selected, which are used to illustrate the selection process of lease blocks on seamounts for the exploration phase and mining operations for cobalt-rich crusts. The analysis presented is based on present state-of-knowledge of the morphology and size of seamounts and the distribution and characteristics of cobalt-rich crusts. The illustrations are not intended to be an economic evaluation, so the crust grade (i.e., content of cobalt, nickel, copper, manganese etc.) is not considered. Only those parameters that directly apply to determining lease-block sizes and the allocation and relinquishment of blocks during the exploration phase are considered. The rationale for those determinations are also discussed. Many seamounts, with a range of appropriate ore grades, do occur within the bounds of the examples illustrated below.

The surface areas of 34 typical north-equatorial Pacific guyots (flat-topped seamounts) and conical seamounts were measured (see *Annex II, Figure 1*). Surface areas were determined using the ArcView 3-D Analyst and the amount of sediment versus hard-rock areas were calculated from side-scan sonar backscatter images. The surface areas of the 19 guyots and 15 conical seamounts vary from 4,776 to 313 square kilometres (see *Annex II, Figure 2*). The total area of the 34 seamounts is 62,250 square kilometres, covering a geographic region of 506,000 square kilometres, although all seamounts within that region were not measured. The average surface area of the 34 seamounts is 1,850 square kilometres. The amount of surface area above 2,500 metres water depth at which mining is likely to occur (see below) averages 515 square kilometres (range 0-1,850 square kilometres). Guyots are bigger than conical seamounts (*Annex II, Figure 1*) because guyots at one time grew large enough to be islands before erosion and subsidence took place. The conical seamounts never grew large enough to breach the sea surface.

Assumptions and calculations used for the model mine site

For many guyots and seamounts, the surface area that is likely to be mined is less than the area that exists above 2,500 metres water depth because of sediment cover, rough or steep topography, biological corridors set aside and other factors (see *Annex II*, *Figure 2)*.

A. Crust exposure/sediment cover

Seamounts with more than about 60 per cent sediment cover are unlikely to be considered for mining in favour of more promising seamounts, although the cut-off percentage will be determined in part by the overall size of the seamount. The following calculations are based on the range of 5 to 60 per cent sediment cover and use 60 per cent sediment cover as a worst-case scenario. A reduction of seamount surface area above 2,500 metres by 60 per cent leaves a remaining area of 204 square kilometres (485 square kilometres for 5 per cent sediment cover) for the average seamount that could potentially be mined, and an area of about 528 square kilometres (1,254 square kilometres for 5 per cent sediment cover) of the largest seamount measured for the present analysis that could potentially be mined (see *Annex II, Figure 2*).

B. Area loss due to impediments to mining

The area not lost to sediment cover will be further reduced because of prohibitive small-scale topography, unmined biological corridors and other impediments to mining; a further 70 per cent reduction to the non-sediment-covered area is considered a worst-case scenario. Consequently, for the largest seamount measured, a worst-case scenario would yield as little as 158 square kilometres (376 square kilometres for 5 per cent sediment cover) for mining. For the average seamount, as little as 61 square kilometres (146 square kilometres for 5 per cent sediment cover) might be available for mining.

C. Annual production

The annual tonnage required to support a viable mining operation is not known and will depend in part on the global market for metals at the time of mine development. Estimates for annual tonnage production have varied widely and in many cases are not useful because it was not specified whether dry weight or wet weight was being considered. The most common suggestions for production range from about 0.70 to 2 million wet tonnes per year. The basis used for the model mine site is 1 million wet tonnes per year and a wet bulk density for crusts of 1.95 grams per cubic centimetre (see *Annex I, Table 2*).

D. Crust thickness and square-metre tonnage

Considered as a worst-case scenario is a mean crust thickness of 2 centimetres (39 kilograms wet weight of crust per square metre of seabed) and 2 million wet tonnes per year production, which would require the mining of 1,026 square kilometres of seabed to satisfy a 20-year mining operation (513 square kilometres for 20 years of 1 million wet tonnes annual production; see *Annex I, Tables 1 and 2*).

Used as a best-case scenario is a mean crust thickness of 6 centimetres (117 kilograms wet weight per square metre) and 1 million wet tonnes per year production, which would require the mining of 171 square kilometres of seabed during 20 years of operation (342 square kilometres for 2 million wet tonnes annual production; during 20 years of operation (*Annex I, Tables 1 and 2*). Scientific exploration has shown that there exist tens of square-metre areas on seamounts with mean crust thicknesses of around 14 centimetres, but it is not known how extensive those areas might be. A mean crust thickness of 14 centimetres would yield an incredible 273 kilograms wet weight of cobalt-rich crusts per square metre of seabed.

E. Number of seamounts

From the data on seamount sizes and the areas that will likely be available for mining (see *Annex II, Figure 2*), it can be concluded that about 1.1 to 2.6 large guyots would be needed for the model 20-year mining operation, or about 2.8 to 6.7 average-size seamounts. Larger seamounts exist than the largest one measured for the present statistical analysis and, under favourable conditions; a single seamount could support a 20-year mining operation (see the example below). In addition, seamounts and guyots do exist that have little sediment cover, relatively subdued topography and an average crust thickness of more than 2.5 centimetres. These are the seamounts that are likely to be mined.

Selection of lease-block size and exploration area

The block size best suited for exploration and that is best suited to define a mine site differ. The choice of a lease-block size to define a mine site is somewhat arbitrary, although the size should be small enough so that areas with continuous coverage by crusts can be enclosed within a single block. Based on what little is known about the distribution of crusts on guyot summits, a block size of about 20 square kilometres (4.47 kilometres on a side, or 4x5 kilometres) is a reasonable size that in aggregate can successfully define a mine site. It is likely that those blocks will be strung together in a pattern that follows summit terrace, platform and saddle topography. About 25 such blocks strung together or clustered would comprise the model 20-year mine site consisting of about 500 square kilometres, all 25 blocks of which may be on the summit of one seamount, or perhaps split between two or more seamounts (see Annex II, Figs. 3-6). The 20 square kilometre block size also corresponds approximately to the area that will be mined annually for the model mining operation. Based on the range of seamount parameters discussed above (see also Annex I, Tables 1 and 2), block sizes of 10 to 40 square kilometres (3.16 to 6.32 kilometres on a side) would be considered reasonable for defining a mine site.

The choice of a lease-block size for exploration is also somewhat arbitrary, although it should be large enough that a limited number of seamounts would be included in a single licence. A reasonable block size would be 100 square kilometres, or five times the block size used to define a mine site. This 100 square about five times the area needed for a 20-year mine site. Using that number, the area of exploration would be 2,500 square kilometres for our model crust mine site (*Annex I, Table 2*). Thus, for the model mine site about twenty-five 100 square kilometre exploration blocks would be allocated.

It may be considered that exploration leases would cover most of the summit area of guyots above 2,500 metres water depth and that blocks would be relinquished as unfavourable areas are identified along a given summit. In reality, the interested parties will likely have a good idea, prior to applying for exploration licences, where the most promising crust blocks are located on a seamount and may request blocks on numerous seamounts in a region of previously defined promise. If that is not a desirable outcome, the dual lease-block size proposed in the present paper is a favourable compromise. Twenty square kilometre sub-blocks should be the size used for relinquishing territory and ultimately in defining the final mine site.

In summary, for the model mining operation, about twenty-five 100 square kilometre blocks would be leased for exploration, thus providing 2,500 square kilometres for each initial exploration licence. Within designated periods of time, groups of 20 square kilometre blocks would be relinquished until the 25 blocks of 20 square kilometres remain that will define the final 500 square kilometre 20-year mine site used as the example.

Model mine sites

Two exploration/mine-site scenarios are presented. The first includes a very large seamount with little or no sediment cover above 2,500 metres water depth (*Annex II, Figures 3 and 4*). Seamount A was not included in the statistical analysis of surface areas for the 34 seamounts discussed above; its surface area was measured subsequently, specifically for the present mining and exploration example. Seamount A has a total surface area of 9,309 square kilometres, with 2,939 square kilometres above 2,500 metres water depth. That is enough area to accommodate a single exploration licence of 2,500 square kilometres for the mine site parameters listed in *Annex I, Tables 1 and 2*. *Figure 4* in *Annex II* shows twenty-five 100 square kilometre blocks which were leased for exploration, each composed of five 20 square kilometre sub-blocks. Some of that exploration territory would be relinquished during two or more stages, ending up with twenty-five 20 square kilometre blocks that would define the final 500 square kilometre mine site (indicated by black dots).

The second example splits the exploration area between two nearby seamounts (Annex II, Figs. 3, 5 and 6, seamounts B and C). In this example, the twenty-five 100 square kilometre exploration blocks are not always contiguous. The final choice of twenty-five 20 square kilometre blocks for mining operations is also not always contiguous, but do occur in clusters (indicated by black dots).

Rationale for seamount selection parameters

The characteristics of seamounts and crusts that are most conducive to mining can be broadly defined as follows:

(a) Mining operations will take place around the summit region of guyots on flat or shallowly inclined surfaces, such as summit terraces, platforms and saddles, which may have either relatively smooth or rough small-scale topography. These are the areas in which there are the thickest and most cobalt-rich crusts. In contrast, conical seamounts are smaller in area overall and, most importantly, have much smaller areas above 2,500 metres water depth. Conical seamounts also have much more rugged summit topography than guyots. Much thinner crusts occur on the steep flanks of both guyots and conical seamounts. The flanks of atolls and islands will not be considered for mining because crusts are generally very thin on those edifices;

(b) The summit of the guyots that are most likely to be leased will not be deeper than about 2,200 metres and the terraces no deeper than about 2,500 metres. The 2,500 metre cut-off depth is important for several reasons. Guyot slopes are more rugged at depths greater than 2,500 metres, crusts are generally thinner, and content of cobalt, nickel and other metals is generally lower. There are also technological reasons for mining at water depths as shallow as possible. Other cut-off water depths have been proposed in the literature, the most common being 2,400 metres. That is a valid depth to use, but would eliminate some areas of potentially thick crusts on seamounts. Another cut-off water depth that has been cited is 1,500 metres. Since the flanks of atolls and islands will not be mined, this leaves only a few very large seamounts with enough surface area to be considered for mining. Of the 34 typical seamount surface areas measured for the present analysis, only one has a summit area greater than 400 square kilometres (487 square kilometres) above 1,500 metres water depth (see below). In contrast, 15 of the 19 guyots have summit areas greater than 400 square kilometres above 2,500 metres water depth; only 1 of the 15 conical seamounts has a summit area of that magnitude. If 1,500 metres is used as the cut-off water depth, then a large number of seamounts would have to be mined to support a single 20-year mining operation. In general, the technological requirements needed to operate at 1,500 metres will not be much different from those needed to operate at 2,500 metres;

(c) Seamounts will be chosen that have little or no sediment on the summit region, which implies strong and persistent bottom currents. Sediment cover on the summits of guyots ranges from nearly completely sediment covered to nearly sediment free. Seamounts with more than 60 per cent sediment cover will likely be passed over in favour of guyots with more promising crust distributions. However, this cut-off area will depend in part on the overall size of the seamount, with a greater tolerance for more sediment cover on the largest seamounts;

(d) The summit region above 2,500 metres water depth will be large, at more than 400 square kilometres. This estimate is based on the size of equatorial Pacific guyot summits shallower than 2,500 metres water depth and the range of percentages of the summit area that is likely to be available for mining. This cut-off area yields the fewest number of seamounts that would be needed to support a 20-year mining operation. The mining of many seamounts for a single 20-year operation will likely be technologically and economically feasible, but may be harder to justify from an environmental point of view;

(e) The guyots will be Cretaceous in age because younger volcanic edifices will not have had sufficient time to accrete thick crusts. These older seamounts are the only ones that form large guyots with extensive summit areas that have remained stable enough (from gravity processes) to support crust growth for tens of millions of years;

(f) Areas with clusters of large guyots will be favoured because more than one guyot might be required to fulfil the tonnage requirements for a 20-year mine site;

(g) The thoroughness with which the mining operations recover the available crust deposits will depend on the extraction technique used, which is presently unknown. Therefore the range listed in Table 1 of Annex I is only an estimate. If recovery efficiency becomes an important issue, it is likely that areas with thicker crusts will be chosen to make up for inefficiencies in the collection process. For example, an area with a mean crust thickness of 2 centimetres with a 60 per cent recovery efficiency would yield a recovery of only 1.2 centimetres of crust. It is likely that such a deficiency would be ameliorated by mining thicker crust deposits with 3 to 4 centimetre mean thickness, thus yielding the desired tonnage per square metre of seabed. Recovery efficiency of 80 per cent is considered in the model mine site;

(h) Guyots with thick crusts will be chosen. The detailed distribution of crust thicknesses is not known for any seamount, or known for broad areas of a single seamount. Thicknesses vary from less than 1 to more than 20 centimetres. Sites with crusts less than 2 centimetres thick will not be considered for mining and it is likely that large areas will be found with mean crust thicknesses in the range of 2 to 6 centimetres (see *Annex I, Table 1*). The cut-off thickness will depend on the method ultimately used for mining crusts, which is yet to be established. A mean crust thickness of 2.5 centimetres is used for the model mine site (*Annex I, Tables 1 and 2*);

(i) Summit areas with high grades (of cobalt, nickel, copper, manganese, platinum etc.) will be chosen.

These seamount and cobalt-rich crust characteristics are found mostly in the central Pacific region, especially the central and western parts of the northern equatorial Pacific. In that region, a great many seamounts occur within the Area and promising locations for potential mining occur within the mid-Pacific Mountains, such as the region between Wake and Minami Torishima (Marcus) Islands, the Magellan Seamounts, seamounts between the exclusive economic zones of Johnston Island and the Marshall Islands, and Johnston Island and Howland and Baker Islands.

Suggested revisions to the draft Regulations

The regulations as currently drafted (ISBA/10/C/WP.1/Rev.1) require the contractor to nominate blocks 100 square kilometres in size (in squares of 10 kilometres x 10 kilometres). One hundred such blocks may be selected for exploration (giving a total exploration area of 10,000 square kilometres prior to relinquishment). However, the blocks must be contiguous. The contractor must relinquish 75 of the original 100 blocks, giving a final mine site of 2,500 square kilometres.

22. The arguments set out in the present paper suggest that in the case of cobalt-rich crusts, providing the contractor can define precisely the areas of interest, only 500 square kilometres would be needed to sustain a mine site. Such precision can be obtained by reducing the basic block size from 100 square kilometres to 20 square kilometres. Blocks should be organized according to a grid system at fine scale, but could be either square or rectangular. The applicant should also be allowed to group blocks into non-contiguous clusters in order to take advantage of the geomorphology of seamount groups. The relinquishment schedule would remain the same.

23. These revisions are reflected in the draft clauses presented in Annex III to the present paper.

Annex I

TABLE 1: MINE SITE PARAMETERS

Parameter	*Range*	*Model site*
Seamount area (km^2)[a]	>400	>600
Seamount slope (º)	0-25	0-5
Water depth (m)	<2 500	<2 500
Mean crust thickness (cm)	2-6	2.5
Crust exposure (%)	40-95	70
Crust recovery (%)	70-90	82
Annual production (tonnes)[b]	1.0-2.0	1.0
Area mined in 20 years (km^2)	171-1 026	500
Mine site block size (km^2)[c]	10-40	20
Exploration block size (km^2)[c]	100-200	100

[a] Above 2,500 metres water depth.
[b] Millions of wet metric tonnes, based on a density of 1.95 g/cm^3.
[c] Suggested possible range of block sizes for leasing.

TABLE 2: AREA OF SEABED MINED BASED ON ANNUAL PRODUCTION AND MEAN CRUST THICKNESS (WET BULK DENSITY OF 1.95 G/CM^3)

	Worst case	*Best case*	*Model site*
Mean crust thickness (cm)	2.0	6.0	2.5
Wet tonnage (kg/m^2)	39	117	48.75
Annual production (tonnes)[a]	2 000 000	1 000 000	1 000 000
Area mined per year (km^2)	51.3	8.55	20.5
Recovery efficiency (%)	70	90	82
Area mined per year (km^2)[b]	73.26	9.50	25.0
Area mined in 20 years (km^2)	1 465	190	500
Area for exploration (km^2)[c]	7 326	950	2 500

[a] Wet metric tonnes based on density of 1.95 g/cm^3.
[b] Calculated using the recovery efficiency and the tonnage per unit area.
[c] Arbitrarily set at five times the area mined during 20-year operation.

<u>Annex II</u>

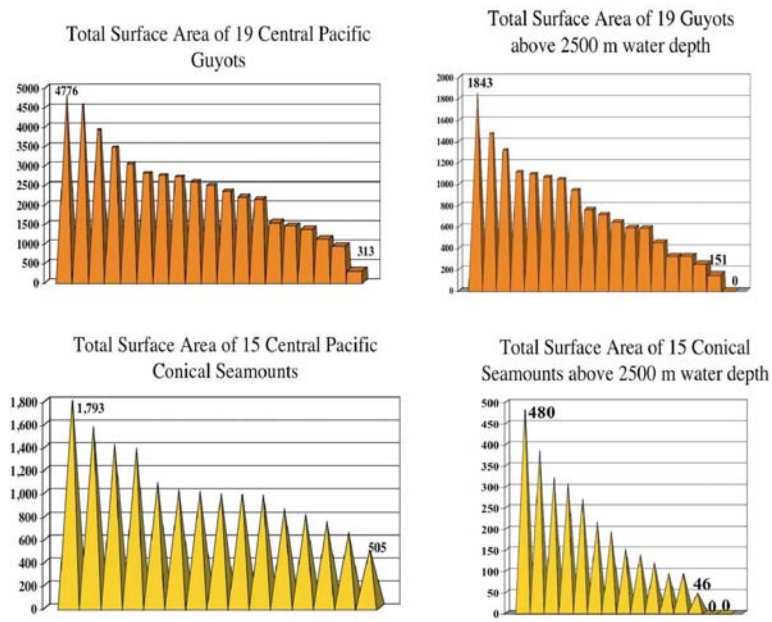


Figure 1. Surface area of 34 central Pacific seamounts in square kilometres.

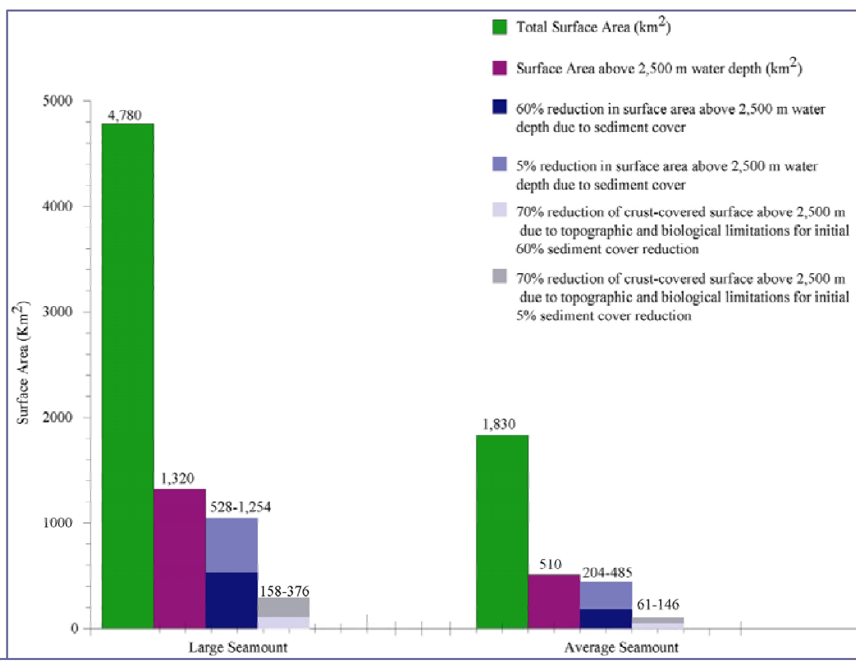


Figure 2 Surface area available for potential mine sites considering worst-case (60% sediment cover) and best-case (5% sediment cover) scenarios.

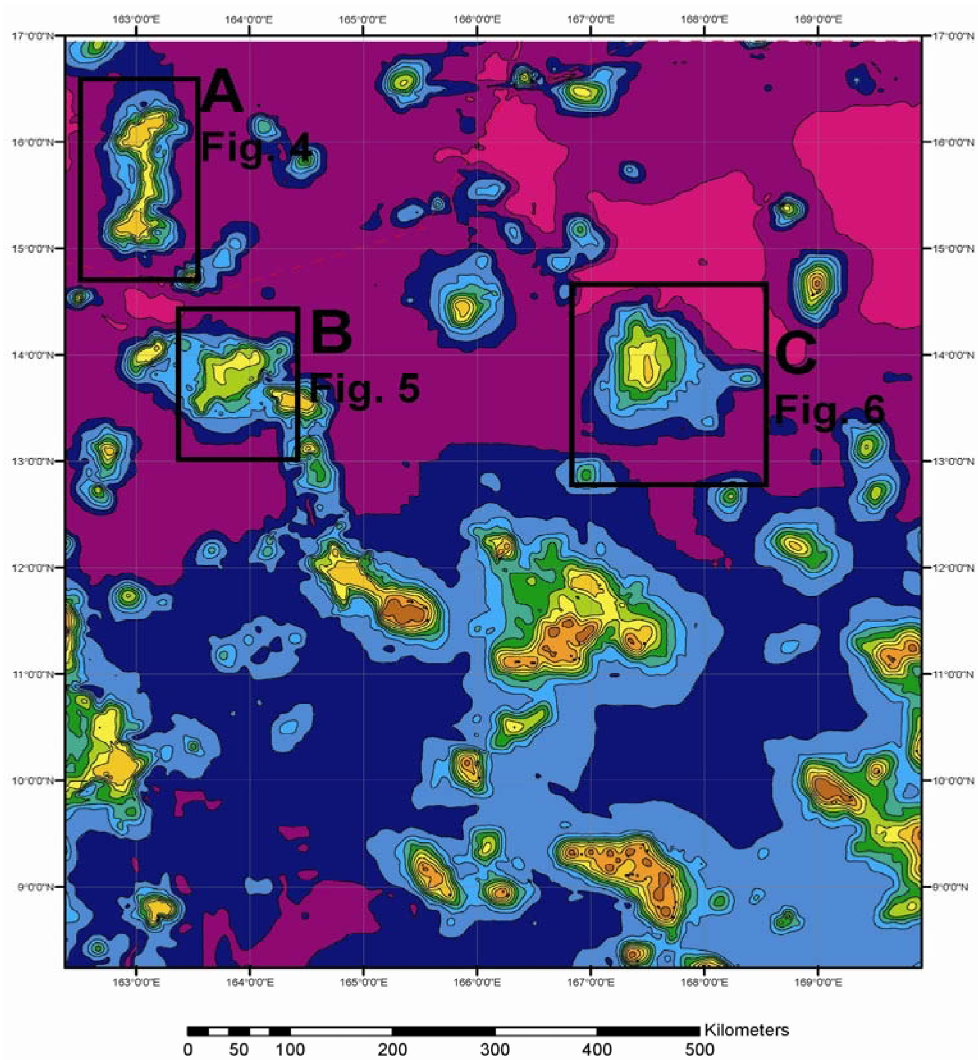
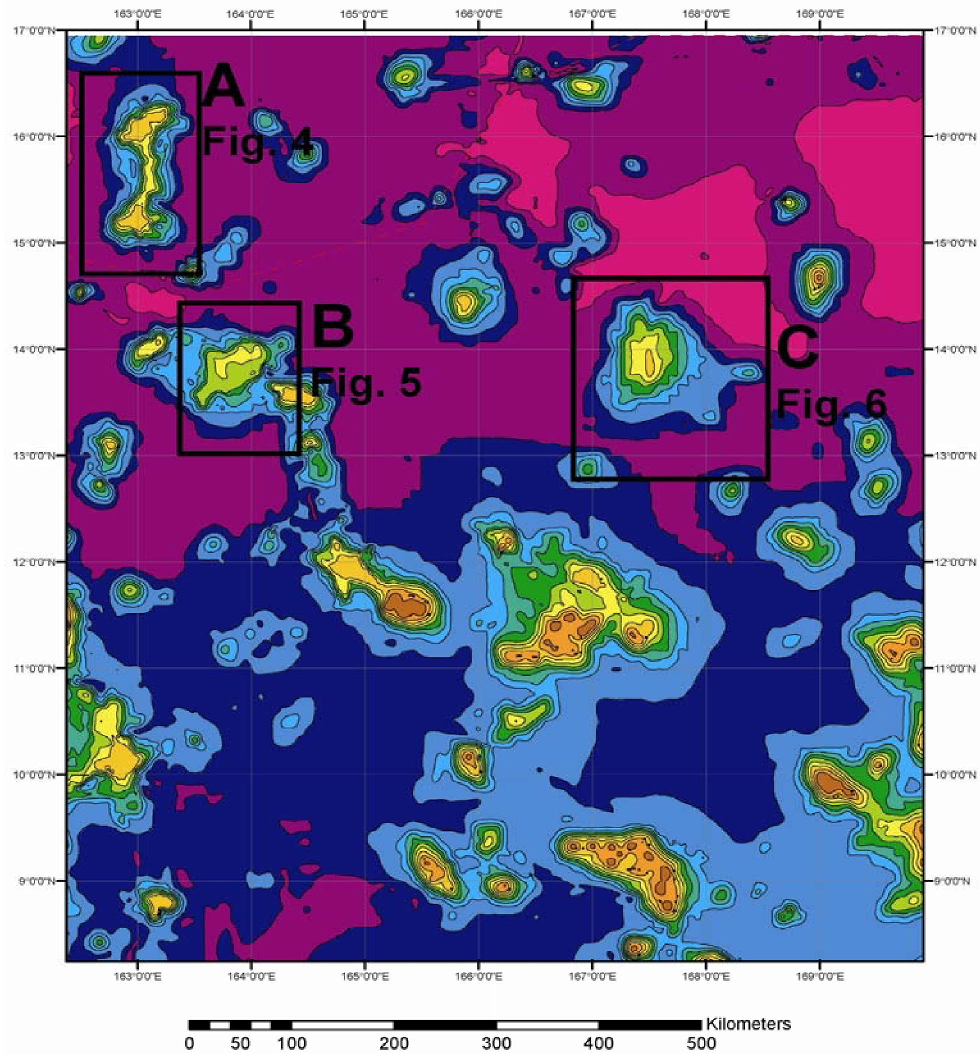


Figure 3. Seamounts A, B, and C are used for example exploration/mine site models (see Figs. 4-6). The faint dashed red line marks boundary between the Marshall Island EEZ to the south and international waters to the north, north-west Pacific.



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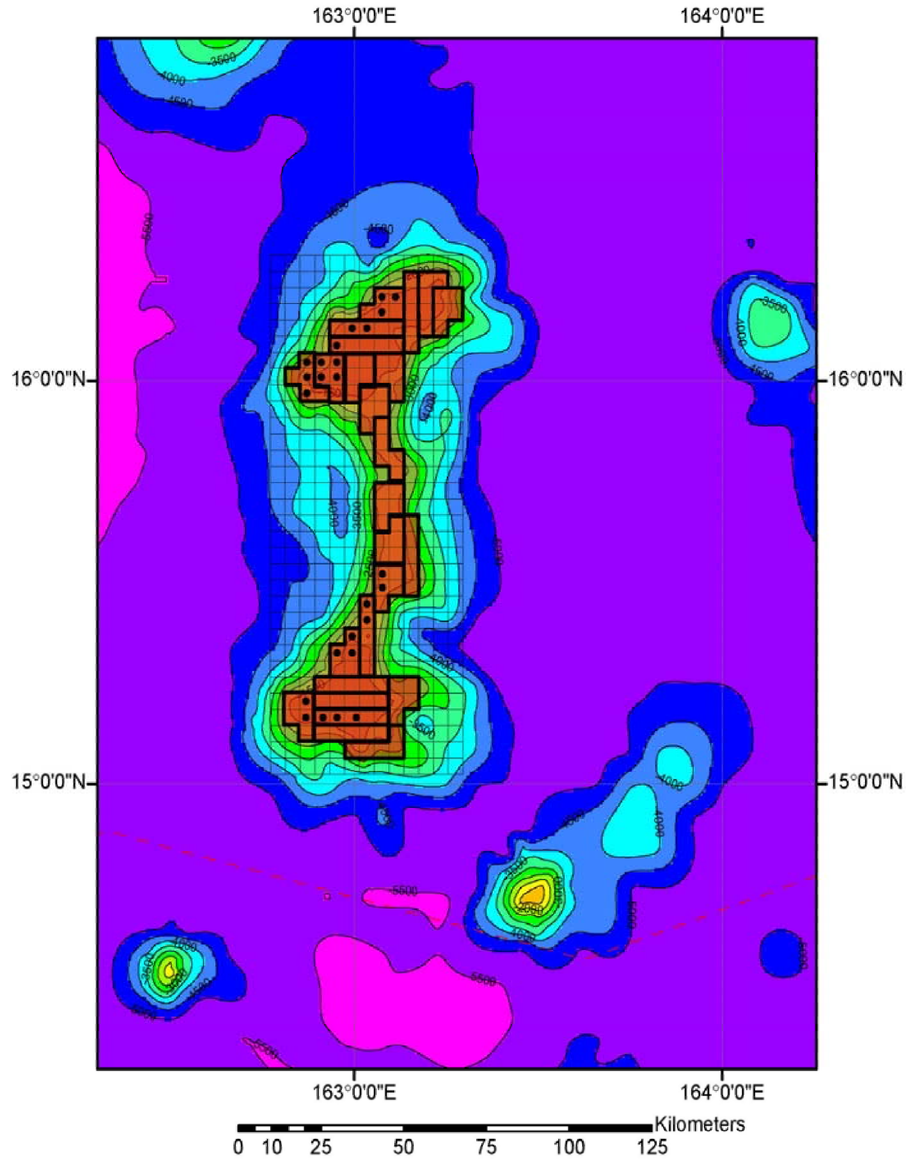


Figure 4. Exploration/mine-site scenario 1, single seamount: Seamount A with 20 km^2 grid; twenty-five 100 km^2 contiguous blocks define the exploration area (bold grid lines), whereas one-hundred 20 km^2 sub-blocks are relinquished during the exploration phase. The twenty-five 20 km^2 blocks chosen for the final mine site are indicated by black dots.

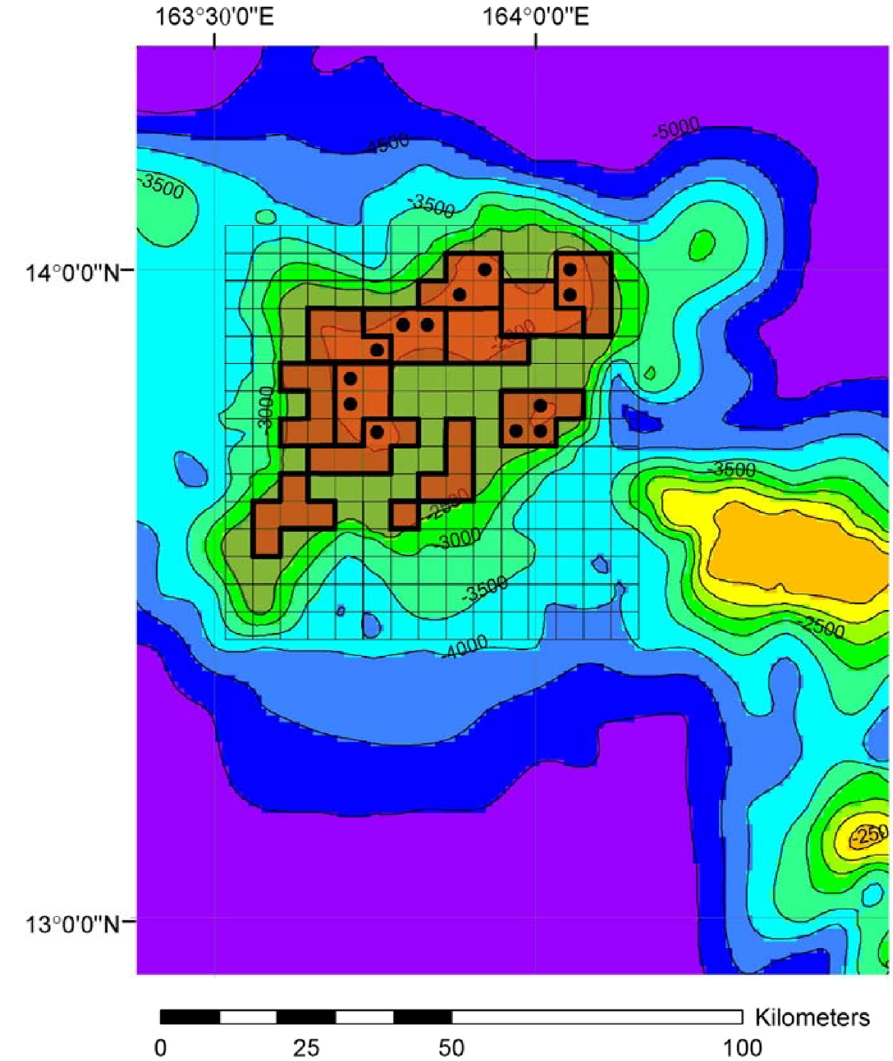


Figure 5. Exploration/mine-site scenario 2, multiple seamounts, first seamount: Seamount B with 20 km^2 grid; twelve 100 km^2 contiguous and non-contiguous blocks define half of the exploration area (bold grid lines), whereas 20 km^2 sub-blocks are relinquished during the exploration phase. The thirteen 20 km^2 blocks chosen for half of the final mine site are indicated by black dots.

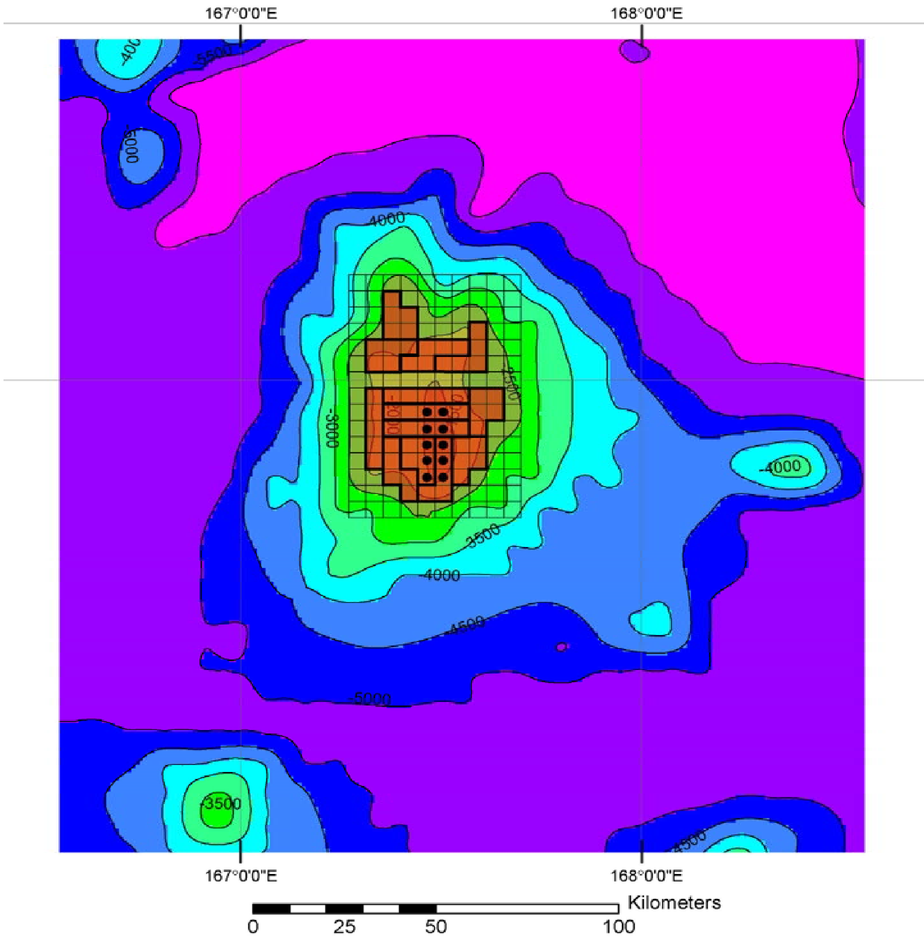


Figure 6. Exploration/mine-site scenario 2, multiple seamounts, second seamount: Seamount B with 20 km^2 grid; thirteen 100 km^2 contiguous and non-contiguous blocks define part of the exploration area (bold grid lines), whereas 20 km^2 sub-blocks are relinquished during the exploration phase. The twelve 20 km^2 blocks chosen for about half of the final mine site are indicated by black dots.

Annex III

Suggested revisions to the draft Regulations

Definition

A block is one or more cells of a grid as provided by the Authority, which may be square or rectangular in shape, no greater than 20 square kilometres.

Regulation 12
Total area covered by the application (cobalt-rich crusts)

1. The area covered by each application for approval of a plan of work for exploration for cobalt-rich crusts shall comprise not more than 100 blocks which shall be arranged by the applicant in clusters, as set out in paragraph 2 below.

2. Five contiguous blocks form a cluster of blocks. Two blocks that touch at any point shall be considered to be contiguous. Clusters of blocks need not be contiguous but shall be proximate and located within the same geographical area.

3. Notwithstanding the provisions in paragraph 1 above, where a contractor has elected to contribute a reserved area to carry out activities pursuant to article 9 of annex III to the Convention, in accordance with regulation 17, the total area covered by an application shall not exceed 200 blocks.

Regulation 27
Size of area and relinquishment

1. The contractor shall relinquish the blocks allocated to it in accordance with paragraphs 2, 3 and 4 of the present regulation.

2. By the end of the fifth year from the date of the contract, the contractor shall have relinquished: (a) at least 50 per cent of the number of blocks allocated to it; or (b) if 50 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

3. By the end of the tenth year from the date of the contract, the contractor shall have relinquished: (a) at least 75 per cent of the number of blocks allocated to it; or (b) if 75 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

4. At the end of the fifteenth year from the date of the contract, or when the contractor applies for exploitation rights, whichever is the earlier, the contractor shall nominate up to 25 blocks from the remaining number of blocks allocated to it, which shall be retained by the contractor.

5. Relinquished blocks shall revert to the Area.

Summary of the presentation

Dr. Hein of the United States Geological Survey (USGS) assisted the Secretariat in the preparation of document ISBA/12/C/3 (Part I) on Exploration and mine site model applied to block selection for cobalt-rich ferromanganese crusts and polymetallic sulphides, in partial response to the request made by the Council at the eleventh session of the Authority. The purpose of his presentation at the workshop was to provide participants with the scientific rationale for the proposal on block size and sizes for areas for exploration and mining of ferromanganese crusts on seamounts in the Area.

In his opening remarks, Dr. Hein stated that his presentation would neither include an economic evaluation of cobalt-rich ferromanganese crusts deposits nor would it address issues of their metal content, resources and reserves. Dr. Hein said that crusts bearing areas with the appropriate content of cobalt, nickel and copper can be found in most parts of the Central Equatorial Pacific Ocean. He said that his presentation would focus on the geologic features of seamounts, their morphology, the sizes of seamounts, the distribution of ferromanganese crusts on seamounts and how this information can be applied to select the size of lease-blocks for both exploration and a final mine site. Dr. Hein stated that the lease-block size on the one hand should not be so wide that it contains large unwanted territories. On the other hand, he said that the grid size should not be too small, so that an applicant could choose only the best available sites ("cherry picking"). He also said that the definition of block size should be based on the best available scientific knowledge.

According to Dr. Hein, at the present time, information on the size of seamounts in the Area was rather limited. He said that a number of seamounts have been measured to ascertain their sizes. In this regard, he said that information on the size of seamounts can only be obtained on the basis of precise bathymetric data and through the use of appropriate GIS techniques. He said that measurements were made for a number of average-size seamounts.

Dr. Hein said that mining companies would probably select areas where crusts were the thickest, the richest in terms of metal content, and the most continuously distributed. He noted however, that the parameters that will be used to define a commercial mine site were not known and similarly that the most favourable areas were probably not yet known, either. He said that random sampling of seamounts during the past 30 years has resulted in discoveries of areas that contain extremely thick ferromanganese crusts. Dr. Hein stated that it was however still unknown what minimum crust thickness and metal grades are required for commercially viable mining. Based on the present knowledge, Dr. Hein said that he had assumed a set of conditions to propose a model mine site using data obtained from the Central Equatorial Pacific Ocean.

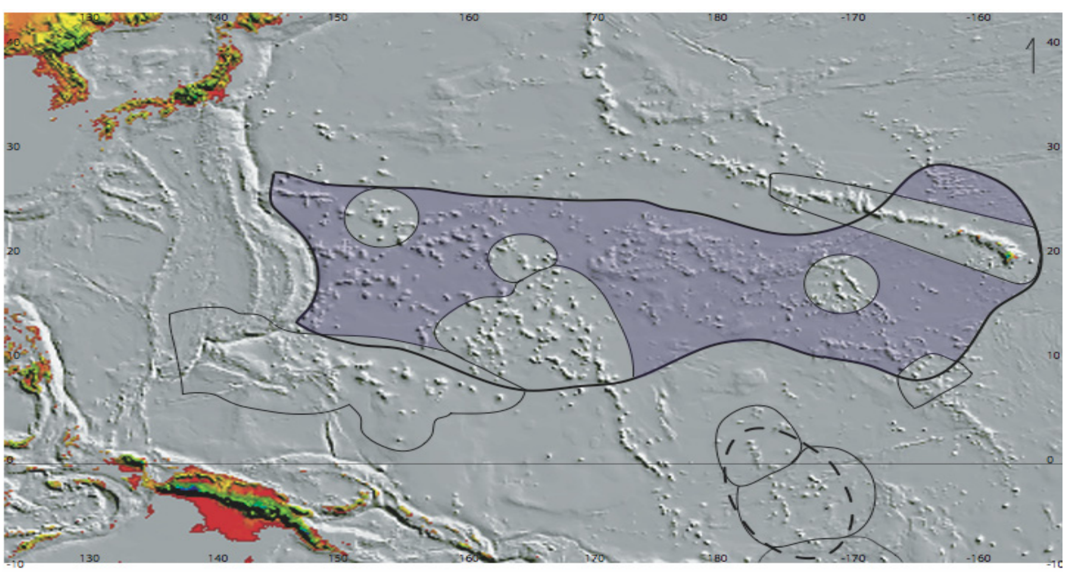
Dr. Hein stated that from the work that had been done so far, it was clear that the best prospects for mining were the summits of flat-topped guyot-type seamounts. Dr. Hein disclosed that this hypothesis was confirmed during his last cruise on a Korean vessel, when, thick ferromanganese crusts had been found in these areas. Dr Hein said that mining operations could take place on the summit regions of guyots on flat or shallowly inclined surfaces. He said that summit platforms, terraces, and saddles of guyots were the areas with the thickest and richest cobalt-rich crusts deposits. He also said that thinner crusts also occurred on steep slopes. Dr. Hein informed participants that the summits of conical seamounts were too small and too rugged for mining. With regard to the depth range, crusts amenable to mining were found. Dr. Hein stated that these summit areas were not much deeper than about 2200 metres, with terraces that were no deeper than about 2500 metres. He said that crusts tend to be thinner below 2500 metres and that their slopes were more rugged below 2500 metres. In addition, Dr. Hein said that the observed contents of cobalt, nickel and copper in crusts are less below the 2500 metres level. He emphasised that the areas likely to be selected for mining would be those where, because of persistent bottom currents, little or no sediment occur.

Based the analyses that has been carried out, Dr. Hein said that the size of the upper platform of seamount summit should be at least 400 square kilometres to allow commercially viable mining. He said that in his opinion the submarine flanks of islands and atolls would also not be considered for mining, because ferromanganese crusts found here were usually relatively thin. In addition, Dr. Hein said that large amounts of debris usually shed down the slopes, continually breaking the crusts and destroying them. Another favourable condition for the selection of an exploration area or mine site was the existence of clusters of large seamounts, because probably more than one seamount may be needed to support a mine site. He noted that there were large areas in the Equatorial Pacific Ocean where clusters of large flat top guyot-type seamounts occur in close proximity. He described this region as suitable for exploration.

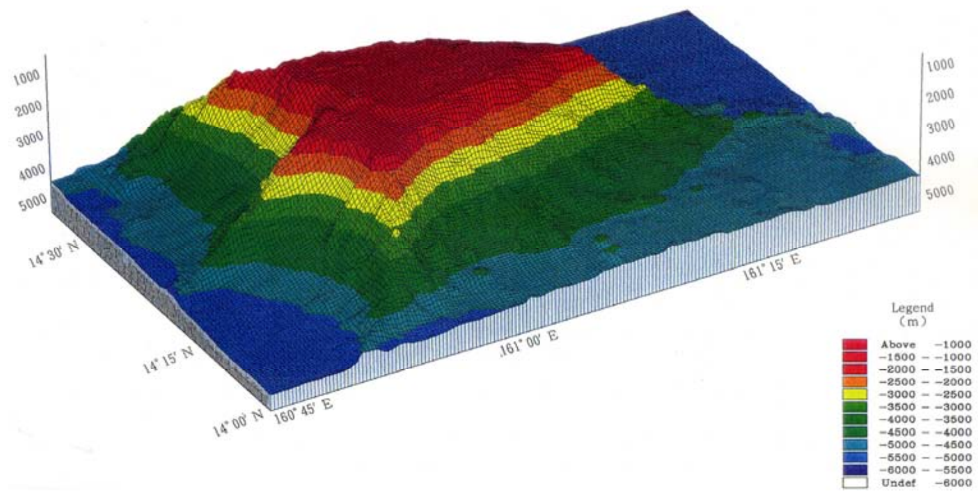
Dr. Hein said that seamounts feasible for mining were relatively old and generally of cretaceous age, because the crusts were thicker and the slope stability usually greater. He said that younger seamounts tended to have more gravity motion on the slopes resulting in higher amounts of debris. In this regard he noted that seamounts in the Atlantic and Indian Oceans were relatively young as compared to the ones in the Equatorial Pacific Ocean.

With regard to the metal content of crusts, Dr. Hein said that almost anywhere in the Equatorial Pacific Ocean, the relevant metal grades were appropriate for mining. He said that lower average regional metal grades were observed in the Atlantic Ocean and in the Indian Ocean. He said that considering all these criteria together the Central Equatorial Pacific Ocean, the North Equatorial Pacific Ocean was the area that best fit all the required conditions.

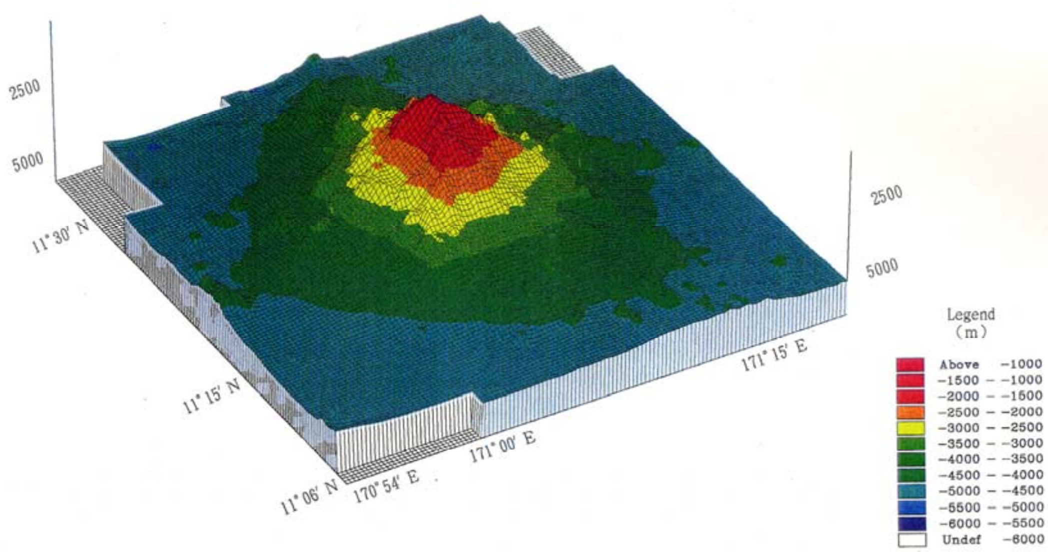
Dr. Hein described the shaded area in the North Equatorial Pacific Ocean depicted in the map below, as the region that was most favourable for cobalt-rich crusts mining. He said that the light grey areas were all in the exclusive economic zones of various countries. The darker colour (pale purple) represented the Area, which constituted about 60 per cent of the area of primary interest and which contained large numbers of seamounts.



Dr. Hein said that the USGS had calculated and mapped the surface area of 34 average seamounts in the Equatorial Pacific Ocean. He said that for the calculation of the surface areas, the GIS software tool ArcMap 3-D analyst was used. In addition, he said that the sediment-hard-rock ratio was calculated from side-scan sonar back-scatter images. Using the 3D images shown below, Dr. Hein illustrated a typical guyot that was 56 km long, with terraces and a large area above 2,500 m depth (shown in orange and red colours).



He also illustrated a typical conical seamount as shown in the next figure, whose surface area is much larger.



Dr. Hein said that from the database of 19 guyot-type seamounts, the one with the largest surface area was determined to be about 5000 square kilometres, with the smallest surface area measured as 313 square kilometres. For 15 measured conical seamounts Dr. Hein said that the range of areas was between 1800 square kilometres and 500 square kilometres. More important than the total surface area was the area above the 2500 meter water depth. For guyots, he said that this value ranges from 1800 square kilometres to zero and for the conical seamounts from 480 square kilometres to zero.

Dr. Hein said that the statistical analyses of all 34 measured seamounts revealed that the average surface area above 2500 meter water depth was 515 square kilometres with the maximum being 1,843 square kilometres. Following this summary of available data, Dr. Hein outlined his assumptions on the appropriate size of a cobalt-rich ferromanganese mine site. According to these estimations a mining area of 25 square kilometres per year was required for a commercial operation resulting in an area of 500 square kilometres that would define a 20-year mine site. Dr. Hein further noted that 2500 square kilometres was an appropriate size for an exploration area.

Dr. Hein said that the actual areas on seamounts for mining would be limited by a number of factors of which the most obvious was the sediment cover. In this regard, he said that seamounts may be entirely covered by sediments or may have no sediment cover at all. He said that the latter situation would be the most favoured. In his analysis, Dr. Hein said that he assumed a maximum sediment cover of 60 per cent as one of the criteria for whether a guyot summit is suitable for mining or not. He identified other impediments to mining as prohibitive small-scale topography, the requirement of maintaining biological corridors on the summits of seamounts and other unforeseen impediments. In his worst-case scenario Dr. Hein said that he considered these factors as introducing an additional 70 per cent reduction in the mining area, apart from the reductions caused by sediment cover considerations. Taking into account all these possible reductions to the mining area, Dr. Hein said that a significantly smaller area would be left for mining, so that on the summit of the largest guyot, if it had 60 per cent sediment cover, only 158 square kilometres would be available.

Dr. Hein illustrated his point, using the histogram below. Depending on sediment cover, he said that for the largest guyot with a total surface area (in green) of 4,780 square kilometres, introducing these reductions would result in only 158-376 square kilometres (grey/light blue) remaining as the potential mining area. For an average seamount with a total surface area of 1,830 square kilometres, Dr. Hein said that introduction of the reductions would result in an area available for mining being reduced to between 61 and 146 square kilometres. He also said that under the worst-case scenario, these would be the sizes of typical areas that would be available for mining on seamounts in the Equatorial Pacific Ocean.

Dr. Hein said that the size of the area that would ultimately be mined was strongly related to the crusts thickness and therefore to the square meter tonnage of crusts. As a worst-case scenario Dr. Hein chose 2 centimetre crust thickness resulting in about 39 kilograms wet weight per square kilometre of seafloor using a density of 1.95 gram per square centimetre. As a best-case scenario he used 6cm resulting in 117 kilogram per square metre. For a model mine site he said that he used a value of 2.5 centimetre net thickness resulting in 48.75 kilogram per square kilometre. Based on the data set on 34 measured seamounts, he said that this amounted to 1.1 to 2.6 large guyots or 2.8-6.7 average-sized seamounts that would be required for 20-year mining project. Dr Hein said that a single large guyot-type seamount could sustain a 20-year mining operation under favourable conditions. He said that large guyots with little sediment cover, subdued topography, and with average crusts of more than 2.5 centimetres are most likely to be mined, all of which would reduce the number of seamounts needed for a 20-year mining operation. Dr. Hein stated that no great expenses would be involved to move the mining system from one seamount to another, but that it would be preferable to stay in one area for the mining operation.

Based on the above described information and the present state of knowledge, Dr. Hein introduced his recommendations for an exploration block size and a mine site block size. Dr Hein recommended an exploration lease-block size of 100 square kilometres, and reasoned that this size would eliminate “cherry picking” in the best areas. According to his recommendations, the 100 square kilometre blocks did not need to be contiguous. These 100 square kilometre blocks were composed of 5 sub-blocks of 20 square kilometres. He said that the five sub-blocks of 20 square kilometre blocks must be contiguous i.e. they must touch each other at least at one point. Dr Hein said that the sub-block size (20 square kilometres) should be small enough to ensure nearly contiguous crust coverage within the selected area. He also said that a larger block size would result in leasing unwanted territories that are not suitable for mining. Dr. Hein pointed out that in his examples he had used equi-dimensional square units, resulting in an exploration lease being defined as twenty-five 100 square kilometre blocks, yielding a total exploration area of 2,500 square kilometres, five times the size of the assumed mine site.

In his exploration and mine site model, Dr. Hein said that relinquishment would require that contractors dispose of unwanted exploration areas based on using the 20 square kilometre sub-blocks. He noted that a mine site can be better defined by releasing small blocks. He said that he assumed that relinquishment would take place in 2 or 3 phases. He stated that the final 25 sub-blocks that would be chosen for a 20-year mine site of 500 square kilometres would be on one seamount or apportioned between two or more seamounts. Dr. Hein said that the delineation of the final mine site would be based on all the information available to a contractor on crust thicknesses, grades and distributions. In his opinion the final mine site for a commercial operation, however, would be closer to 100 square kilometres rather than 500 square kilometres. Dr. Hein said that he was aware of other mine site models, estimating that the required area size would be in a range of up to 2,000 square kilometres.

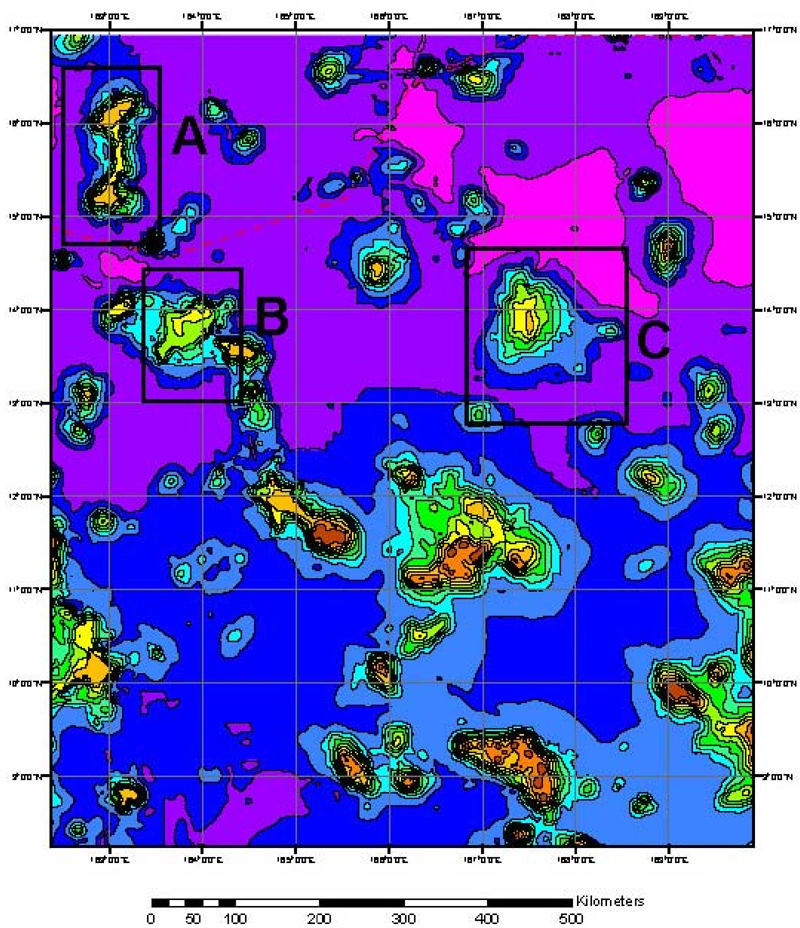
Dr. Hein presented the table below which summarised the range of possible mine site parameters and the values selected for the final model.

	Range	**Model Site**
Seamount summit area (km^2)	>400	>600
Seamount slope (o)	0-25	0-5
Water depth (m)	<2500	<2500
Mean crust thickness (cm)	2-6	2.5
Sediment cover (%)	5-60	30
Crust recovery (%)	70-90	82
Mine block size (km^2)	10-40	20
Exploration block size (km^2)	100-200	100

Dr. Hein also presented the table below to compare his assumed worst-case and best-case scenarios and to show the parameter values that he finally selected for his model. With regard to the production rate, Dr. Hein stressed that the annual production will depend on global metal prices at the time of mining and said that this number could change dramatically.

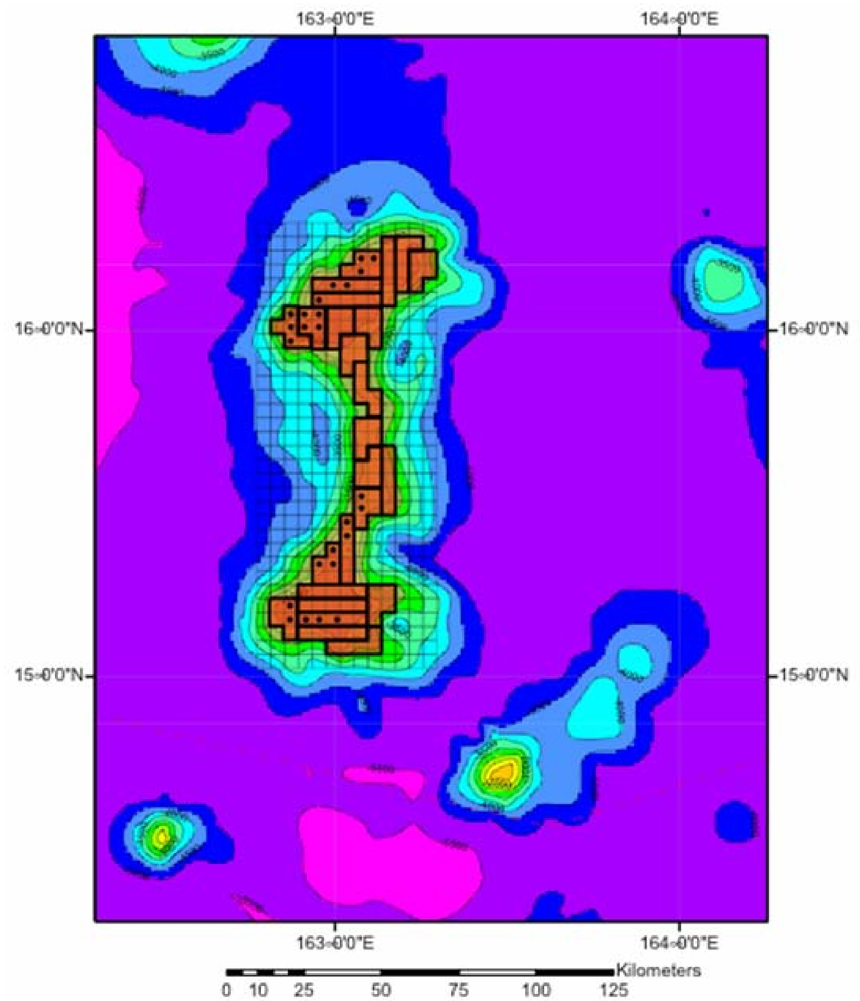
	Worst Case	Best Case	Model Site
Mean crust thickness (cm)	2.0	6.0	2.5
Wet tonnage (kg/m^2)	39	117	48.75
Annual production (106 tons)	2	1	1
Area mined/year (km^2)	51.3	8.55	20.5
Recovery efficiency (%)	70	90	82
Area mined/year (km^2)	73.26	9.50	25.0
Area mined in 20 years (km^2)	1465	190	500
Area for exploration (km^2)	7326	950	2500

Applying his model to real guyots in the Central Equatorial Pacific Ocean, Dr. Hein said that the three guyots used are shown in the map below. He said that two mining scenarios were assumed; one uses a single seamount and another one uses two seamounts for a commercial operation.

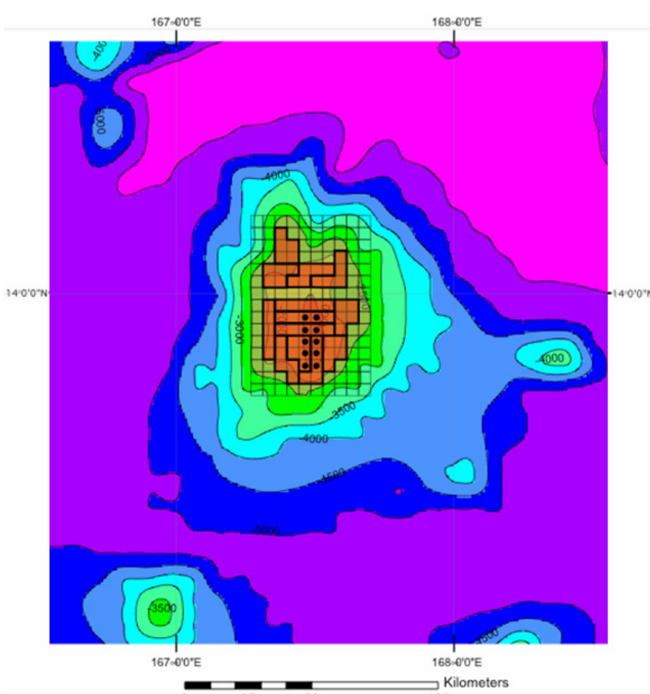


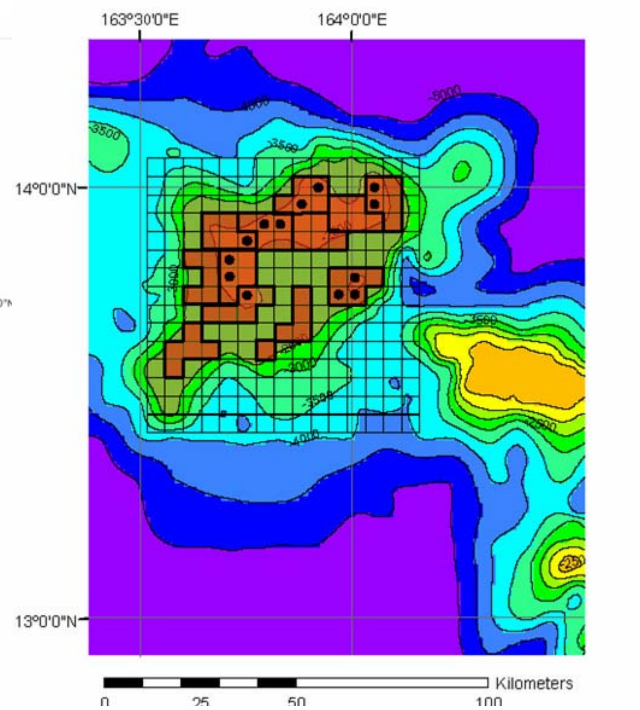
Seamount A is a large composite seamount with a total surface area of more than 9,000 square kilometres. The area above 2500 metres is about 3,000 square kilometres in size. The guyot-type seamount is flat-topped, the topography is relatively subdued and it may not have sediment cover anywhere, even though this was not known for sure. Seamount A was selected as an example for a single seamount that could accommodate a 20-year mine site.

Dr. Hein said that a 20 square kilometre grid was overlaid on the summit areas above the 2,500 m water depth. He said that each square was 20 square kilometres in size (4.47 kilometres on the side) and that groups of five of those squares were grouped into 100 square kilometre exploration blocks. Blocks are relinquished during the exploration phase. The blocks chosen for the final mine site are indicated by black dots and would together comprise an area of 500 square kilometres.



With regard to the two seamounts scenario, Dr. Hein said that after the exploration phase each seamount would comprise about half the area to be mined.





Dr. Hein noted that these examples were taken from about 50,000 seamounts in the Pacific Ocean and that very few of them had been explored. He stressed that other areas could be far more conducive to mining operations than the ones explored so far.

Summary of the discussions

A participant noted that in Dr. Hein's model the draft Regulations had been effectively modified to reflect reality and that the approach was a workable system allowing for flexibility in exploration and mine site blocks. The participant asked whether Dr. Hein deemed the results of his model as a viable method for lease block determination or if he would reconsider his model.

Dr. Hein replied that he developed a method based on the original scenario for block sizes according to the draft Regulations. The results, however, seemed to be artificial to him, he said, and so he went back over it again and built it up to what seemed to him a logical scientific way to do it.

A mining industry participant commented that the most effective way to encourage companies to accelerate exploration is to establish a system with an escalation in the cost of holding the area. This would be a real motivation for companies to relinquish unwanted territory and to quickly explore the leased area. The participant said that this aspect had not been sufficiently addressed in any of the proposed Regulations.

Dr. Hein agreed and stated that the ideas and practical views of industry representatives were particularly valuable for the International Seabed Authority and for the development of the draft Regulations.

Another participant commented on Dr. Hein's model and the factors that would limit the actual mining area, in particular the metal grade and the market-price cut-off for ore recovery. This participant noted that in some mining blocks the grade could be lower than the cut-off grade, so this block would be given up. He therefore suggested that the final mining area should be larger than the size proposed by Dr. Hein.

Dr. Hein replied that some of the reductions already considered in his approach e.g. the reduction due to sediment cover could actually be avoided. He said that the point raised was to some extent valid, but that in his opinion no additional reduction factors needed to be considered and that the size of 500 square kilometres was sufficient for a mine site.

Yet another participant raised the point that mining may not take place where too much substrate rock would have to be collected and that this could reduce the mineable area. He added that in order to give equal opportunities for the development of ferromanganese crusts and polymetallic nodules, the size of the area for exploration should be at least 4 or 5 times larger than suggested by Dr. Hein.

Dr. Hein agreed that collecting substrate rock was a crucial issue. He said that as a prerequisite to mining, crusts technology would need to be such that substrate recovery was kept to a minimum. As an example he mentioned in-situ leaching. He stressed that the technology that would ultimately be used was unknown.

Another participant stated that mining companies would probably mine areas where the metal grade and crust thicknesses were higher than the values assumed in Dr. Hein's model. This participant noted that mining could take place in areas where crust thickness was in the range of 4.5 to 6 centimetres and not 2.5 centimetres. The participant said that consequently less than 500 square kilometres would be needed for exploitation. Dr. Hein agreed and said that this opinion corresponded to his analysis.

Yet another participant said that commercial exploitation would look at the best-case scenarios of which the factors were unknown, because little knowledge was available on the almost 50,000 seamounts that existed in the Pacific Ocean. The participant commented that it was not expected that there would be a large number of prospecting activities in the near future, but that more marine scientific research was expected. He asked what efforts were likely to take place to increase knowledge about the 50,000 seamounts that remained unknown to date.

Dr. Hein said that many activities were currently underway by biologists, including scientific cruises to deposits. He said that he expected modest research to be done on ferromanganese crusts as a cruise-dominant factor, and that information would need to be gathered from all the different and related disciplines. He mentioned the Scripps Institute of Oceanography which was mapping seamounts on a regular basis with a primary interest in research on plate tectonics. He also said that swath bathymetric maps for many seamounts in the Pacific Ocean were being made available by volcanologists, and added that a lot of additional data were being collected in international waters by scientists from different countries, although most of these data were proprietary.

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Chapter 7: A Suggested Consideration to the Draft Regulations on Prospecting and Exploration for Cobalt-rich Ferromanganese Crusts. (The Size, Block and Number of Blocks for Exploration)

Mr. Yang Shengxiong, Guangzhou Marine Geological Survey, China Geological Survey

Introduction

On June 9, 2006 the Secretariat issued a document ISBA/12/C/3/Part I on the size of areas and the number of blocks for exploration. The document provides a model for the selection and quantification of parameters that can be used to define a seamount mine site for cobalt-rich crusts deposits. Then, it suggested revisions to the draft Regulations, primarily:

(1) The area covered by each application for exploration for cobalt-rich crusts shall comprise not more than 125 blocks which shall be arranged by the applicant in 100 square kilometre clusters as set out in paragraph 2.

(2) Each 100 square kilometre cluster shall consist of no less than five contiguous blocks. Two blocks that touch at any point shall be considered to be contiguous. Clusters need not be contiguous but shall be proximate and located within the same geographic area.

(3) The total area covered by an application shall not exceed 250 blocks.

Block Size

The model suggests that a block size of about 20 square kilometres is a cell of a grid as provided by the Authority and no more than 5 blocks comprise a 100 square kilometres cluster. This model is made in conformity with the distribution of cobalt-rich crusts on the seamounts, especially the seamounts and cobalt-rich crusts characteristics located in water depths shallower than 2500 metres.

The model does not include an economic evaluation, thus some of the parameters are very difficult to determine, such as the annual production, crust thickness and square-metre tonnage.

If a 2 million wet tonnes annual production for 20 years of operation and 0.7 coverage of cobalt-rich crusts in the contractor's nominated blocks with other parameters referenced to, in the model, the resources of 500 square kilometres, or 25 blocks is far from sufficient.

$$500\ km^2 \times 2.5cm \times 1.95g/cm^3 \times 0.82\ (efficiency) \times 0.7(coverage) = 13.99\ million\ wet\ tonnes$$

If we consider the 2 million dry tonnes annual production for 20 years of operation, the condition of the technology and economics of mining, 500 square kilometres or 25 blocks is very insufficient.

In fact not all block are fully covered by crusts. Some areas of the blocks are covered by sediments or base rocks (*Figure 1*), whatever the exploration of the nominate blocks for the contractor.

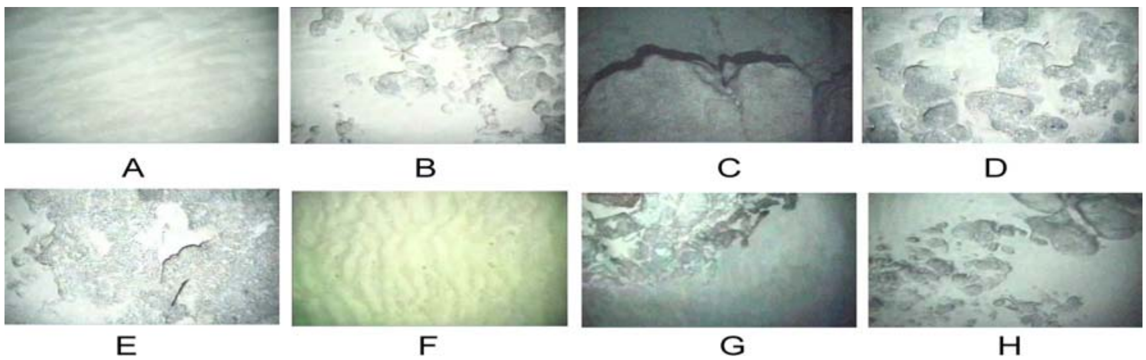

Figure 1: The photo pictures by TV cameras showed the crusts covered by the sediments (whiteness). The location on the seamounts of A-H identified in Figure. 3 where the water depth and slope is variational.

Efficiency of mining operation

Based on present knowledge about extraction techniques and mining operations, the estimated efficiency of 0.82 is too high. Generally, the efficiency may be less than 0.3 referenced to the mining model for ferromanganese nodules.

According to the sub bottom profiler, seismic, grab sampling, core sampling, and TV grab investigations of north-equatorial Pacific seamounts by COMRA, most flat surface areas of the guyots are covered by sediments tens of metres thick (*Figure 2*) where there are no crusts. At the edge of the guyots, there are slopes ten to twenty degrees in topography (*Figure 3*) where mining is impossible with present mining technology.

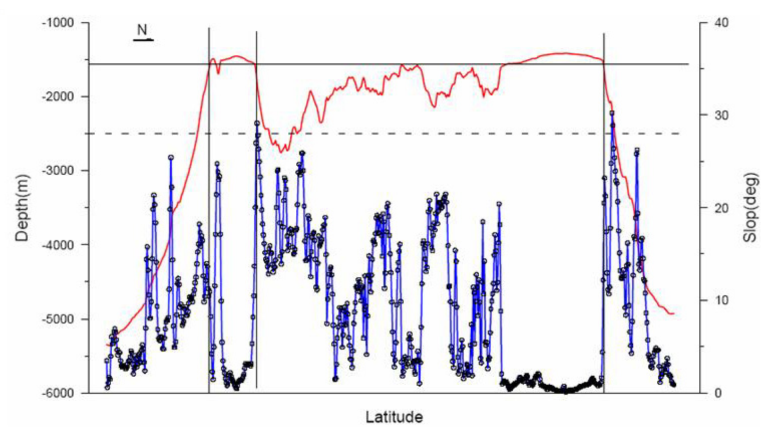

Figure 2: The relationship of water depth vs slope of a typical guyot by multibeam bathymetry

According to our statistics, 75 percent of the flat-top of the seamounts are covered by sediments, which should be cut-off for exploration.

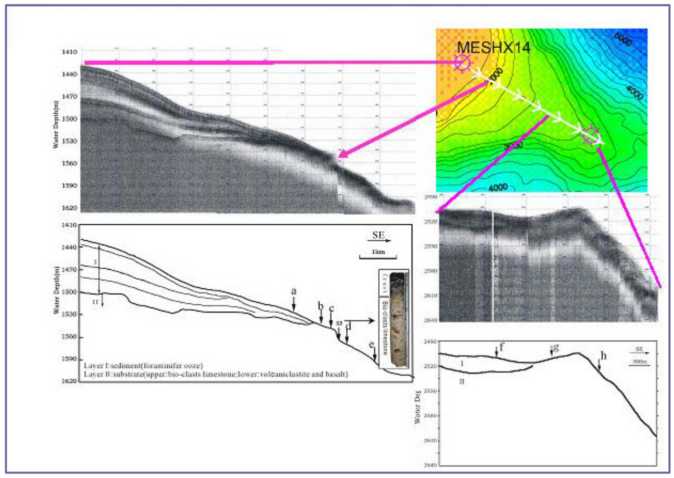

Figure 3: Subbottom profiler showed that tens of metres sediments cover the surface of the summit and the small-scale trough edge of the guyot. The coring sample showed the depth of the sediments. The surface distribution of the crusts is showed in Figure 1.

Based on the present mining technology and the economic evaluation of cobalt-rich crusts, we suggest that final mining blocks totalling 2800 square kilometres is appropriate for a contractor to sustain a mining operation of 2 million wet tonnes annual production for 20 years with a 0.3 efficiency as:

2800 km² x 2.5 cm x1.95 g/cm³x0.3 (efficiency) = 40.95 million wet tonnes

A total exploration area of 10,000 square kilometres is a good choice to provide the contractor before further scientific identification and technology for exploration and mining of crusts are available.

Even though the block clusters may be non-contiguous, it is needed to limit the number of seamounts. This is in conformity with the common heritage principle.

<u>Definitions</u>

Sub-block is a cell of a grid as provided by the Authority, no greater than 20 square kilometres.

Block comprises five contiguous sub-blocks, no greater than 100 square kilometres.

Cluster comprises several continuous sub-blocks.

Exploration area comprises several clusters, no more than 100 blocks and not greater than 10,000 square kilometres.

Therefore, Regulations 12 and 27 should read as follows:

Regulation 12
Total area covered by the application (cobalt-rich crusts)

1. The exploration area for approval of each application for cobalt-rich crusts shall be not greater than 10,000 square kilometres, comprising not more than 100 blocks (500 sub-blocks).

2. The exploration area may comprise several clusters. Two clusters that touch at any point shall be considered to be contiguous. Clusters need not be contiguous, but shall be proximate and located within the same geographic area.

Regulation 27
Size of area and relinquishment

(1) The contractor shall relinquish the sub-blocks allocated to it in accordance with paragraphs 2, 3 and 4 of this regulation.

(2) By the end of the fifth year from the date of the contract, the contractor shall have relinquished:

(a) at least 40 per cent of the total number of sub-blocks allocated to it;

(b) if 40 per cent of that number of sub-blocks is a whole number and a fraction, the next higher whole number of the sub-blocks

(3) By the end of the tenth year from the date of the contract, the contractor shall have relinquished:

(a) at least 65 per cent of the number of sub-blocks allocated to it: or

(b) if 65 per cent of that number of sub-blocks is a whole number and a fraction, the next higher whole number of the sub-blocks.

At the end of the fifteenth year from the date of the contract, or when the contractor applies for exploitation rights, whichever is the earlier, the contractor shall nominate up to 140 sub-blocks from the remaining number of blocks allocated to it, which shall be retained by the contractor. Where the size of the exploration originally allocated to the contractor was less than 10,000 square kilometres, the contractor shall nominate no more than 28 per cent of that original number of sub-blocks to be retained. If 28 per cent of that number of sub-blocks is a whole number and a fraction, the contractor shall nominate the next higher whole number of sub-blocks.

Assuming an initial allocation of 500 sub-blocks, the contractor would relinquish as follows:

- 40 per cent with 200 sub-blocks at year 5;
- 65 per cent with a further 125 sub-blocks at year 10;
- 72 per cent with a further 35 sub-blocks at year 15;
- Leaving it with 140 sub-blocks for exploitation.

Summary of the presentation

Mr. Shengxiong began his presentation with a summary of document ISBA/12/C/3/Part I: Exploration and mine site model applied to block selection for cobalt-rich ferromanganese crusts and polymetallic sulphides

Mr. Shengxiong said the model suggested that a block size of about 20 square kilometres is a cell of a grid as provided by the Authority and no more than 5 blocks comprise a 100 square kilometres cluster. This model was made in conformity with the distribution of cobalt-rich crusts on the seamounts, especially the seamounts and Cobalt-rich crust characteristics located in water depths shallower than 2500 metres.

He said the model did not include an economic evaluation, thus some of the parameters such as the annual production, crust thickness and square-metre tonnage were very difficult to determine. Given the parameters used in the model as well as the assumption of 70 per cent coverage of cobalt-rich crusts in the contractor's mine site blocks, the total production over 20 years would be 13.99 million wet tonnes according to the following equation:

$$500\ km^2 \times 2.5cm \times 1.95g/cm^3 \times 0.82\ (efficiency) \times 0.7 (coverage) = 13.99\ tonnes$$

Assuming a minimum of 2 million wet tonnes annual production over 20 years of operation, Mr Shengxiong said the resources in 500 square kilometres, or 25 blocks were far from sufficient.

He said, based on the present knowledge about extraction technology and a possible mining operation, the estimated efficiency of 0.82 was too high. The efficiency would be less than 0.3.

He added that according to COMRA's investigation of north-Equatorial Pacific Ocean seamounts using sub-bottom profilers, seismic analysis techniques, grab sampling, core sampling and photographic analysis, most of the flat surface areas of the guyots were covered by sediment that were tens of metres thick. At the edge of the guyots, the slopes had angles of ten to twenty degrees. This would make mining impossible based on present mining technology. With 75 per cent of the flat tops of these seamounts covered by sediment, this could prove prohibitive for mining.

Based on the statements above, Mr. Shengxiong presented COMRA's suggestions for the revision of the relevant definitions and modifications to regulations 12 and 27 as follows:

<u>Regulation 12</u>
<u>Total area covered by the application (cobalt-rich crusts)</u>

3. The exploration area for approval of each application for cobalt-rich crusts shall be not greater than 10,000 square kilometres, comprising not more than 100 blocks (500 sub-blocks).

4. The exploration area may comprise several clusters. Two clusters that touch at any point shall be considered to be contiguous. Clusters need not be contiguous, but shall be proximate and located within the same geographic area.

Regulation 27
Size of area and relinquishment

(4) The contractor shall relinquish the sub-blocks allocated to it in accordance with paragraphs 2, 3 and 4 of this regulation.

(5) By the end of the fifth year from the date of the contract, the contractor shall have relinquished:

(c) at least 40 per cent of the total number of sub-blocks allocated to it;

(d) if 40 per cent of that number of sub-blocks is a whole number and a fraction, the next higher whole number of the sub-blocks

(6) By the end of the tenth year from the date of the contract, the contractor shall have relinquished:

(c) at least 65 per cent of the number of sub-blocks allocated to it: or

(d) if 65 per cent of that number of sub-blocks is a whole number and a fraction, the next higher whole number of the sub-blocks.

Summary of discussions

A participant stated that for tonnage estimates, experts were using higher values for crust thickness than 2.5 centimetres and asked why COMRA used 2.5 centimetres. Mr. Shengxiong answered that 2.5 centimetres was the mean thickness.

The same participant raised a point regarding metal grades and stated it was likely that mining companies would carry out exploitation in areas where the grade was much higher than the average values used in the models. Mr. Shengxiong agreed that grade was a very important parameter and said that it was not known what grade would finally be considered for mining.

Dr. Hein stated that a crust thickness of 25 centimetres was common in the Central Pacific Ocean and that this thickness could be found in many places. He said that for his mine site model he used an average case in the Pacific Ocean. He said however, that the areas with average crust thickness were not likely to be mined and consequently the area size he assumed for his model would probably be too large. He stressed that ultimately, the required area sizes remain unknown at this point of time. With regard to the sediment cover issue that Mr. Shengxiong outlined in his presentation Dr. Hein confirmed that there were many seamounts covered by sediment, but there were also others with little sediment. Those would be the ones that would be considered by mining companies.

Mr. Shengxiong replied that his elaborations on sediment cover were based on a statistical analysis of the results of COMRA's investigations.

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Chapter 8: Mining Development Scenario Summary (Cobalt-rich Ferromanganese Crusts deposits)

Dr. Charles Morgan, Environmental Planner, Planning Solutions, Inc.,Mililani HI, USA

Introduction

Cobalt-rich crusts deposits are known to occur in the Exclusive Economic Zone (EEZ) of the United States adjacent to Hawaii and Johnston Island. As a result, the Minerals Management Service (MMS) of the U.S. Department of the Interior has joined with the State of Hawaii Department of Business and Economic Development (DBED) (formerly the Department of Planning and Economic Development) to examine the possibility of future exploitation of these crusts. This joint effort has produced this Environmental Impact Statement (EIS) which evaluates the potential impacts of the exploration, mining, and processing of these cobalt-rich deposits.

This report provides a description of the likely characteristics of a future crusts mining industry. It was prepared by a group of experts in fields of mineral resource assessment, mining technology, metallurgical processing, and logistic support, and is based on presently available information and conventional technology. It is a summary of a more detailed analysis presented in a mining development scenario study prepared in 1987 (Marine Development Associates, Inc., 1987).

Resource Assessment

Crusts in the US EEZ Adjacent to Hawaii and Johnston Island

Crusts in Hawaii were first examined in the late 1960's and early 1970's by researchers at the Hawaii Institute of Geophysics (HIG) (Craig et al., 1982). These earlier studies were integrated with new data from the Mid-Pacific region (Halbach and Manheim, 1984) to provide the first resource assessment of crusts potential in the Hawaiian archipelago (Clark et al., 1984).

Recognition of the resource potential of crusts and their associated strategic metals led to initiation of the present study specifically directed toward an area-by-area assessment of crusts potential within the United States EEZ adjacent to Hawaii and Johnston Island. To undertake this study a series of three cruises was sponsored by the U.S. MMS and organized by the Resources Systems Institute of the East-West Center and HIG. The cruises were designed to provide: (1) crusts and substrate materials for study and chemical analysis; (2) detailed bathymetry; (3) bottom photos of crusts occurrences; and (4) SeaMARC data and seismic data on individual seamounts. Data collected by the U.S. Geological Survey (Hein et al., 1985) and West German studies (Halbach and Puteanus, 1985) are used to estimate the resource of the EEZ adjacent to Johnston Island.

The resource assessment is based on the following model for crusts occurrence and distribution:

1. The permissive zone for crust occurrence is on seamount areas between the depths of 800 to 2,400 metres (m). The study area is shown in Figure 1.

2 Crusts thicknesses vary with age. Based on the present state of knowledge, there are two generations of development: an older crusts generation which formed at the rate of 4.8 mm/my (millimetres per million years between 9 to 16

my ago), and a younger generation which formed at the rate of 2.7 mm/my during the period 8 my to the present.

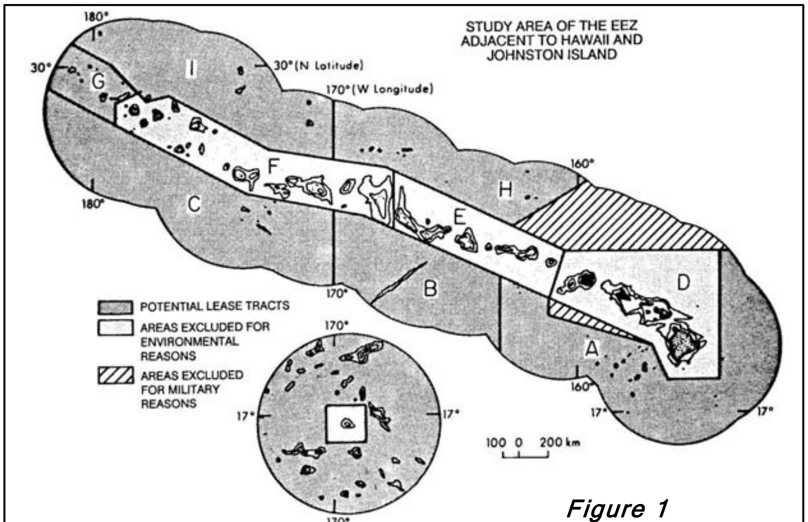


Figure 1

The period 8 to 9 my was marked by phosphate deposition. The maximum average computed crust thickness was 5.52 centimetres (cm). Averages for individual areas vary depending on age and location, and apparently do not achieve this maximum average at any site yet examined. The thickest crusts are expected on off-axis seamounts (those not associated with the Hawaiian Islands) and are estimated in this study to average 2.5 cm in thickness. Individual deposits, particularly in the Johnston Island area, appear to average 10 cm in thickness (J. Hein, USGS, personal communication, 1988).

Crusts coverage within the permissive zone ranges from 0 per cent (areas of thick sediment cover) to 100% (areas of thick crust "pavements"). From available information it appears that the Hawaiian axis deposits have coverages of about 25 per cent; other deposits at off-axis sites and within the Johnston Island EEZ average 40 per cent coverage.

3. The average weight density for crust is estimated at 1.95 grams per cubic centimetre (grams/cubic centimetres) for wet crust and 1.34 g/ cubic centimetres for dry crust. Metal concentrations presented here are for dry crust.

The estimated metal concentrations and resource potential in the study area are summarised in *Table I*; they show an overall in-place resource potential of 2.6 million tonnes (t) of cobalt, 1.6 million t of nickel, 81 million t of manganese, and 58 million t of iron.

Purpose and Scope of Resource Study

The objective of this study is to provide a preliminary estimate of the resource potential of cobalt-rich manganese crusts occurring within the EEZ adjacent to Hawaii and Johnston Island. The definition of the areas of variable resource potential is based on a number of geological and oceanographic parameters that are believed to influence the occurrence and distribution of crusts.

Specifically, data were compiled both from earlier studies and from the recent cruises of the research vessel Kana Keoki sponsored by MMS, and resultant research by the Hawaii Institute of Geophysics and the Resource Systems Institute of the East-West Center. The scope of this report is limited by the lack of data from many large areas of the Hawaiian archipelago and the overall lack of scientific research on crusts in general. These limitations result because: (1) crusts are a new and only recently studied resource; (2) extensive detailed studies have not been conducted in any area; (3) no commercial exploitation has taken place which would thereby provide mining data; and (4) to date, only limited research has been completed within the study area.

Area Studied

The study area falls within the United States EEZ adjacent to Hawaii and Johnston Island as shown in Figure 1. The EEZ boundaries on the maps in this report are not exact; however, this does not introduce any significant error in the resource estimates in the study since the seamounts of interest are virtually all well within the boundary. The sub areas A to I in the Hawaii portion of Figure 1 were made for purposes of resource assessment. Other sub areas of the United States EEZ adjacent to Hawaii and Johnston Island (presented in *Figure 2*) have been tentatively assigned as potential lease tracts.

Table 1: SUMMARY OF RESOURCE POTENTAL

Sub-Area	Dry Weight Percent (in pure crust)				Thousand Tonnes				
	Co	Ni	Mn	Fe	Crust	Co	Ni	Mn	Fe
Included In Initial Offer									
A	.471	.287	18.01	19.55	26,854	126	77	4,836	5,250
B	.551	.280	19.27	20.01	37,413	206	105	7,209	7,486
C	.630	.330	18.65	18.70	14,110	89	47	2,631	2,639
G	.892	.504	24.14	15.20	10,834	97	55	2,615	1,647
H	.648	.332	20.16	18.91	17,487	113	58	3,525	3,307
I	.964	.483	25.90	15.61	25,313	244	122	6,556	3,951
Johnston area	.785	.536	24.40	15.60	217,777	1,710	1,167	53,138	33,97
Sub-Total	--	--	--	--	349,788	2,585	1,631	80,510	58,25
Excluded From Initial Offer									
D	.380	.224	16.05	14.96	34,215	130	77	5,492	5,119
E	.888	.368	21.46	16.83	52,076	462	192	11,176	8,764
F	.652	.365	19.56	14.17	156,499	1,020	571	30,611	22,17
Johnston area	.785	.536	24.40	15.60	14,016	110	75	3.420	2,186
Sub-Total	--	--	--	--	256,806	1,722	915	50,699	38,24

Assumption (see Johnson et al., 1985 for discussion)

1. Mean crust coverage in permissive area is 40% in A, B, C, H, I, and Johnston; and 25% in D, E, F and G.
2. Crust thickness: Areas A, B, C, H, I and Johnston - 2.5 cm; Area D -).5 cm; Area E - 1.0 cm; Area F - 1.5 cm; Area G - 2.0 cm

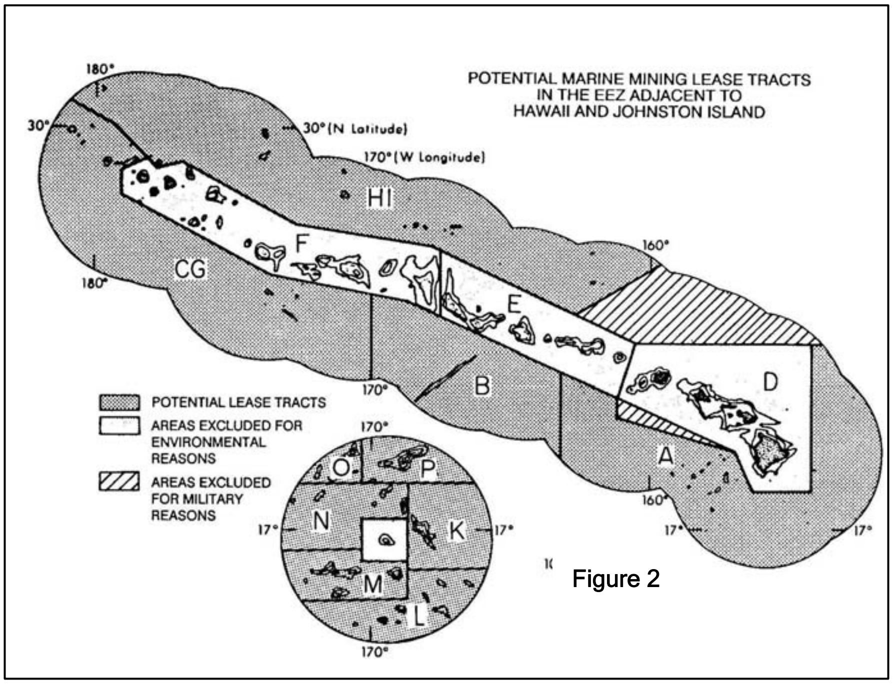


Figure 2

Study Approach

As with all resource assessments, the estimation of the crusts potential of the Hawaiian archipelago is highly data dependent. Unlike mineral resources that occur on land and thereby are available for direct observation and more detailed analyses, the crusts resources can only be studied remotely through a limited number of broadly spaced samples. Therefore, a considerable amount of data analysis and interpretation are required prior to undertaking a resource assessment of crust potential. The authors have, therefore, organized the present report in such a way as to present the basic data available for the resource assessment, to interpret and analyse the data in terms of the present research and other relevant research in the region and, finally, to provide a quantitative statement of the values used in the resource assessment and explain why they were chosen.

The critical elements in the resource assessment are as follows: geology and age of the archipelagic region; permissive areas for crust coverage; crust attributes (coverage, density, thickness, accretion rates, and depth dependence); geochemistry of crust occurrences; substrate parameters; and microtopography. Each of these elements is input into a full assessment model and subsequent evaluation of potential mining activities. In the following, each of these elements is described as a basis for the concluding resource assessment and description of mine site characteristics.

Permissive Area

Permissive Area Estimates

Within the United States EEZ adjacent to Hawaii and Johnston Island, the areas of interest fall between 800 and 2,400-meter water depths. *Table 2* describes the seamounts and islands which have areas within this depth range. These areas are referred to as permissive areas. It should be noted that for a number of physical reasons (lack of a suitable substrate, slopes, age, etc.), more than 50% of the permissive area, probably contains little or no manganese crust. *Table 2* includes estimates of the size of the permissive areas and ages (for the Hawaiian seamounts) of associated seamounts in the study area.

The areas surrounding the seven populated Hawaiian Islands are excluded from the initial lease offerings (Sub area D). Other areas (wildlife preserves and military use zones) also result in further reduction in the size of areas that will eventually be considered for leasing.

The selection of a depth range from 800 to 2,400 m is an estimate of the depth range in which cobalt-rich ferromanganese crusts deposits of greatest commercial interest are most likely to be discovered. To date, the most important crusts occurrences discovered in the Pacific Ocean are located within this depth range. However, it is known that crust deposits are found at all depths in the ocean where a suitable substrate exists. Therefore, it is possible that future research might discover a relatively rich crusts deposit outside of the permissive area defined for this study.

Method Used in Estimating Area Size

The permissive areas were measured by placing transparent small-scale graph paper over the best available bathymetric maps of the United States EEZ adjacent to Hawaii and Johnston Island and counting the squares within the depth limits of 800 to 2,400 m.

Table 2: SEAMOUNT DATA FOR THE UNITED STATES EEZ ADJACENT TO HAWAII AND JOHNSTON ISLAND

EEZ Adjacent to Hawaii

Map No.	Resource Subarea (see Fig. A-2)	Sample Site	Lat.	Long.	Name	Permissive Area (km^2)	Age (million years)
1	D	AX11	19 30N	155 30W	Hawaii	7384[x]	0
2	D(A)		18 30N	155 30W	Apuupuu	66[x]	75*
3	D(A)		18 40N	156 00W	Dana	38[x]	75*
4	D(A)		18 40N	156 20W	Day	19[x]	75*
5	A		18 40N	156 35W	Palmer	8	75*
6	D	AX10	21 00N	157 00W	Maui-Oahu	8534[x]	1-3
7	D		22 05N	159 30W	Kauai	2476[x]	3
8	D		21 40N	160 20W	Niihau-Kaula	1910[x]	6-10
9	E		22 45N	161 03W	33 fathoms	919[x]	7
10	E	AX9	23 05N	162 00W	Nihoa	3503[x]	7
11	E		23 15N	163 35W	250 fathoms	380[x]	9
12	E	AX6	23 30N	164 30W	Necker	2535[x]	9-12
13	E		24 15N	166 03W	388 fathoms	397[x]	11-15
14	E	AX8	23 50N	166 00W	Fr. Frigate	7811[x]	11-15
15	F	AX3-AX5	25 00N	168 00W	Gardner	11,192.5[x]	16
16	F		25 30N	169 30W	Raita Bank	1444[x]	18
17	F		24 40N	169 40W	844 fathoms	157[x]	18*
18	F		25 30N	171 00W	Maro-Laysan	6651[x]	20
19	F		25 30N	172 30W		2751[x]	19-22
20	F		26 00N	173 30W	Lisianski-Pioneer	3273[x]	21
21	F		26 15N	174 35W	30 fathoms	438[x]	21
22	F		27 00N	175 35W	62 fathoms	442[x]	21
23	F		27 35N	175 00W	665 fathoms	193[x]	21
24	F	AX7	27 50N	175 50W	Pearl-Hermes	1303[x]	18-21
25	F		27 08N	176 07W	786 fathoms	299[x]	21
26	F		26 45N	176 07W	810 fathoms	84[x]	21
27	F		27 00N	176 30W	Salmon Bank	535[x]	21
28	F		27 05N	176 55W	830 fathoms	113[x]	21
29	F		27 03N	177 15W	700 fathoms	47[x]	74
30	F		28 05N	176 55W	950 fathoms	26[x]	28*
31	F		28 30N	176 40W	Ladd	608[x]	28
32	F		28 20N	177 25W	Midway	538[x]	27
33	F		28 00N	177 55W	Nero	423[x]	28
34	F		27 45N	178 18W	1058 fathoms	14.5[x]	28
35	F		27 35N	178 25W	1000 fathoms	93[x]	28
36	F		28 13N	178 45W	1160 fathoms	31[x]	27
37	F		28 25N	178 20W	Kure	488[x]	28

EEZ Adjacent to Hawaii							
Map No.	Resource Subarea (see Fig. A-2)	Sample Site	Lat.	Long.	Name	Permissive Area (km²)	Age (million years)
38	HI		28 55N	177 48W	Wentworth	128	72
39	HI		29 05N	178 40W	1080 fathoms	33	27
40	CG		28 35N	178 40W	1000 fathoms	53	28
41	CG	AX2	28 55N	178 40W	460 fathoms	863	26-28
42	CG		29 20N	178 50W	825 fathoms	50	27
43	CG		28 54N	179 40W	150 fathoms	372	26-28
44	CG		29 50N	179 55W	940 fathoms	19	28-30*
45	CG		30 00N	179 50E	950 fathoms	37	28-30*
46	CG	AX1	29 33N	179 30E	1050 fathoms	21	28-30*
47	CG	AX1	29 25N	179 20E	1110 fathoms	19	28-30*
48	CG	AX1	29 50N	179 05E	Hancock	183	28-30
**							
**							
51	CG		28 10N	178 00E	1070 fathoms	26	80*
52	CG		24 45N	173 45W	720 fathoms	387	80*
53	CG		24 20N	173 55W	1048 fathoms	16	80*
54	CG		24 15N	173 08W	550 fathoms	28.5	80*
55	CG		24 00N	173 00W	950 fathoms	455	80*
56	CG		24 48N	172 53W	1127 fathoms	12	80*
57	CG		24 37N	172 45W	960 fathoms	91	80*
58	CG		25 00N	172 30W	940 fathoms	37	80*
59	B	OF5	22 00N	168 30W	Necker Ridge	2792	84
60	A		21 55N	162 25W	1175 fathoms	10	75*
61	A		21 35N	162 20W	1055 fathoms	11	75*
62	A		18 50N	159 05W	Bishop	112	80*
63	A		19 05N	158 42W	Brigham	44	80*
64	A		18 20N	158 30W	Swordfish	90	80*
65	A		18 40N	158 10W	Cross	286	85
66	A		18 52N	157 58W	Washington	109	80*
67	A		19 10N	157 40W	Ellis	106	80*
68	A	OF4	19 27N	157 17W	Perret	33	80*
69	A	OF4	19 18N	157 10W	538 fathoms	114	76
70	A	OF4	19 20N	157 00W	Jaggar	122	74-82
71	A	OF4	18 40N	157 07W	McCall	363	82
72	A		18 16N	157 25W	Pensacola	263	75*
73	A		18 06N	157 45W	Daly	59	75*
74	A		17 34N	157 40W	Finch	146	75*
75	A		16 50N	157 45W	1135 fathoms	22	75*
76	A		17 10N	154 04W	Wilkes	20	75*
77	A		17 35N	154 05W	Shepherd	14	75*
78	A		19 00N	153 55W	Wini	72	59

EEZ Adjacent to Hawaii

Map No.	Resource Subarea (see Fig. A-2)	Sample Site	Lat.	Long.	Name	Permissive Area (km^2)	Age (million years)
79	HI		23 15N	153 55W	1176 fathoms	8	80*
80	HI		23 10N	154 25W	779 fathoms	52	80*
81	HI		23 20N	158 21W	Kaluakalana	28	80
82	HI		24 53N	157 05W	Paumakua	27	65
83	HI	OF3	25 30N	160 20W	Schumann	12	82
84	HI	OF3	25 30N	160 20W	Schumann	106	82
85	HI		26 10N	162 00W	Chopin	107	85*
86	HI	OF2	25 20N	161 40W	Mendelssohn	50	80
87	HI	OF2	25 20N	162 00W	Mendelssohn	181	80
88	HI		25 35N	164 13W		20	85*
89	HI		25 42N	165 28W		30	85*
90	HI		26 45N	167 00W	450 fathoms	253	80*
91	HI		26 45N	167 00W	1080 fathoms	57	80*
92	HI		26 45N	167 15W	1017 fathoms	61	80*
93	HI		26 55N	168 10W	392 fathoms	194	80*
94	HI		27 00N	168 30W	832 fathoms	116	80*
95	HI		26 55N	168 55W	962 fathoms	3	80*
96	HI		27 55N	171 00W	936 fathoms	345	80*
97	HI		28 40N	171 05W	818 fathoms	203	80*
98	HI	OF1	29 07N	174 05W	640 fathoms	446	81
99	HI	OF1	29 50N	174 00W	360 fathoms	552	80*
100	HI		31 10N	179 45W	480 fathoms	182	77

Total Hawaiian Permissive Area = 77,776 km^2

Permissive Area Excluded From Initial Lease Sale = 67,116 km^2

EEZ Adjacent to Johnston Island

Resource Subarea (see Fig. A-2)	Location Lat.	Long.	Identifier	Permissive Area (km^2)
P	19 15N	169 5W	Horizon Seamount	5147
P	18 35N	170 5W	A2	129
N	18 5N	168 55W	Karin Seamount (N)	586
N	17 30N	169 15W	B2	33
K	17 5N	168 25W	Karin Seamount (S)	2612

EEZ Adjacent to Johnston Island				
Resource Subarea (see Fig. A-2)	Location Lat.	Long.	Identifier	Permissive Area (km^2)
M	15 40N	169 15W	C1	1447
L	15 10N	168 2W	C2	98
L	15 10N	166 55W	C3	98
L	13 55N	167 50W	Blackhaw Seamount (S)	132
L	14 35N	168 15W	Blackhaw Seamount (N)	165
L	14 30N	169 W	C6	99
L	14 5N	169 30W	C7	33
L	14 10N	169 45W	C8	232
M	15 45N	170 50W	D1	1513
M	15 10N	170 55W	D2	1120
M	15 30N	171 55W	D3	33
L	14 N	170 25W	D4	33
O	19 35N	170 45W	E1	1319
O	19 10N	170 30W	E2	96
N	18 15N	169 45W	E3	325
N	17 55N	169 55W	E4	65
N	18 5N	172 45W	E5	65
N	18 10N	171 50W	E6	130
O	19 5N	171 20W	E7	194
O	18 45N	171 20W	E8	97
O	18 55N	171 10W	E9	161
O	18 50N	170 50W	E10	290
J	16 45N	169 30W	Johnston Island[x]	1046

Total Johnston Island Permissive Area = 17,298 km^2

Excluded Permissive Area = 1,046 km^2

TOTAL EEZ PERMISSIVE AREA = 95,074 km^2

TOTAL EXCLUDED = 68,162 km^2

NET PERMISSIVE AREA IN POTENTIAL LEASE SALE = 26,912 km^2

x Excluded from initial lease offering
* Indicates inferred ages
** Map numbers 49 and 50 do not exist
(A) Off-axis seamounts in Subarea D

Corrections were made for changes in map scale at different latitudes, and area measurements were increased by 3.5 per cent to correct for an assumed average seamount slope of 15 degrees. Various maps covering the area are not consistent in showing the depth contours of seamounts. It is reasonable to assume that detailed studies of many of the seamounts in the study area will reveal substantial variations from the dimensions shown on existing maps. However, for the purposes of the present study, the present estimates are believed adequate with respect to the relative sizes of permissive areas.

Size Distribution of Seamounts

There are 126 known seamount and island sub areas in the EEZ adjacent to Hawaii and Johnston Island that contain permissive areas within the depth range of 800 to 2,400 m. As shown in *Table 2*, 42 seamounts and islands are on-axis, 56 seamounts are off-axis, and 28 are in the Johnston Island area. The total on-axis permissive area is 68,611 square kilometres (km^2). The total off-axis permissive area in the Hawaii area is 9,166 square kilometres. The Johnston Island area contains a permissive area of about 17,000 square kilometres.

The mean size of the on-axis seamount permissive areas is 1,634 square kilometres, ten times the mean size of 164 square kilometres for off-axis seamounts. The mean size of Johnston Island seamounts is 618 square kilometres. In addition, as expected, the mean size of seamount permissive areas decreases with increasing age of the seamount. The youngest on-axis seamount and island permissive areas in Sub area D have the largest mean size, and the oldest on-axis seamount group in Sub area G has the smallest mean size.

Resource Assessment Estimates

Resource Estimation Model

The following resource estimation model (model parameters summarised in *Table 3* provides a "rough" indication of the quantity of crusts and associated metal resources that are expected to exist within the study area. These estimates do not indicate the fraction of estimated in-place “resources" that may eventually be upgraded to the "reserves" (economic) category. Much more exploration and evaluation work will be required before it will be realistic to discuss the economic potential of the resources in the study area.

Estimates of the parameters required to complete a resource assessment of the study area were developed in section 3 of the mining development scenario (Marine Development Associates, Inc., 1987). Where data were incomplete, the writers used subjective estimates that combined theoretical knowledge of the factors controlling the parameters with available physical data. The parameters required for the resource assessment are: the permissive area, crust thickness, crust coverage, crust density (dry), and metal grades. These parameters consist of the following:

1. *Permissive area.* Crusts occurrence is on seamount areas within the depth range of 800 to 2,400 metres.

2. *Crust thickness.* This varies with age as well as other physical variables. The maximum average thickness that could be present under optimum conditions is about 5.5 cm; however, averages for the older off-axis seamounts in the Hawaii area are expected to be closer to 2.5 centimetres. Johnston Island area deposits thickness are assumed to average 2.5 centimetres (Halbach and Puteanus, 1985). *[A commercial*

deposit would probably need to have greater thickness than the average for initial ventures. Based upon preliminary estimates made for some of the Johnston Island deposits, we assume this to be 3.5 cm].

Table 3
MINE SITE PARAMETERS OF POSSIBLE
COMMERCIAL INTEREST IN THE PACIFIC

Parameters		Possible Range Of Parameters	Hypothetical Parameters
1. Mean Crusts Thickness		3.0-5.0 cm	3.5 cm
2. Crusts Specific Gravity		1.95 (wet)	1.95 (wet)
		1.34 (dry)	1.34 (dry)
3. Crusts Grade:	Co	0.8-1.1%	0.9%
	Ni	0.4-0.6%	0.5%
	Mn	20-25%	22.5%
	Pt	0.4 g/t	.4 g/t
4. Seamount Slope		5-20°	10°
5. Crusts Coverage		60-90%	75%
6. Substrate Types		Basalt clay	hyaloclastics
7. Depth		800-2,400	800-2,400 in
8. Crusts Recovery		50-70%	70%
9. Production (dry t/yr)		550,000-1,000,000	700,000

3. ***Crusts coverage.*** This varies from 0% (areas of thick sediment cover) to 100 per cent (areas of thick crust "pavements"). The mean crust coverage for on-axis seamounts is estimated to be about 25 per cent, and for the off-axis seamounts (including the Johnston Island area) an average coverage of 40 per cent is anticipated.

4. ***Crusts density.*** This is estimated to average 1.34 grams per cubic centimetre for dry crusts and 1.95 grams per cubic centimetre for wet crusts.

5. ***Metal grades.*** The average metal grade, crusts tonnage, and resource estimates are presented in Table 1 for the United States EEZ adjacent to the Hawaii and Johnston Island crust deposits.

These parameters are used in the following model to estimate the resource potential of the Hawaiian study area.

1. The weight of crusts per unit area is estimated as follows:

   Kilograms crusts/ square metre = C_m = 0.1 AuDT,
   and Tonnes crust/square kilometre = C_k = 1,000 C_m

   Where Au = fraction crusts cover;

T = average crustal thickness (cm); and
D = dry weight density of crusts (gm/cubic centimetre).

2. The total resource potential (RP) of the area for crusts and for each metal are estimated as follows:

RP Crusts (t) = RP, = A_tC_k,
and RP Metal (t) = RP_m =
$A_tC_kM_c$

Where A_t = total area (km^2); C_k = t crust/square kilometre;
$M^{\sim}$ = metal concentration.

Model Results

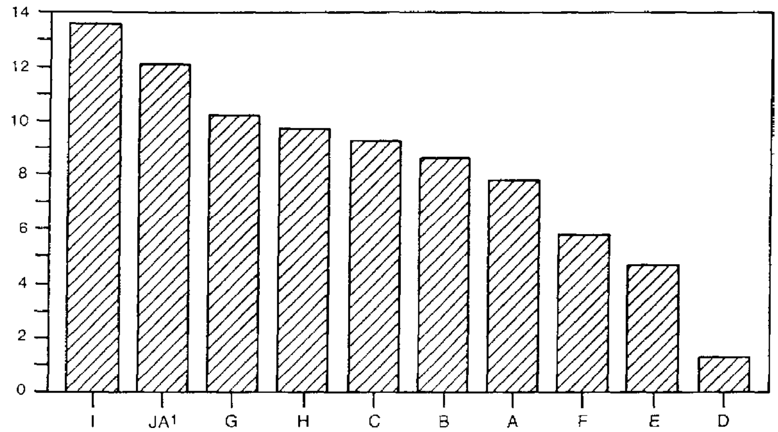
As shown in *Table 1*, the total in-place resource potential of the study area is substantial. If 10% of this resource proves to be commercially recoverable, it would supply a major portion of the United States needs for cobalt and manganese for at least 25 years (yr) (Marine Development Associates, Inc., 1987). Substantial quantities of iron are present in crusts which for some processes could be produced in conjunction with manganese as a ferromanganese product. However, under present industry marketing practices it is unlikely that the added iron units would add significantly to the total sales revenue of metal products.

Table 1 shows that for the United States EEZ adjacent to Hawaii, the excluded crusts resource is more than twice as large as the off-axis resource. However, because of the expected thinner average crust thickness and higher percentage of sediment cover, the majority of the excluded areas are not likely to attract commercial exploration interest. The most promising on-axis area (sub area G) is included in the areas open for potential lease sales. The off-axis areas are expected to contain the most favourable deposits from a possible commercial perspective.

In order to obtain an indication of the possible areas of highest commercial interest, the sub areas are ranked in Figure 3 based on gross in-place metal value. It is important to emphasize that gross in-place metal cannot be equated with the possible recovered metal value or profits. The dollar figures in *Figure 3* are only useful for a general ranking of areas on the basis of per unit area in-place value. As shown in *Figure 3*, the estimated highest average values per square meter of crust are for off-axis seamounts with sub area I having the highest value per square metres (m^2) and Sub area D having the lowest value.

Two important variables not considered in *Figure 3* are the size and roughness of seamounts. Small seamounts with permissive areas of less than about 200 km^2 may not attract as much commercial interest as much larger permissive areas because of the low potential for large, relatively smooth areas with thick crusts accumulations. Based on the analysis in this report, all off-axis sub areas and on-axis sub area G should receive greater attention for possible future leasing than sub areas D, E, and F.

Figure 3
GROSS In-Place Value



Crusts Deposits from the United States EEZ Adjacent to Hawaii and Johnston Island

<u>Sub-Area</u>
1 JA denotes EEZ adjacent to Johnston Island
Note: Values are based on the following assumptions: (a) On, Ni, Mn values (Sit) - 22,000, 8,000, 600 respectively (1985 dollars); (b) metals percentages in ore from Table 2-1; (c) crust thickness from 'Best Estimate" in Table 3-6 in Johnson et al. (1987); (d) crust density 1.34 g/cm^3

To date, the best crust deposit known is located approximately 100 km south of Johnston Island. The permissive area of the seamount is almost 1,500 km^2 and it contains about 10 million t of crust. The deposit thickness averages about 3 cm and is located on a series of small cones on a large volcanic platform (Halbach, 1985, personal communication).

<u>Mine Site Characteristics</u>

The purpose of this present resource assessment study is to define the nature and distribution of crust resources in the study area. The study is not intended to define specific mine sites. However, based on the authors' present state of knowledge about the physical characteristics of crust deposits in the Pacific, the parameters indicated in *Table 3* appear to be a useful guide to defining the broad physical parameters of a possible mine site. These parameters will undoubtedly be modified in the future as we increase our understanding about the distribution of crust resources.

It is reasonable to assume that a number of individual crust deposits will be required to sustain a commercial mining operation over the 15 to 20-yr period required for a major mining investment. Based on the hypothetical mine site characteristics in *Table 3*, it will require an area of roughly 600 km^2 to sustain one commercial mining operation for 20 years. *Table 4* is useful for estimating the size of crust resources for various crust thicknesses and percent coverages. This table, combined with the following examples, can be used to make rough resource estimates, resource metal contents, and to estimate mine site areas for a range of assumptions.

Resource Estimates. To estimate the tonnage of in-place crust resources in an area, multiply the appropriate tonnage number from *Table 4* times 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 is:

Crust Resource = 19,500 x 425 = 8,775,000 t (wet)

Resource Metal Content. To determine the in-place metal content multiply the appropriate number in the table times a dry density conversion (.6872) times the permissive area times the decimal metal content. For the above example, if the average cobalt grade is 0.008 (0.8%) the in-place cobalt resource is:

Cobalt Resource = 0.6872 x 19,500 x 425 x 0.008 = 45,561 t

Resource Data Problems

The resource assessment of the cobalt-rich manganese crusts of the EEZ adjacent to Hawaii and Johnston Island, as is the case with any resource assessment, is totally data-dependent. The quantity, accuracy, location, and appropriateness of the data determine the level of specificity which can be achieved by the resource assessment and hence the applications of the estimate. Therefore, the attributes of the data used in the present assessment are critical and clearly defined for the technical analyst as well as diverse members of the user community. The following discussion is an overview of the attributes of the data used in this study and provides insight to why and how data were used in the resource assessment.

Table 4
TONNES CRUST PER SQUARE KILOMETERS
(Wet Crusts, Specific Gravity = 1.95 g/crn^3)

Crust Thickness (cm)	Percent Cover					
	20	40	60	70	80	90
0.5	1,950	3,900	5,850	6,825	7,800	8,775
1.0	3,900	7,800	11,700	13,650	15,600	17,550
1.5	5,850	11,700	17,550	20,475	23,400	26,325
2.0	7,800	15,600	23,400	27,300	31,200	35,100
2.5	9,750	19,500	29,250	34,125	39,000	43,875
3.0	11,700	23,400	35,100	40,950	46,800	52,650
3.5	13,650	27,300	40,950	47,775	54,600	61,425
4.0	15,600	31,200	46,800	54,600	62,400	70,200
4.5	17,550	35,100	56,650	61,425	70,200	78,975
5.0	19,500	39,000	58,500	68,250	78,000	87,750
5.5	21,450	42,900	64,350	75,075	85,800	96,536

[a] To convert wet t to dry t multiply figures by 0.6872

Marine mineral resource data are unique when compared with data used in land-based resource assessments. The more obvious differences concern the sampling location, sampling control, and sample density. These factors are discussed below.

Sampling Location

Control of the sampling location presents a problem on two levels. First, it is difficult to determine within 1-5 kilometres (km) the location of the research vessel unless considerable time is taken to position the ship. Second, while the sampling device is operating several hundred or thousand metres below the vessel, its exact location on the ocean floor is largely unknown. A number of actions can be taken to locate more closely the ship and the sampling device. However, the cost may be inhibiting and the precision of doing so is far less than for land-based samples.

Sampling Control

Considerable uncertainty is introduced by sampling devices. The most common type of collection device used in sampling both crust and substrate material is a bottom dredge. Dredges vary in size, construction, and efficiency-factors that affect sampling results. As stated earlier, the dredge is towed along the ocean floor and during its traverse breaks off or picks up loose fragments of the ocean substrate. Although rather simple in concept, the actual use of a dredge to collect samples is a highly complex activity including several factors which impact the samples collected and the ability to evaluate the resultant data.

Dredge Traverse

The distance traversed by a single dredge haul is normally from less than one to several kilometres. As a result, the substrate contained in a sample haul may represent samples collected over a wide area and several substrate types. Even in dredge hauls of similar rock type the individual samples may represent slabs of bedrock and crust, encrusted boulders to cobble-sized fragments, talus material, and nodules. Overall, the fact that an individual dredge haul represents sampling over a substantial distance necessitates caution in ascribing either a dominant substrate type or the relative percentage of each substrate type.

Preferential Collection

The geometry of the individual dredge and its total weight affect the type of sample which will be collected. For example, only the largest dredges (so-called mega-dredges weighing several thousand kilograms) are large enough to remain continuously on the ocean floor during a dredge haul. Similarly, most dredges are constructed in such a manner that fine-grained material and water pass through the open mesh of the dredge. This preferential size selection may cause some bias in the types of samples collected. Smaller dredges also have the unfortunate attribute of "flying" during sampling (i.e., rising above the seafloor for considerable periods of time). Resulting samples, therefore, do not always represent the diverse substrate occurring within an area. Finally, dredges tend to fill with loose and easily collected substrate rather than hard massive material. The lack of these larger samples is particularly troublesome in terms of defining the engineering characteristics of crusts and substrate.

Dredging Procedures

The procedures and duration of an individual dredge traverse are in large part determined by the seafloor topography. Dredge hauls taken up steep slopes tend to be shorter than those taken along a continuous gentle slope. From a sample interpretation perspective, one would expect the latter to contain a larger proportion of bedrock samples than those taken at the base of slopes where talus and debris collect. Also, dredging operations sample best in more rugged terrains. As a result, much of the dredging activity may not sample the most favourable crust areas. Regardless of the inherent problems, dredging will continue to be the most common form of bottom sampling for marine resources.

Sample Handling

In a normal marine mineral resource sampling program, considerable bias may be induced by the handling, description, and selection of dredged samples. As a result, valuable data are lost during the sample handling phase of the program. A particular problem is that the volume of sample material may be very large and difficult to handle onboard ship. Many of the necessary descriptions and analyses that should be made on the fresh samples must await subsequent work onshore - a period of several days to several months in some cases. In such cases, only a limited subset of samples is adequately examined and stored on board and available for study onshore. The remainder of the material must be analysed without a context of its relationship to other samples or the dredge haul in total. This problem is compounded by the fact that not all the dredge material may have been retained by the scientist at sea, but rather only the more illustrative examples. This selection further biases the samples available for study and the results of subsequent analyses.

Sample Density

The number of dredge hauls and physical samples which may be collected during an individual cruise is limited ultimately by the available time within an area. Because of economic factors this time is normally limited; as a result, the number of samples is also limited.

Overall, within the Hawaiian study area the number of analysed crust samples to 1984 was approximately 50. Subsequent work during this study and by Hein et al. (1985) and Halbach et al. (1984) has increased the number of analysed samples to approximately 190. If these were equally distributed throughout the permissive areas of the study area (77,775 km^2) it would result in a sample density of 1 sample/409 square kilometres. Clearly the sample density within individual areas is considerably greater (e.g., 1 sample/45 square kilometres on site OF-1). In contrast, land-based reconnaissance exploration programme would normally have a sample density of 1 sample/ 2-3 square kilometres and for prospect evaluations at least 10 samples/ square kilometres.

Regional Implications

The sampling difficulties described above make it difficult, with this data set, to isolate the regional variance in ore grade and abundance from the true local and experimental induced variance components. Quantitative determination of the spatial distribution of crust grade and abundance could be initiated with a rigorous geostatistical analysis of these and other available data, and then completed with a field programme based upon the results of this analysis.

The present data on geochemistry increase the known analyses substantially but still represent a very small number of analyses for such a large area. Even when considered in terms of only the permissive area in total or individual seamounts, the sample density is still extremely sparse. As a result, any estimate of resource potential, necessarily bounded by the amount and location of geochemical data, must be considered preliminary.

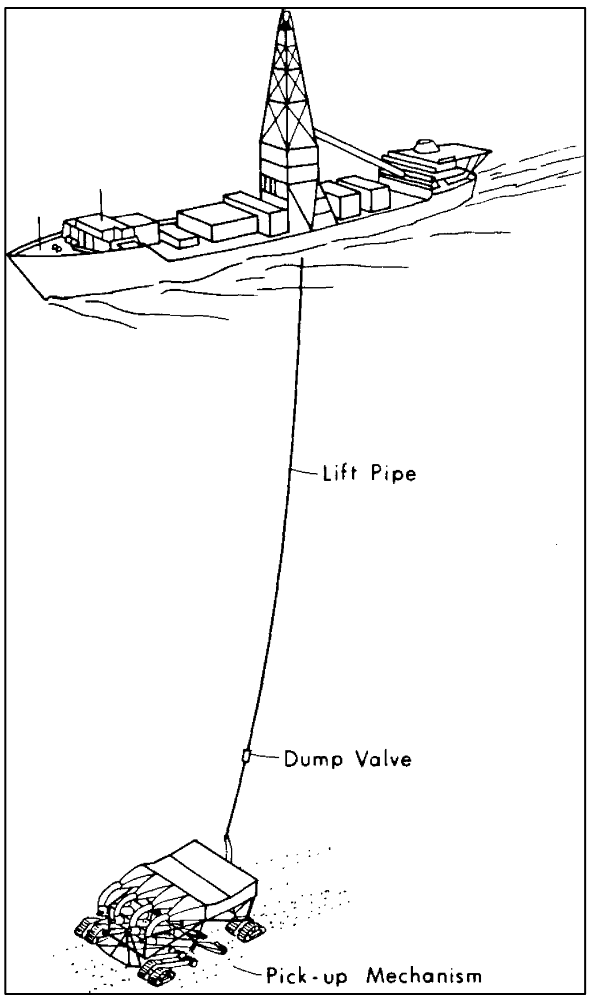
Mining System

System Description

The selected method for manganese crust recovery will 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 (*Figure 4*).

The mining machine would provide its own propulsion and travel at a speed of approximately 20 centimetres per second (cm/s) 1.66 feet per second (ft/s)]. The bottom machine (miner) would be approximately 8 metres (26.2 feet) wide by 13 metres (42.6 feet) long and 6 metres (19.7 feet) high, and would weigh approximately 100 tons in air.

MANGANESE CRUST MINING SYSTEM REQUIRED COMPONENTS
Figure 4



The miner would have articulating cutting devices which would allow the crust to be fragmented while minimizing the amount of substrate collected. Also on the miner, behind the cutter heads would be a series of parallel pickup devices consisting of either articulated hydraulic suction heads or a mechanical scraper/rake device. Approximately 95 per cent of the fragmented material would be picked up and processed through a gravity separator prior to lifting.

A candidate miner with rotary cutting drums, hydraulic pickup and gravity separation is shown in *Figure 5*. The hydraulic suction dredges are similar to trailing suction dredge heads commonly used with hopper dredges for sand and gravel mining.

The lift system would consist of a 27-centimetres [10-3/4 inches (in)] diameter pipe carrying a slurry of 10-20 per cent (by volume) crust and substrate. Compressed air would be injected into the pipe at approximately 1/3 of the water depth to achieve the necessary lift force.

Under normal operations, the mining ship and the miner would follow a coordinated track following bottom contour lines. System speed and/or pipe length would have to be altered to accommodate changes in depth over approximately 100 metres (330 feet). Steering of the miner would be used to manoeuvre around obstacles, over areas of particularly high abundance, or around a previously mined swath.

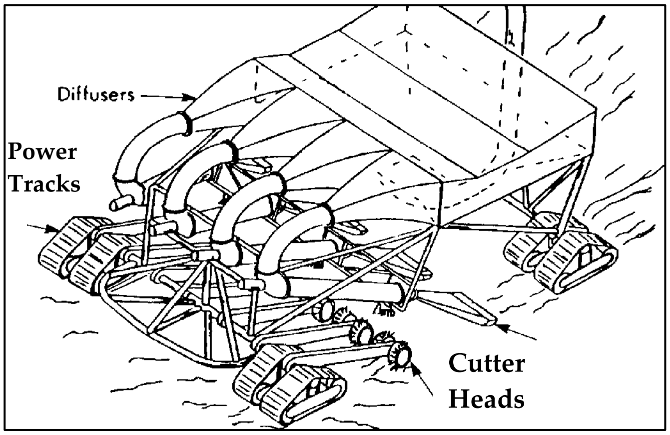
Bottom navigation would be by means of acoustic transponders. Ship positions with accuracies about 1 metre (3.3 feet) would be obtained by long baseline acoustic navigation. Transponders would be placed on an approximate 20 kilometres (12.4 miles (mi)) grid in the mining area. The miner's position would be determined within 5-10 metres (16-33 ft) accuracy using a short baseline navigation system with shipboard mounted transponders, and to within +1 m or better (relative to previous swaths) using for-ward and side looking sonar capable of tracking previous swaths.

Maintenance would be performed on the miner every 20-50 days to replace cutting teeth and other components. Recovery, repair and redeployment of the miner are expected to require 3-5 days, provided weather is acceptable. Allowing four days of down time for every 20 days of operation would result in 83 per cent mechanical availability. Weather down time is not expected to be significant in the Hawaiian archipelago, with waves averaging less than 2 metres (6.6 feet) most of the time and tropical hurricanes limited to about one every 5-10 years. An allowance of 10 per cent weather down time and an additional 10 per cent for other down time (e.g. ship dry dock) results in an overall availability of 245 days per year (d/yr). A conservative base case of 206 days of continuous mining per year has been used in sizing the mining system in this report. This figure is a compromise. General dredging experience indicates a yearly schedule of 100-150 days of operations (Read, 1986), while scenarios for deep seabed manganese nodule mining use scenarios which assume 300-day operating years.

Performance Parameters

Material flows for the base case mining scenario are summarised in *Figure 6* for the 1,000,000 t/yr operation and the assumed mining parameters are shown in *Table 5*. This scenario assumes 80 per cent fragmentation efficiency and 25 per cent dilution of crust with substrate during fragmentation. These values were selected during the Manganese Crust EIS Workshop in December 1984 as reasonable design goals for a miner, although achieving them may require a development effort. Higher recoveries with greater dilution appear achievable with existing technology, although any significant increase in dilution could be uneconomical.

MANGANESE CRUST MINER (HALKYARD, 1987)
Figure 5



<u>MAJOR DIMENSIONS</u>
Length: 13 m
Width: $ m
Height: 6m Weight: 100t
Installed Power: 900 KW

Figure 6. Base case material flows (wet weight).

	RESOURCE	<u>Crust (125 kg/m^2)</u>	<u>Substrate</u>
	↓		
	FRAGMENTATION	90.3 kg/sec.	30.1 kg/sec
	↓		
←	PICK-UP	85.8 kg/sec.	28.6 kg/sec
	↓		
←	SEPARATION	58.3 kg/sec.	14.3 kg/sec.
	↓		
←	LIFT	58.3 kg/sec.	14.3 kg/sec.
	↓		
	DEWATERING	57.2 kg/sec.	14.0 kg/sec.
	↓		
←	BENEFICIATION (land based)	51.4 kg/sec (1,000,000 mt/yr)	1.4 kg/sec.

Table 5
BASE CASE MINING PARAMETERS
(25% Substrate in Recovered Ore)

Operation	Recovery Efficiency (%)
Crust Fragmentation	80
Pickup Crusts	90
Pickup Substrate	95
Separation @ 0.25 m/s	
Crust Recovery	68
Substrate	52
Shipboard De-watering	
Crust	98
Substrate	98
Beneficiation	
Crust	90
Substrate	10

Depth of Disturbance into the Seafloor

The depth of disturbance will need to be controlled in order to maximize efficiency while minimizing dilution. Dilution is defined as the ratio of weight of substrate to weight of total fragmented material.

The cutting depth will depend on the roughness of the bottom over the width of the cutting tool. *Figure 7* shows the results of, a number of runs with a mining simulation programme showing fragmentation efficiency as a function of the non-dimensional ratio of depth of cut to RMS roughness. This indicates that a minimum cutting depth of approximately 3 times the RMS roughness, or the crust thickness (whichever is less), would be required to achieve fragmentation of 80% of the crust.

For the possible roughness of the seamount crusts (see *Figure 8*), this means a cutting depth of 15 cm for a 1 m articulating cutter head. Wider cutter heads would require corresponding greater depths of cut.

Quantity of Substrate Entrained with Ore

The amount of substrate fragmented depends on substrate hardness, cohesion to crust, thickness of crust, morphology of the crust/substrate interface and roughness of the crust surface.

Assuming that the substrate is hyaloclastic deposits (common in the Hawaii samples) and that the fragmentation model (described in §4.3 of the mining development scenario (Marine Development Associates, Inc., 1987)) is accurate, dilution based on present fragmentation methods will be between 25-70% (i.e. fragmented substrate will amount to 30-70% of the total material fragmented). Further data should be obtained on crust roughness, thickness variation, and substrate properties to confirm these values.

DEPTH OF CUT/ RMS ROUGHNESS OVER SWATH
Base Case Microtopography

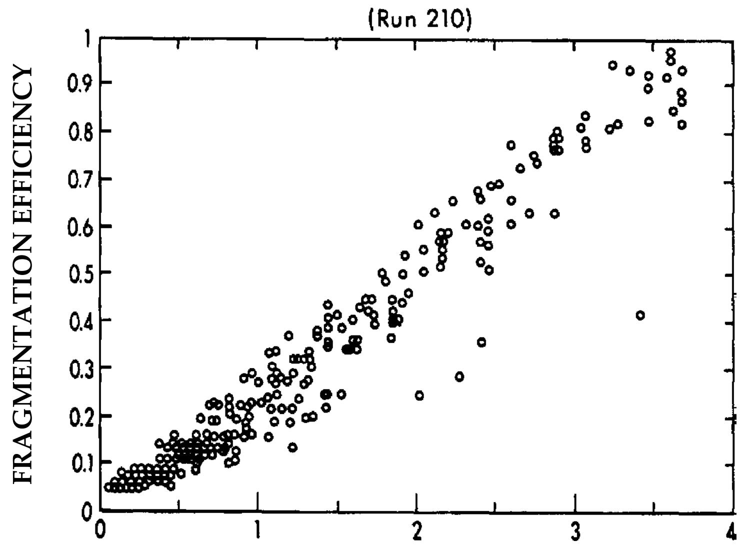


Figure 7. Efficiency vs. cut\RMS roughness.

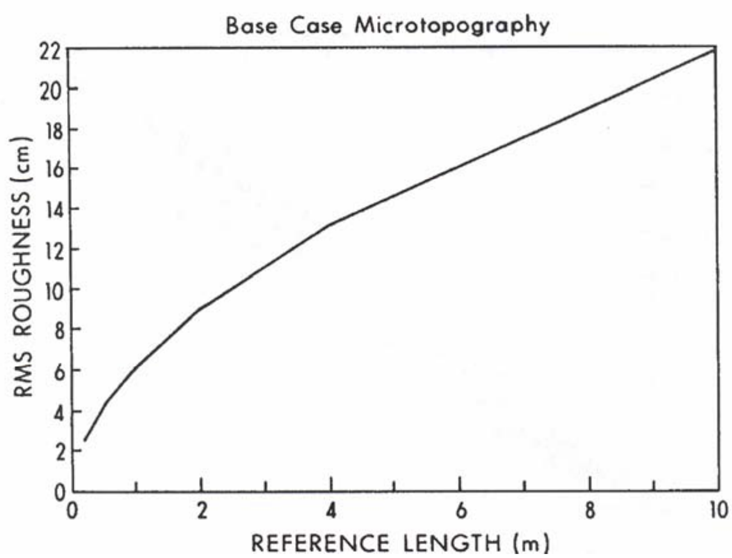


Figure 8 RMS roughness vs. reference length – base case microtopography

Harder substrates, such as basalt, would result in lower dilution of the crusts recovered. Since higher dilutions are likely to be uneconomic to mine, a dilution value of 25 per cent has been assumed as a base case for fragmentation performance. Achieving this lower value for dilution will require either selection of a mine site with lower RMS roughness values than assumed for the base case, development of new fragmentation methods or preferential mining on harder substrates.

Separation of recovered substrate from crust may be performed using screens, gravity settling, hydrocyclones or possibly froth-flotation. Preliminary work at the U.S. Bureau of Mines, Salt Lake City Research Center indicates that over 90 per cent removal of several substrate types can be accomplished with froth-flotation (Foot, 1985). For purposes of this study, we have assumed that 90 per cent of the substrate delivered to the ship could subsequently be removed by using froth-flotation.

Net Recovery Rates and Efficiency

Net recovery of crust depends on fragmentation efficiency, pickup efficiency, and separation losses. As previously discussed, fragmentation efficiencies depend on microtopography and depth of cut. Values of 80 per cent or more are reasonable based on a postulated roughness.

Pickup efficiencies will also depend to a lesser extent upon roughness, size of fragmented particles, and type of pickup device. Hydraulic suction heads will collect 90-100 per cent of loose material in its swath, but could lose larger fragments around its edges. Also, it may not be practical to have 100 per cent dredge head coverage across the swath, so windrowing devices might be required. *Figure 6* summarises the overall recovery rates. A mechanical scraper would recover 60-90 per cent of the material, depending on its depth of cut. A base case value of 90% for pickup efficiency has been selected based on hydraulic suction. Sizing and separation of the material will result in additional losses ranging from approximately 20-50 per cent. Based on this assessment, from 40-60 per cent of the crust in the path of the miner would be delivered to the mining ship. Other computer simulations of mining operations using variable crust thickness and actual, fine-scale (resolution about 2 cm horizontal) topographic measurements from Cross Seamount in Sub area A have been completed recently (Morgan, 1989; Morgan et al., 1988). These indicate that the recovery efficiency and dilution of ore with substrate assumed in this scenario are reasonable.

Note that this does not represent the net recovery from the mine site, which needs to take into account the area between swaths and the amount of overlap. This latter net recovery efficiency, as much as net recovery rate, has the effect of reducing actual abundance.

The percent of the mineable crust covered by the miner is approximately equal to the ratio of collector width to the collector width plus distance between swaths. To avoid significant overlap, the nominal separation of tracks should be on the order of navigational accuracies, or approximately one meter. This would result in a value of 90 per cent.

Generation of Suspended Solids at the Seafloor

Solids could be suspended at the seafloor due to the following: (a) track and mining tool disturbances, (b) crusher or screen products, (c) hydrocyclone or gravity settler overflow, and (d) lift system dumping. Since the crust deposits are almost void of sedimentary overburden, the turbidity plume from bottom disturbance is expected to be slight - especially when compared to nodule mining (see NOAA, 1981).

Fines generated by cutting could become suspended if they are not collected. Impact tests performed for this analysis suggest that 13% of the fragmented material is smaller than 2.5 mm. If a Weibull distribution for size is assumed, about 2 per cent of the material is less than 1 mm. Sizing by the Bureau of Mines yielded approximately 0.5-1 per cent of the samples minus .075 mm (Willard, 1984), and settling observations from crushed samples suggest a minimum effective floc size of around 60 micrometres.

It thus appears that the amount of fines generated in fragmentation will be approximately 1% minus 100 micrometers. For the base case, this corresponds to about 9 kilograms per second (kg/s) fine particles contributing to a bottom plume during mining operations.

A large percentage of these particles would be collected in the hydraulic dredge head and passed into the separator. Most of these (92 per cent) would pass out the overflow of a gravity-type settler at a distance above the seafloor of approximately 4 metres (13.1 feet). *Table 6* gives estimated separator overflow properties for the base case.

Table 6

PROPERTIES OF SOLIDS IN SEPARATOR OVERFLOW (Base Case - 25% Dilution)

Size (mm)	Crust		Substrate	
	Flow Rate (kg/s)	Settling Vel. (^{o} V^s)	Flow Rate (kg/s)	Settling Vel. (=/s)
Total %	27.4 (100%)		14.3 (100%)	---
12	0		6.6 (46%)	25.0
6	0		3.3 (23%)	20.0
2.5	9.6 (35%)	25.0	1.3 (9%)	17.0
1.0	9.6 (35%)	16.0	1.7 (12%)	11.0
0.1	7.1 (26%)	5.0	1.3 (9%)	4.0
<0.1	1.1 (4%)	0.6	0.1 (1%)	0.5
<0.01	0.1 ---	0.006	0.01 ---	0.005

It is not possible to estimate with any confidence the particle size distributions of the mined material that is delivered on the mining vessel. Virtually all of the fine material is removed on the seafloor in the separator and contributes to the benthic discharge. However, abrasion between the lift pipe and the lifted ore will generate more fine particles which will contribute to the surface discharge. Proper design of the shipboard dewatering operation will minimise this discharged fraction, but it will not be possible to eliminate.

For the purposes of modelling, two situations are defined. First, a worst case discharge of 50 kg/s solids, and then a normal discharge of 1.4 kg/s which conforms to the base case material flows presented in *Figure 6*. To examine how different particle sizes will respond to the model, 70 per cent of the material is assumed to be 1 mm in radius (sand-sized), 28 per cent is assumed to be 0.01 mm (silt-sized), and 2 per cent is assumed to be 0.002 millimetres (clay-sized). The impact analysis of the EIS is based upon the worst case discharge. Since the 50 kg/s discharge constitutes over 65 per cent of the entire yearly production, it is an extreme worst case. The results of the modelling and the consequent impact analysis are therefore not very sensitive to the assumed particle size distribution. The normal discharge, even if it consists of 70 per cent clay-sized material, will not equal the clay-sized fraction assumed to be discharged in the worst case selected.

Settling Rates of Suspended Solids

Table 6 lists estimated settling rates for crust fragments. These are theoretical values based on unhindered settling velocities using either Stokes' (Re <1) or Newton's (Reynold's Number, "Re" >1) law for the drag coefficient, and an assumed shape parameter based on crushed coal slurry.

Observations of fractured samples indicate settling of the silt cloud layer in a salt water solution of approximately 15 centimetres per minute (cm/min).

System Reliability

As discussed in *System Description* above, a four-day maintenance period is likely every 20-50 days. This could change depending on the wear life of the fragmentation equipment.

The reliability of other equipment on board the miner should be such that the mean time between failure (MTBF) of the system is at least 2-3 times the wear life - otherwise unplanned down time at frequent intervals is likely.

The miner should include provisions for dumping material blockages, or at least provide the option of on-bottom repairs using remotely operated vehicles (ROV). The use of these vehicles may also be considered for routine maintenance such as changing of the cutting drums.

The miner ship could stay at sea for eleven months per year. A total availability of 65-75 per cent is likely for the miner and lift system, allowing operations between 235-275 d/yr. Prudent design suggests designing for lower availability in order to have excess capacity should it be needed. A total of 206 d/yr has been assumed for the base case of continuous lifting of ore.

Consequences of Subsystem Failures

The most environmentally significant failure is likely to be the loss of power to the lift system, causing a back-flow and discharge from a dump valve 25-50m (83-165 ft) above the seafloor. The contents of the lift system would consist of approximately 24 min equivalent mining production (the residence time of solids in the lift pipe). This amount would be on the order of 30 t of solids.

This occurrence would be a very rare event, and in any case the solids would settle rapidly with only a few percent being fine enough to travel any distance.

Other subsystem failures, such as those which might occur on the bottom miner, would not have any environmentally significant effects.

Test Mining Operations

Prior to commercial operations, approximately five years of testing of a prototype mining system would be necessary to develop adequate operational control and to acquire sufficient ore for pilot-scale metallurgical processing tests. The mining system for these tests would be the same as that described above, but would operate for much shorter periods of time. We estimate the completion of one test each year, each comprising an average of 12 days of continuous operation.

Mining System Alternates

Mining of crusts is similar to manganese nodule mining in some ways, and consider-ably different in others. Nodule mining concepts (see, e.g. Halkyard, 1982; Pearson, 1975; Welling, 1981) developed by mining consortia in the last decade consisted of a hydraulic dredge and a slurry lift system. The nodule dredge head, or "collector," is either towed across the bottom by the lift pipe/hose combination, or it is self-propelled. Recovery of the nodules themselves is relatively easy (compared to crusts) since the nodules adhere loosely to the sedimentary bottom. One of the more severe problems in collecting nodules was the directional control of the collector and suspension on the soft clay bottom.

Manganese crusts, on the other hand, have a strong adhesive bond to the substrate and do not appear to separate easily. The key to successful mining will be the ability to attain efficient crust recovery while avoiding dilution with substrate. This was relatively easy in the case of nodules since the fine clays could be re-moved by washing after the nodules were recovered as slurry. This will not be the case for the substrate collected with crust, and new separation techniques will be needed.

An alternative mining system for nodules using the continuous line bucket (CLB) system was tested in 1970 by (Masuda, Cruickshank and Mero, 1971). Recently, the Japan Resource Association (1985) studied the applicability of this method to crust mining. While there is some merit in the CLB's simplicity, the most likely commercial crust mining systems will probably utilise the hydraulic lift together with a mechanical fragmentation system attached to a self-propelled collector. This type of system has a better likelihood of efficient crust recovery and substrate separation, and has been favoured by nodule mining consortia in the past. The economics of ocean mining has tended to favour efficient mining techniques even at a cost penalty over simpler but less efficient systems such as drag-line or continuous line bucket dredging. The CLB could be competitive if it is found that crust may be separated from substrate easily, or that the substrate is soft enough to be removed by washing. Further study of this possibility will need to be carried out as more data become available from specific sites.

The following sections discuss the likely scenarios for five crustal mining functions: (1) fragmentation, (2) crushing, (3) lifting, (4) pick-up, and (5) separation.

Crushing and separation are optional steps which may be incorporated into other functions. For instance, fragmentation, as utilised in continuous coal mining, results in the desired size of ore for hauling.

Lift System

The lift system could be either hydraulic or mechanical (e.g., continuous line buckets). As discussed previously, the likely mining scenario would consist of a hydraulic pump - either an airlift or submerged mechanical pump. The technology of these lift systems is described in the literature (see e.g. Halkyard, 1978).

A base case airlift system is assumed for this scenario. In order to conserve power, the pipe diameter is increased in the upper 600 m to reduce mixture flow velocities. Also, the air supply system is closed with the slurry discharging into a pressurized air/slurry separator on the ship. The compressor inlet air is drawn from this separator under pressure to reduce compressor power requirements.

Metallurgical Processing

Overview

In developing the metallurgical processing component of the overall scenario, a fresh look was taken at the compatibility of resource and relevant extractive metallurgy. Although ferromanganese oxide crust is apparently closely related to ferromanganese oxide nodules from the same broad area of the Pacific, recognition of the crust as a potential resource has occurred more recently. Accordingly, it was necessary, for purposes of this chapter, to fill in the gaps of information concerning composition and structure of crust. This was done by using a combination of judgment and analogy with the nodules.

It should also be noted that the extraction of possible by-products is not assumed in this scenario. An aggressive search for by-product uses for processing wastes could have two benefits. First would be the sales of additional products, such as titanium and cerium, fine filler material for plastics (hydrometallurgical waste), and agricultural supplements containing molybdenum, phosphate, calcium, copper, zinc, iron, etc. The second benefit would be reduction of some of the very substantial costs for waste disposal.

The point here is that any industry capable of handling the complex chemical engineering problems of metal separation from such a complex and unusual matrix, may well be in a position to create special products responding to special needs in society, or pursuant to the deliberate reduction in quantity of disposable wastes.

Assays of the potential value metals in cobalt-rich crust had been sufficiently well defined that it was readily seen, at present and anticipated metal prices, to be a cobalt ore with nickel as an important by-product and with minor by-product values of copper and zinc and, perhaps, platinum. It is important to note that the roles of cobalt and nickel are reversed for crust as compared with nodules. Furthermore, the economic importance of copper is sharply less. These quantitative differences are reflected in the selected metallurgical routes, which are keyed to high recovery of cobalt in marketable form. This feature more or less ensures an equally high, or higher, co-recovery of nickel. Copper and zinc are recovered as a sulphide concentrate for shipment to a custom smelter.

The status of manganese as a value element of the crust requires more scrutiny. While its average assay appears to be somewhat less than for the nodules, manganese represents about 27 per cent of the total solids content of the crust; so that manganese oxide makes up over 40 per cent (manganese and iron oxide minerals together comprise about two-thirds of the weight of anhydrous crust). Given that the price of natural high-grade manganese ore is very low, even on a contained-manganese basis, production of a higher value manganese product is indicated for the crust.

Production of standard high-carbon ferromanganese would be appropriate for the pyrometallurgical process, and the amount would be smaller in relation to its market than would be the corresponding production of cobalt metal in relation to that market. For the hydrometallurgical process example, production of manganese metal, synthetic manganese dioxide or simple manganese inorganic chemicals is appropriate. However, the demand for these products would be swamped by full production from crust. Therefore, in a leach process, the major portion of the manganese content of the crust would require disposal.

The strategy adopted for a conceptual metallurgical extraction operation based in the Hawaiian Islands consists of producing a sulphide concentrate of the nonferrous value metals, i.e. cobalt, nickel, copper, and zinc for conversion to saleable product forms. This could be carried out at a nearby refinery that is part of the metallurgical plant or at a remote refinery, as on the Gulf Coast. The configuration of an appropriate cobalt refinery plant and operation has been described in this section, in the event that the vertically integrated approach is selected over processing to concentrate for shipment elsewhere.

Whatever could be done on board ship by way of size reduction and salt extraction would reduce the requirements for completing these operations on shore. In order to upgrade the ore adequately for metallurgical processing, the shore facility would subject crust that is reclaimed from the receiving and storage ponds to whatever supplemental size reduction would be required for effective elutriation of residual sea salts. Ore of the proper size range would then be treated in an elutriation plant to extract the contained sea salts into hot (about 90 °C) process water. Following elutriation as described, the residual soluble salt content of the crust should be reduced to not more than about 10% of its original value.

In addition, if adequate selectivity in mining and subsequent separation and rejection of co-mined substrate is not achieved prior to delivery to port, a mineral beneficiary step would need to be inserted in advance of metallurgical processing. This is because significant quantities of substrate of any of the three recognized types (basalt, altered basalt, or hyaloclastites, and phosphorite) would be detrimental to either or both of the extractive metallurgical alternatives.

At the December 1984 Workshop in Honolulu, it was concluded by the mining sector that the lifting of significant amounts of substrate is highly probable. Subsequently, it was proposed that the gross composition of the ore as lifted onto the ship would range between roughly 20 per cent and 42 per cent of contained substrate. The mining strategy was then revised to provide for lifting sufficient ore to include 1.1 million t of cobalt-rich crust, wet-basis, i.e., containing the characteristic approximately 30% of pore water. This strategy allows for the loss of 0.1 million t of crust to the tailings of the mineral beneficiation plant. The mineral beneficiation step cannot be confidently specified at this time; in the absence of firm information that a simpler physical separation would suffice, a froth-flotation separation, preceded by ore grinding, was assumed. In addition, the amount and composition of the beneficiated ore (assumed to consist 90%, or greater, of crust) were taken to be the same as had been earlier assumed for the undiluted crust. Note: As indicated earlier in this appendix, the unit "tonne" is abbreviated "t" and always denotes a metric ton.

Pyrometallurgical Processing

For the base case 700,000 t of anhydrous, beneficiated ore to be treated annually, the smelting alternative would produce about 5,800 t of cobalt and 3,000 t of nickel contained in a granulated sulphide matte. High-carbon (78 per cent Mn) ferromanganese, comprising as much as 150,000 annual t of contained manganese, could be produced as a co-product but with attendant difficulties. In particular, the iron content of the manganese-rich slag from the initial reduction smelting (to a molten ferroalloy of the other value metals) would need to be lowered by a factor of about 2.5 in order to arrive at the proper manganese-to-iron ratio for smelting to ferromanganese.

A second major difficulty in utilization of the smelter slag for ferromanganese production lies in the presence of impurities, including phosphorus, alkali metals, and copper, at sufficiently high levels to be of concern in meeting purity specifications for commercial ferromanganese. Moreover, realization of a net advantage from the heat content of the molten smelter slag is unlikely, owing to serious operational problems anticipated to result from inadequate contact between the liquid slag and the low-density carbonaceous reductant. A study of economic trade-offs, outside of the scope of this study, is needed to define the ore value of the contained manganese.

The fuel and energy requirements of the fully integrated smelting process are very large. For the plant without ferromanganese production, they are annually about 290,000 megawatt hours (MWh) of electricity, 260,000 t of coal for various uses, and 75,000 t of coke for reduction. There are also substantial requirements for silica flux (about 290,000 t) and sulphiding agent (about 21,000 t of anhydrous gypsum). Depending upon the quantity of substrate assumed to be present in the mined ore, process water and total steam requirements are 3-4 million cubic metres (m3) and 250,000-420,000 t, respectively. With or without ferromanganese production, cooling water requirements for smelting are appreciable, estimated at 13 to 14 million cubic metres annually for once-through cooling, or roughly 0.7 in the same units for cooling tower make-up.

The annual consumption of coal for all uses would be more than doubled by the production of ferromanganese. In addition, electrical energy consumption would be increased to as high as 780,000 MWh. The greatly increased lime requirement (about 200,000 t for maintaining a suitable slag composition in the ferromanganese furnace) would dictate installation of a lime kiln to calcine about 390,000 t of limestone/yr.

Waste streams from smelting/refining would consist mainly of smelter and converter slags, about 900,000 t annually, and small amounts of collected smelter dusts and of iron oxide precipitate (from the cobalt refinery). Disposal of these materials is assumed to take place on site. In addition, about 55,000 t, including accompanying water, of gypsum sludge ($CaSO_4$ $2H_2O$) would be produced in neutralization and would require appropriate treatment for disposal on land. The slags, however, would most likely be inert, vitreous substances that might find use as aggregate in road construction, as land fill, etc. Assuming that slags will pass the EPA toxicity test and other applicable leachability tests, they could probably be stored on land without further treatment. EPA elutriation tests for toxic metals were performed on slag generated at the Bureau of Mines Avondale Laboratories. No measurable metal releases were detected, and the slags passed the EPA requirement for sanitary land-fill (Haynes, Magyar and Godoy, 1987). On the order of 1.6 hectares (ha) (4 acres) of land would be required for storage of one year's production of slag. If the local situation is not atypical, land so used could be reclaimed. The feasibility of disposal of the slag at sea could also be considered, in logistic as well as environmental aspects. (*For land transport of substrate tailings slurry pumping is assumed - Ed.*). Estimates of the compositions and fluxes of all waste streams from the pyrometallurgical process are presented in *Table 2-6* of the Final EIS.

Disposal on land of the large quantity of substrate tailings (0.7-1.8 million t, including accompanying water) from ore beneficiation would entail 3-4 times the land requirement as for the granulated slags. The main impediments to returning substrate tailings to the sea are their relatively fine state of subdivision and the possible presence of residual flotation reagents. In this, as in other significant aspects, it would be highly desirable to reject as much substrate as possible on the ocean floor during mining of the crust.

The smelter/refinery complex would have a work force of approximately 450-600 personnel of all categories, of which about 200 are assigned to the refinery (operating and maintenance personnel and foremen). Total area requirements for 20 years of operation would range from about 112 to about 224 ha (280-560 acres).

Hydrometallurgical Processing

The complexion of the leach plant is qualitatively different from that of the smelter. The ore is not dried, but is moved as slurry through the high-pressure leach reactors. Direct electrical energy use for the leach plant and refinery combined is appreciably less (about 90 MWh for pumps and motors, etc., and, mainly, for electrowinning) than for the smelting route. However, the process steam requirements are considerably greater: about 510,000-680,000 t of steam, depending upon the ore grade assumed. The substantial consumption of sulphuric acid, estimated at 175,000 annual t, dictates that a dedicated sulphuric acid plant be located on the site. In that case, sulphur (about 66,000 t/yr) would be shipped in as raw material, rather than sulphuric acid. For economy of fuel use, the sulphuric acid plant would be integrated with the boiler plant in production of process steam and electricity.

In addition to burning to sulphur dioxide/trioxide for sulphuric acid manufacture, about one-eighth of the sulphur would be reacted with hydrogen to produce about 10,000 t of hydrogen sulphide for precipitating the cobalt-nickel-copper-zinc sulphide concentrate. The necessary hydrogen could be generated in a small auxiliary plant reforming liquefied petroleum gas (LPG). Other raw materials requirements include about 32,500 t of lime-equivalent for neutralization of free acid. The consumption of ammonia (about 540 t) would be largely for make-up purposes, as it is proposed to recycle ammonia from ammonium sulphate solution by means of a standard "lime boil."

Process water consumption by the hydrometallurgical route is conspicuous at about 5.4 to 7.0 million m^3/yr; a good deal of thought and engineering analysis would need to be given to its efficient utilization and proper disposal. Use of solar evaporation ponds would not be particularly attractive. Because of the large amount of water associated with the ore as delivered in slurry form to the port, possibilities for recycle of barren leach liquor to the leach process are limited.

After neutralization and manganese removal, the bleed-off stream of process water from pressure leaching and sulphide precipitation would contain essentially only magnesium and potassium sulphates, plus whatever soluble halides were not removed during washing and elutriation or vented during leaching. In other words, this treated process water would possibly meet drinking water standards in terms of toxic solutes (but not, of course, with respect to total dissolved salts). If so, it would be worth considering whether the water is suitable to be transported back to the mine site and there used to slurry the drained ore for transfer from the mine ship to the transport ship. Similarly, clarified wash water from the on shore elutriation (salt extraction) plant could, presumably, be used in transferring the drained ore from the transport ship to the port facility. The most likely option, chosen here for the mining scenario, would be an ocean outfall.

Quantity of substrate tailings and associated disposal considerations and land requirements would be the same for the hydrometallurgical route as for the pyrometallurgical route. The largest solids waste stream of the leach process is that contained in the approximately 1.3 million t (solids plus slurry water) of leach tailings, including gypsum slurry generated in neutralization and ammonia recovery. Assuming that the leach tailings will be deposited in lined ponds with an average pond depth of 10 metres, 5-8 ha (12-20 acres) of land would be required each year for leach tailings disposal. Estimates of the compositions and fluxes of all waste streams from the hydrometallurgical process are presented in *Tables 2-3* and *2-4* of the Final EIS.

The leach-plant/refinery complex would employ approximately 600 personnel of all categories, of which about 50 would be assigned to the sulphuric acid and hydrogen sulphide plants. Estimated total land area requirements for a normal 20-year operation range from 185-350 ha (470-880 acres).

<u>Environmental Factors</u>

Beneficiation

According to the above conceptual plant description, the substrate waste stream (flotation tailings) will contain 0.37-0.91 million t of finely divided solids annually and approximately an equal amount of process water. The substrate wastes will contain manganese (mainly in unseparated crust material) and probably several inorganic and organic flotation reagents, whose presence may preclude disposal at sea. Disposal of the substrate wastes on land would require lined ponds meeting design requirements as specified in the Resource Conservation and Recovery Act (RCRA).

The ponded tailings would be covered with water to prevent drying out with consequent blowing of fine solids on windy days. After each disposal pond had been completely filled, it would be covered with earth and returned to a natural state (revegetated).

Disposal of the flotation tailings would require a substantial amount of land. Assuming that the lined tailings ponds are filled to a depth of 10 m, between 3.2 and 7.2 ha (8 and 18 acres) of land would be required each year for disposal of tailings. Hence, for a 20 or 30-year operating life of a process plant, disposal of substrate tailings will require 64 to 144 ha (160 to 360 acres) of land.

A froth-flotation plant can be operated in a reasonably clean manner. Certain types of flotation reagents can generate unpleasant odours in the work area (depending, of course, on the reagents which are used), but should not pass beyond the perimeter of the plant in sufficient concentration to be objectionable. All processes of this nature can be contained in tightly sealed buildings.

<u>Pyrometallurgical Processing</u>

Ore Drying Steps

Except for the filter cake feed to the drier kiln, this section of the process involves the movement of heated, dry solids. Fine particulates can fall from transfer conveyors and collect on surfaces throughout the plant, including floors, plat-forms, beams, etc. Transport of solid particulates to general plant areas is likely to occur when maintenance crews work on the equipment. The kilns and bins are sealed, so they are not significant sources of gaseous or particulate emissions. However, points where solids are transferred between two pieces of equipment are always potential sources of emissions.

The process gases are a potential source of fine particulate emissions to the environment from the plant stack. The use of filter bag-houses for all process gases generated in the drier and pre-reduction kilns would eliminate almost all of the discharge of fine particulates to the general plant surroundings.

Smelting and Alloy Treatment

The process waste from the pyrometallurgical sequence consists mostly of slag, which would be produced in quantities sufficiently conspicuous as to warrant concern over its proper treatment and disposal. Under consideration here are the combined smelter (major) and converter (minor) slags or, if ferromanganese is produced, the converter and ferromanganese furnace slags. Unless these slags are more than quantitatively different from slags produced commercially from analogous terrestrial ores or (in the laboratory) from manganese nodules, they will be chemically inert, vitreous materials. Furthermore, they will be coarsely granulated at most, and not finely divided.

Based on the Bureau of Mines in-house characterization of waste materials from the processing of manganese nodules (Haynes and Law, 1982), one can predict with some confidence that slags from the smelting of cobalt-rich ferromanganese oxide crust will meet the EPA toxicity test and other applicable leachability tests for safe disposal on land. Following normal practice for land disposal of innocuous metallurgical slags, a pile or heap would be constructed of the waste slag. The major detriments of this disposal method would be visual and land-use related. To the extent feasible, the waste slag would be employed locally as aggregate, as ballast for road beds and as land fill. For slag not utilised in this way, the preferred alternative would be disposal at sea. Obscuration of the water column and ingestion by organisms would not be predicted to be consequential.

Should slags from the processing of cobalt-rich crust unexpectedly not meet toxicity and leachability criteria, the at-sea and slag-heap disposal options might be closed. In that case, it would probably be necessary to store the waste in lined or otherwise impervious ponds according to applicable RCRA rules. This would be a relatively disadvantageous outcome, since the volume of slag generated annually would be roughly comparable to or greater than that for separated substrate from the prior ore beneficiation step. The two waste streams would probably not be combined, owing to their different characteristics and in view of the possibility of subsequently finding an inexpensive treatment or beneficial use for either or both. Unlike the case for waste substrate or leach tailings (if a hydrometallurgical process were employed), dewatering and dusting would not be factors of concern for waste slag. Moreover, the slag-filled excavations could promptly be covered with earth, re-contoured as appropriate and revegetated.

Further consideration of the treatment of slags and minor process wastes is not warranted for this pre-EIS study. Characterization, treatment and storage of wastes generated in the conceptual processing of ferromanganese oxide ocean nodules, whose average composition is only quantitatively different from that of the cobalt-rich ferromanganese oxide crust, has been described in four earlier reports that may be consulted for more detailed information:

1. Dames & Moore and EIC Corp. report to NOAA (1977)
2. Haynes and Law, Bureau of Mines IC 8904 (1982)
3. Rogers, Golden and Halpern report to USBM (1983)
4. Arthur D. Little, Inc. report to NOAA (1984)

Hydrometallurgical Processing

Waste Water Treatment

The aqueous waste stream from the sulphide precipitation stage contains some sulphuric acid, which was generated as the metals reacted with the hydrogen sulphide, and remaining soluble salts. These salts are, chiefly, sodium, manganous, and magnesium sulphate. Some fluoride from the fluorapatite present in the ore and a small concentration of chloride, originating from unelutriated seawater, may also be present in the barren liquor. In the illustrative process design, approximately 25 tonnes per hour (t/hr) of barren liquor is returned directly to the leach circuit to make up the initial slurry. The remaining 99 t/hr would be treated for, at minimum, acid neutralization and manganese removal. Potential recovery of the 5 per cent or so of the manganese contained in the beneficiated ore, that is assumed to be solubilised in the pressure leach step, is considered in the next section.

Neutralized and demanganized barren leach liquor would contain essentially only solutes that are major constituents of seawater, in particular, magnesium, sodium, potassium, sulphate and remaining chloride (see *Tables 2-3 and 2-4*). Accordingly, it should be acceptable, as well as conserving of valuable fresh water, to ship the dilute, treated liquor to the mine site as ballast (in place of seawater) in the hold of the transport ship. On location, it would be used for slurry-transfer of ore from the mining ship and for whatever elutriation of sea salts could be effected on board the transport ship. The resulting waste water, intermediate in composition between the barren leach liquor and ordinary seawater, ought to be suitable for discharge into the ocean, after filtration to remove entrained solids (finely divided crust and substrate).

Solid Waste Treatment

The major wastes of the hydrometallurgical process, as identified above and quantified in §A4.5, are the substrate tailings, the pressure leach residues, or tailings, gypsum, $CaSO_4 \cdot 2H_20$, and spent process liquor. Treatment and disposal strategies are proposed above (*Waste Water Treatment*) for the last-named, aqueous waste stream. The other three waste streams contain solids in the form of washed slurry. The type of treatment required for disposal on land will be determined by whether the wastes are considered hazardous by virtue of the content and leachability of toxic or otherwise environmentally deleterious constituents.

Any hazardous designation of the substrate tailings would likely be a consequence of reagents added during the beneficiation step for removal from the desired crust. It is likely that waste substrate, if disposed of on land, would be kept separate from the leach tailings and the waste gypsum. Here and there, gypsum produced in sulphuric acid neutralization is utilised as a byproduct for such end-uses as wallboard, retarder in cement, and soil conditioner and nutrient. For the most part, however, natural gypsum is employed for these uses, and waste gypsum is discarded. In general, one cannot count on finding beneficial uses for the gypsum that would be produced by the hydrometallurgical plant. Thus, land disposal is indicated for at least a major portion of the waste gypsum, as well as for the leach tailings. Indeed, unless a beneficial use, or an economical treatment making possible at-sea disposal, might be developed for either or both solid wastes, they would probably be disposed of together.

The severity of problems associated with disposal of these solid wastes on land will be affected very much by weather and by how much the intended disposal sites are net evaporation, or transpiration, areas. This site-specific characteristic is determined by climatic conditions: temperature, relative humidity, rainfall, wind, and seasonal variations thereof. In the phosphate regions of central Florida, which are flat and experience heavy rainfall, the waste gypsum of phosphoric acid production is commonly stored on the ground in huge, long heaps, or "stacks." In addition to questions as to whether runoff from that waste gypsum is truly innocuous, land-use and visual impacts militate against this form of disposal in Hawaii for any of the solid wastes under consideration.

In the same Florida phosphate regions, the voluminous clay wastes of phosphate rock beneficiation are impounded within big earthen "dams." The environmental drawbacks to this disposal method are equally as obvious as for the gypsum stacks. It would appear, then, that the land-fill method of disposal is the most appropriate for solid wastes generated by the conceptual hydrometallurgical plant and for which at-sea disposal is not feasible. The stringency of the regulations governing construction and maintenance of the disposal facilities depends, of course, on whether the waste is considered hazardous.

The minimum treatment of the solid wastes prior to disposal is thorough washing so as to remove to acceptable levels any possibly deleterious solutes from the associated slurry water. The major solid wastes from the hydrometallurgical processing of cobalt-rich crust should be sufficiently stable toward degradation and further leaching by slurry water and rainwater as to avoid an official hazardous classification. This view is suggested by their composition and chemistry and supported by leachability tests performed on similar wastes from manganese nodules processing (Haynes and Law, 1982). Should this favourable result be confirmed on actual crust processing wastes, a simple land-fill technique should suffice. Disposal areas would then be relatively simply constructed and maintained and subsequently re-claimed by distribution of removed top-soil, recontouring as appropriate and revegetating.

For the worst-case situation, where one or more of the wastes unexpectedly does not qualify for classification as innocuous, disposal requirements would be more stringent, as summarised in the following excerpt (Kahane et al., 1985):

Hazardous Waste Disposal

- Incorporate liner to prevent migration of waste out of facility during its active life.
- Collect and remove leachate from the facility and ensure that leachate depth over the liner does not exceed 1 ft (0.45 metres).
- Design to control flow during at least 25-year storm.
- Cover waste or manage unit to control wind dispersal.
- Prevent overtopping or overfilling.
- Install system to monitor groundwater in uppermost aquifer.
- Implement compliance monitoring program if hazardous constituent is detected.
- Upon closure, design final cover (cap) over waste unit to minimize infiltration of precipitation.
- Maintain effectiveness of final cover.
- Operate leachate collection and removal system.
- Maintain groundwater monitoring system (and leak detection system where double liner is used).
- Continue 30 years after closure.

Plant Inputs and Outputs

General

Between 1.37 and 1.91 million t of ore (crust plus unseparated substrate) will be delivered to the plant each year. As described in the preceding sections, the ore will be comminuted and elutriated with process water to extract sea salts from the porous matrix. The ore will then be beneficiated by flotation to produce one million t of upgraded ore containing not more than 10 per cent of substrate material. This metallurgical plant feed will consist of 700,000 t (oven-dry basis) of solids and 300,000 t of pore water that is at least ten-fold more dilute with respect to sea salts than the original pore seawater. The major and value metal contents of the beneficiated ore are:

Element	Percent	Tonnes per year
Cobalt	0.92	6,440
Nickel	0.47	3,290
Copper	0.074	520
Manganese	24.2	169,400
Iron	14.5	101,500

In this study, metallurgical processes were examined for the production of cobalt and nickel in saleable form (e.g., electrolytic cathode), of copper (and zinc, if recovered) as an intermediate sulphide product, and of manganese, principally as ferromanganese. The types and quantities of raw materials and the energy requirements for the two processes selected are quite different. The metal production statistics and process requirements are summarised for each process separately in the subsequent subsections. The metallurgical plant is assumed to operate during 330 d/yr.

Pyrometallurgical Processing

The estimates of the process requirements and metal production and waste generation rates are shown in *Tables 7* and *8* for two configurations: one in which only the nonferrous metal values are recovered and a second, in which ferromanganese is additionally produced (from the smelter slag). The data presented are derived from preliminary material and energy balances for each plant configuration and do not necessarily correspond to an optimised plant design.

Approximately 75,000 annual t of coke is consumed as a reductant for the nonferrous metals in the pre-reduction kilns. This coke could be in the form of relatively low-cost coke "breeze" (undersize, including coke dust). Coke for this use might even be replaced by certain high-grade coals of lower cost. Silica flux is used to form a molten slag with the major metallic constituents of the crust; an estimated 287,000 t, combined, is consumed in the smelting furnace and in the top-blown rotary converter. Approximately 21,000 t of calcium sulphate, anhydrous basis, is consumed as a sulphur source in the sulphidation step to produce the cobalt-nickel-copper matte. Although gypsum (hydrated calcium sulphate) sludge is a byproduct of the cobalt refinery, it has been assumed that an anhydrous form would be purchased for matte smelting. A relatively small amount of lime (9,000 t) is required for ammonia regeneration in the cobalt refinery. However, if ferromanganese is produced from the smelter slag, an additional approximately 200,000 t of lime would be required to maintain a suitable slag composition in the ferromanganese furnace. At the large tonnage needed for ferromanganese production, it would probably be necessary to install a lime kiln at the plant site. In that circumstance, the plant would need an estimated 390,000 t of limestone/yr for calcining to lime, including the requirement for the cobalt refinery.

An estimated 11,600 t of oxygen is required annually for treatment of the iron, cobalt-nickel alloy. However, if ferromanganese is produced at the plant site, the oxygen requirement would be increased to about 18,800 t. The additional oxygen would be used, in effect, to move more iron into the converter slag in order to achieve a higher manganese-to-iron ratio in the smelter slag feed to the ferromanganese furnace. The pyrometallurgical plant will use 2,400-3,400 million cubic metres (standard temperature and pressure) of process air per year. The process air, provided at low pressure by fans, is used for combustion, except for 8 per cent of the amount, which is compressed to high pressure and used in the cobalt refinery for oxidation of the cobalt-nickel matte. Used process air, with its oxygen content largely replaced by carbon dioxide, is a major component, together with ventilation gases, of the gaseous waste stream of the plant (*Tables 7 and 8*). Carbon electrodes are consumed in the electric furnaces. Annual consumption is 920 t, carbon-basis, for the smelting furnace and another 2,880 t for the ferromanganese furnace.

Table 7

PROCESS REQUIREMENTS, PRODUCTION, AND WASTES
PYROMETALLURGICAL PROCESS PLANT

Item	Annual Quantity	
	NonFerrous Metals	NonFerrous Metals and Ferromanganese
A. Major Raw Materials		
1. Ore (crust and substrate) (million t)	1.37 to 1.91	1.37 to 1.91
2. Beneficiated ore (million t)	1.0	1.0
3. Coke (t)	74,700	74,700
4. Silica flux (t)	287,000	287,000
5. Calcium sulfate (dry) (t)	21,000	21,000
6. Lime (t)	9,000	--
7. Limestone (t)	--	390,000
8. Sulfuric acid (t)	small	small
9. Ammonia (makeup) (t)	540	540
10. Sodium hydrosulfide (t)	200	200
11. Solvent extraction reagents (kg)	ca. 200	ca. 200
12. Oxygen (t)	11,600	18,800
13. Carbon electrodes (t)	920	3,800
14. Process air (million m^3)	2,400	3,400
15. Flotation reagents (t)	700 to 900	730 to 980
16. Coal (t)		
a. process use	145,900	>237,400
b. power and steam	113,400	<291,000
c. lime kilns	--	65,000
Total	259,000	593,000
B. Utilities		
1. Electrical energy (MWh)	285,100	<780,000
2. Steam (thousand t)	250 to 420	250 to 420
3. Cooling water (m^3)		
a. direct consumption or	13,260,000	14,250,000
b. cooling tower makeup	650,000	690,000
4. Process water (million m^3)	2.85 to 4.10	2.85 to 4.10
C. Metal Products		
1. Cobalt (t)	5,710	5,710
2. Nickel (t)	2,990	2,990
3. Copper (in sulfide ppt.) (t)	120	120
4. Ferromanganese (78% Mn) (t)	--	195,000
D. Waste Streams		
1. Substrate tailings (million t)	0.74 to 1.82*	0.74 to 1.82*
2. Smelting furnace slag (t)	780,000	780,000

Item	Annual Quantity	
	NonFerrous Metals	NonFerrous Metals and Ferromanganese
3. Converter slags (t)	98,000	180,000
4. Smelter dusts (t)	200	200
5. Iron oxide precipitate (t)	120	120
6. Gypsum (t)	55,000*	55,000
7. Process gases (million m^3)	2,400	3,400
8. Ventilation gases (million m^3)	1,890	2,490

* Includes both solids and accompanying water

The pyrometallurgical process is highly energy-intensive, especially if ferromanganese is produced. The plant for production of nonferrous metals, only, will require about 290,000 MWh of electrical energy, most of which is consumed in the electric smelting furnace. Other important users of electrical energy are the cobalt refinery, machinery for the ore-receiving and elutriation sections, drive machinery for the drying and pre-reduction kilns, and the environmental control systems. The total plant power requirement, approximately 35 MW, is a small fraction of the output of a modest-size electric power plant.

If ferromanganese is also produced, the total annual energy consumption will be about 910,000 MWh, or 115 MW of power. However, there is a potential for co-generation of electricity from un-reacted carbonaceous reductant carried in the off-gases from the ferromanganese furnace. The co-generation potential is estimated at 130,000 MWh, if an amount of coal equal to that used to reduce the ferromanganese is recovered and burned in a waste-heat boiler connected to a turbine generator. The <780,000 MWh requirement shown in *Table 7* is the difference between these two figures. If coal injection in ferromanganese smelting were several times stoichiometric, there would be a correspondingly greater co-generation potential. Actual quantities would be very dependent on the specifics of the ferromanganese furnace design and operation. In general, electricity required for process use, in addition to any that is co-generated as described, would be obtained from a central utility station or would be generated on-site in a small industrial power station.

Coal is used as fuel in the driers and in the pre-reduction kilns and as reductant in the ferromanganese furnace. Estimated annual coal requirements are 260,000 and 590,000 t for the nonferrous metals plant and the nonferrous metals plus ferromanganese plant, respectively. Several months coal supply will be stored on-site. All of the coal used in the process will be pulverized on-site prior to feeding into the kiln burners or into injection lances in the ferromanganese furnace. Relatively small amounts of fuel oil will be used for heaters in the smelter building and for the heating of buildings generally. There is a steam requirement of 250,000-420,000 tonnes per year (t/yr), primarily for the ore elutriation section and for the cobalt refinery. This steam could be raised in conjunction with on-site power generation. The fuel for raising this amount of steam is about 5,000 t of coal per year.

Water is a major factor in the plant operation. The estimated need for process water is essentially unaffected by ferromanganese production and is in the range 2.9-4.1 million t/yr. The corresponding flow [1,600-2,300 gallons per minute (gal/min)] is equivalent to the output of an average municipal well field. Sources of process water could be underground wells (connecting to aquifers), mountain streams, lakes, etc. Depending upon the quality of the water supply, it may require treatment prior to use, e.g., clarification to remove suspended solids, chemical treatment to remove undesirable components, such as dissolved iron, etc.

A second major water need is for cooling purposes. Energy balances on the illustrative processes show a requirement of 13-14 million t of cooling water annually, if direct cooling of the process equipment is employed. The amount in question is equal to roughly 8,000 gal/min. Where water is in short supply, an alternative is to use an evaporative cooling water system (i.e. cooling towers); the corresponding water make-up is estimated at 650,000-690,000 t/yr. Direct cooling would be indicated if the plant were located near the ocean and if the appropriate process equipment were designed for use with seawater.

The cobalt production rate is calculated at 5,710 t/yr, for an overall yield of 89 per cent. Estimated annual nickel production is 2,990 t, or 90 per cent yield. The predicted production of copper is very low, namely, 120 t/yr, or 23 per cent yield. Although it should be possible to recover some zinc, no calculations have been made for this element. For the case where the ferromanganese furnace is operated, it is assumed that the equivalent of 195,000 t of 78 per cent ferromanganese is produced, representing about 90 per cent of the manganese contained in the crust feed. These figures for manganese are probably optimistic.

The principal solid wastes of the overall process are the substrate tailings from ore beneficiation, furnace slags, dust from metallurgical process equipment, and precipitated solids from the cobalt refinery. The quantities of these wastes are summarised in *Table A-7*. The amount of smelter slag is large, and its production will be accompanied by substantial discharge of process and ventilation gases.

Without specific proposed sites for the pyrometallurgical processing plant, only very rough estimates of land requirements can be made. The total area needed for a plant will include land for: (I) storage of ore and other raw materials; (2) process buildings and outdoor process equipment; (3) support buildings; (4) service structures such as a powerhouse; (5) roads, parking, etc.; and (6) disposal of wastes. Apart from the waste disposal area, the total plant area requirement will be determined by the size and location of buildings and of storage, processing, and services areas, in consideration of the site topography and the movement of major materials. The probable ranges of land-area requirements for the conceptual pyrometallurgical plant are summarised below by major category:

Table 8

Plant Area	Hectares	Acres
Raw materials storage and handling, buildings, process equipment, etc	24-48	60-120
Slag disposal (20 years)	24-32	60-80
Substrate tailings, slag tailings and other waste slurries	64-144	160-360
Total	112-224	280-560

The predominant land-area requirement is for disposal of wastes. Raw materials storage and processing are estimated to require 10-12 ha, of which the process buildings will take up only 1-2 ha. An earlier study (Dames & Moore and EIC Corp., 1977) indicated a land area requirement of 40-50 ha for a pyrometallurgical plant processing 900,000 t of nodules/year and recovering the nonferrous metals and ferromanganese. The roughly estimated land-area requirements for disposal of slag are appreciably less than those for leach tailings, mainly because the height of the slag heap has been reasonably assumed to be about 30 metres as opposed to the assumed 10 m depth of the tailings pond.

The number of people directly employed in various capacities is estimated at 450-500 for a plant recovering only cobalt, nickel, and copper, and 550-600 for a plant which also produces ferromanganese. This staffing includes hourly operating and maintenance personnel, direct supervision, support services (such as quality control, engineering, accounting, purchasing, etc.), and general plant management, but it does not include sales personnel, research and development staff or other corporate support which may be provided by a parent company.

Hydrometallurgical Processing

The process materials requirements and metal production and waste generation rates are summarised for the sulphuric acid pressure leach plant in *Tables 9* and *10*. The quantities shown were estimated on the basis that only the nonferrous metal values (cobalt, nickel, copper, and zinc) are recovered.

Of the major process materials, elemental sulphur is used to produce sulphuric acid on-site for leaching the beneficiated ore and to generate hydrogen sulphide for selectively precipitating the nonferrous metals from the pregnant leach solution. An estimated 58,000 t of limestone (shown as 32,500 t of equivalent lime) is used mainly to neutralise residual sulphuric acid in the acid leach liquor and in the barren solutions after precipitation of the metal sulphides. The remainder is converted to slaked lime (calcium hydroxide slurry) and used to recover ammonia from the raffinate of the cobalt refinery. In these uses, the limestone becomes converted into gypsum, which is ultimately discarded from the plant with the pressure leach residue, or tailings.

A small quantity of anhydrous ammonia is required as make-up in the cobalt refinery. Relatively small quantities of hydrogen (for onsite manufacture of hydrogen sulphide), solvent extraction reagents (make-up for the cobalt refinery), and flotation reagents are also consumed in the hydrometallurgical complex.

Fuel is required for the generation of electric power and steam. It is estimated that about 83,000 t of coal would be consumed annually for these purposes at the lower ore delivery rate of 1,370,000 t/yr and that 99,000 t of coal would be needed for 1,910,000 t/yr of ore. The increase in coal consumption is attributed to the steam energy needed to heat the larger quantities of ore and process water.

Electrical energy is employed in the hydrometallurgical plant primarily to drive pumps, mechanical agitators in reactor tanks, and mechanical equipment such as thickeners, flotation cells, sulphuric acid plant, etc. At 86,000 MWh/yr, the electrical energy consumption is only about 30% of that for the pyrometallurgical process without manganese recovery. Net steam consumption, mainly for the pressure leaching step and for the elutriation (salt extraction) step is estimated at 510,000 and 680,000 t for the lower and higher ore delivery rates, respectively.

Table 9

PROCESS REQUIREMENTS, PRODUCTION, AND WASTES
HYDROMETALLURGICAL PROCESS PLANT

Item	Annual Quantity	
	Minimum Ore	Maximum Ore
A. Major Raw Materials		
1. Ore (crust and substrate) (t)	1,370,000	1,910,000
2. Beneficiated ore (t)	1,000,000	1,000,000
3. Sulfur (t)	66,200	66,200
4. Lime (t)	32,500	32,500
5. Ammonia (makeup) (t)	540	540
6. Hydrogen (m^3)	100,000	100,000
7. Solvent extraction reagents (kg)	ca.200	ca.200
8. Flotation reagents (t)	650	900
9. Coal (t) (generation of power @ steam)	82,700	99,250
B. Utilities		
1. Electrical energy (MWh)	85,900	85,900
2. Steam (t)	512,400	681,000
3. Cooling water (m^3)		
a. direct cooling	3,191,000	3,191,000
b. cooling tower makeup	154,000	154,000
4. Process water (m^3)	5,410,000	7,015,000
C. Metal Products		
1. Cobalt (t)	5,365	5,365
2. Nickel (t)	2,900	2,900
3. Copper (in sulfide ppt.) (t)	420	420
D. Waste Streams		
1. Substrate tailings (t)	740,000*	1,820,000*
2. Leach tailings (t)	1,183,000*	1,183,000*
3. Iron oxide precipitate (t)	120	120
4. Gypsum (t)	80,000*	80,000*
5. Process gases (million m^3)	490	430
6. Ventilation gases (m^3)	na	na

* Includes both solids and accompanying water

Table 10

SUMMARY OF SUPPORTING PLANT SERVICES AND OFFSITES
HYDROMETALLURGICAL PROCESS PLANT

Service	Minimum Ore 25% Substrate	Maximum Ore 50% Substrate
1. Water (m^3/d)		
Process Cooling	16,400	21,300
Direct	9,670	9,670
Cooling Tower Makeup	470	470
2. Steam (t/d)	1,550	2,060
3. Electricity, MW		
Plant Operation	10.8	10.8
Plant Generation	--	--
Net Requirement	10.8	10.8
4. Process Gases		
Air (m^3/d)	1,490,000	1,490,000
5. Sulfuric Acid Plant (t/d)	530	530
6. Hydrogen Sulfide Plant (t/d)	30	30
7. Fuel Storage		
Coal (t)		
Oil (t)	--	--
8. Wastewater Discharge (m^3/d)	13,360	17,450
9. Process Gas Discharge (m^3/d)	1,310,000	1,310,000
10. Hooding and Ventilation Gas Discharge (m^3/d)	na	na

Small quantities of cooling water are required in the leaching and sulphide precipitation sections of the plant and in the cobalt refinery, but the major use of cooling water is in the sulphuric acid plant. In total, about 3.2 million t of cooling water is required annually (equivalent to about 1,800 gal/min). Compare the much larger cooling water requirement for the pyrometallurgical complex. If the hydrometallurgical complex were located near the ocean or near sufficient stream flow, direct cooling could be used. Alternatively, cooling towers would be used, in which case the annual make-up of cooling water would be about 154,000 t (86 gal/min). A still larger amount of process water is needed, estimated at 5.4 million t for the lower ore delivery rate and 7.0 million gal for the higher. The major fraction of the process water is used in the elutriation and pressure leaching operations, including counter-current washing of the leach residue.

The hydrometallurgical plant as described will produce 5,365 t of cobalt/yr, or 83 per cent of that contained in the beneficiated ore. This estimated cobalt yield is somewhat lower than that for the pyrometallurgical process, primarily because of the assumed limitation of 85 per cent average solubilisation of cobalt in the pressure leaching step. Nickel production is estimated at 2,900 t annually, or 88 per cent overall yield. Copper recovery is significantly higher than in the pyrometallurgical process; it is calculated at 420 t/yr, or about 80 per cent overall recovery.

These are two large slurry waste streams. These are the substrate tailings from ore flotation (740,000 and 1,820,000 t annually for the two ore-input cases, respectively) and 1,180,000 t of tailings from the acid leach steps. These figures include both the solids and the accompanying slurry water.

The process-gas waste stream from the hydrometallurgical complex is estimated at 740 million cubic metres (at standard temperature and pressure or STP) annually. This figure includes small amounts of gases discharged from various points in the sulphuric acid pressure-leach plant, but the largest volume is derived from the on-site manufacture of sulphuric acid for the leaching operations. The second major source is spent oxidation-air from the autoclaves of the cobalt refinery. Total waste gases from the hydrometallurgical plant have about one-third the volume (at STP) of total waste gases from the pyrometallurgical plant.

Supporting plant services and off-sites for the hydrometallurgical processing plant are summarised in *Table 10*. The estimated process water requirement is 16,400-21,300 cubic metres/d. This consumption rate, 3,000-3,900 gal/min, is equivalent to the out-put of a moderately large municipal water system. Approximately 9,700 cubic metres/day (1,800 gal/min) of cooling water would be used by the plant if direct cooling were employed. The use of cooling towers would reduce the daily water requirement to about 470 cubic metres (86 gal/min).

The plant requires provision of 1,550 to 2,060 t of steam per day and 10.8 MW of electric power. It is assumed that coal would be burned in a fluidized-bed boiler to generate steam on-site. (An advantage of this type of combustion system for industrial steam generation is excellent control over emissions of nitrogen oxides, sulphur oxides, and particulates.) If the required electric power were not available from a central power station, a co-generation unit could be built at the plant site to provide both the steam and electric power requirements of the process. In any case, the sulphuric acid plant would be integrated with steam generation so as to take advantage of the significant reaction heat attending sulphuric acid production.

The hydrometallurgical plant uses about 1.50 million cubic metres of air per day, including about 1.33 million for the production of 530 t/d of sulphuric acid. The remaining major use of process air is in the autoclaves of the cobalt refinery. A relatively small amount of air is required for the burning of fuel in the 30 t/d hydrogen sulphide plant.

The hydrometallurgical complex will discharge an estimated 13,400-17,500 cubic metres of waste water daily. This waste water is generated largely in the elutriation and acid leaching sections. There will be some hooding and ventilating gas requirements, but the quantity has not been estimated. The ventilation gases will consist primarily of air but may contain small concentrations of noxious chemicals (e.g., hydrogen sulphide and ammonia), or acid mist (electrolytic tank-houses). After appropriate treatment, the ventilation gases would be discharged to the general plant stack with the process off-gases.

A rough estimate of the land requirement has been made based on the areas needed for: (1) storage of ore and other process materials; (2) process and off-site equipment; (3) operations and support buildings; (4) services, such as powerhouse and acid plant; (5) roads, parking, etc; and 6) disposal of wastes. Estimated ranges of sectional area requirements are summarised below:

Plant Area	Hectares	Acres
Raw materials storage and handling, buildings, process equipment, etc	25-50	60-120
Substrate tailings (20 years)	60-140	160-360
Leach tailings (20 years)	100-160	250-400
Total	185-350	470-880

By way of comparison, it was estimated in a recent study (Arthur D. Little, Inc., 1984) that an ammonia leach plant with ferromanganese production would require 600 ha of land for processing 3 million t of ocean nodules/yr.

The above-tabulated area estimates show that disposal of the substrate tailings (ore flotation step) and the leach residues impose the major area requirements, if these materials must be discarded on land. For these estimates, it was assumed that the waste ponds are 10 m deep, but tailings ponds are much deeper than this at many domestic mining operations. The area requirement for slurry waste disposal would be reduced inversely with average pond depth.

The number of people required for the plant is estimated at approximately 600. Staffing includes hourly operating and maintenance personnel, direct supervision, support services (such as quality control, plant engineering, accounting, purchasing, etc.), and general plant management. Sales, research and development and other corporate staff who would likely be involved in such a venture are not included in the estimated number of plant personnel.

Accidental Release

Perspective

Process plants for cobalt-rich ferromanganese oxide crust will be large and complex industrial facilities through which large quantities of material in solid, liquid and gaseous form will pass. While much of this material is innocuous and is transferred or processed at ambient conditions, some is processed at high temperatures and/or pressures. Accidental release, or discharge, of more than an insignificant quantity could result in its widespread dispersion and the development of a hazardous situation. Hazards could also result from the uncontrolled release of flammable or toxic liquids or gases, or of other materials that could cause environmental damage if dispersed. Chronic releases of smaller amounts of material, as from undetected accidents, improperly designed equipment, or malfunction of the process, could also create hazardous situations.

The possibility of the release of such materials and the consequences of their release are recognized in the detailed plant design, and measures are taken to decrease the risks to an acceptable level. Since the present analysis is based on conceptual designs of crust processing plants, it is not possible to describe in detail the measures that would be taken to reduce risks or to quantify the consequences of an accidental release. However, it is possible to describe the amounts and types of materials that would be of concern if accidentally released from crust processing plants. These are specific to the process used, e.g., pyrometallurgical or hydrometallurgical, while the other categories apply to any type of process plant.

Ore Storage, Elutriation and Beneficiation

Although about 150,000 t of wet mined ore is inventoried in the ore storage area, the probability of its accidental release would be very low for a properly designed plant and selected site. The storage ponds would be in-ground; dusting would not be troublesome, because the solids would be covered with water. About 2,500 t of ground solids are inventoried in the salt-extraction reactors in slurry form, but uncontrolled release of this amount of material is highly unlikely, since the elutriation area would be diked to contain spillage. Comparable amounts of material are inventoried in bins as filter cakes, and about 200 t/hr of coarsely milled ore would be moved as moist solids to and from the elutriation tanks by enclosed conveyors. Good maintenance and careful housekeeping would be required to prevent dispersal of manganese and other oxide constituents of the ore, in the form of dusts emitted from the equipment or resulting from spillage and drying. The reactors and filters would be hooded to control steam emissions, for operational as well as for environmental reasons.

Approximately 10,000 t of finely ground ore is inventoried in the ore beneficiation plant with about two-thirds of the total being held as slurries in in-ground thickener tanks and, therefore, not of major concern. The separated substrate wastes are pumped to disposal in slurry form, while the washed, beneficiated crusts are filtered and transported as filter cake to the metallurgical plant for recovery of the metal values. The previously mentioned techniques would be used to control dusting and spillage. Relatively small amounts, possibly of the order of 10 kilograms per hour (kg/hr), of liquid flotation agents will be added to the pulp to effect separation of crust from substrate. While odorous, and hazardous by virtue of flammability, these reagents are generally either absorbed on the solids or dissolved in the slurry water and, so, are not likely to be dispersed in their original form in the event of a release in the flotation area.

The major environmental and health hazards in the ore storage, elutriation, and beneficiation sections of the plant would be chronic releases of fine manganese oxide and other oxide-containing dusts. Chronic releases can generally be prevented or substantially reduced by proper plant design, operation, maintenance and house-keeping.

Pyrometallurgical Plant

In keeping with the original stipulation, the pyrometallurgical plant proper is considered, for purposes of this analysis, not to include a cobalt refinery. The in-plant inventories or consumption rates of hazardous materials and the conditions under which they are stored or processed are summarised for the pyrometallurgical process in *Table 11*. This list is not intended to be fully comprehensive since it does not include minor or incidental materials commonly used in processing, such as anti-dusting agents, chemicals for process water treatment, chlorine used for potable water purification, etc. While release of these minor materials could be hazardous, their in-plant inventory is small and their properties are well known; accordingly, they are usually considered to be of less concern than major process materials.

Table 11

HAZARDOUS MATERIALS INVENTORY, PYROMETALLURGICAL PROCESS

Material/Origin/Use	Composition (Particulates)	Condition	Amount
A. Gases (STP)			
1. Prereduction kiln	CO	~1 atm, 900° C	900 m^3/min
2. Smelting furnace	CO	~1 atm, 1400° C	250 m^3/min
3. Sulfiding converter	CO, S	~1 atm, 1400° C	100 m^3/min
4. FeMn furnace	CO	~1 atm, 1500° C	300 m^3/min
5. Oxygen to process		3 atm, 50° C	15 m^3/min
B. Liquids			
1. Oxygen		10 atm, -150° C	200 t
2. Fuels		Ambient	50 t
C. Solids			
1. Coke		Ambient	20 x 10^3 t
2. Coal		Ambient	60 x 10^3 t
3. Dried crust (ore)		150° - 200° C	2 x 10^3 t
4. Pre-reduced solids		825° C	3 x 10^3 t
5. Process dusts		150° - 825° C	500 t
6. Fume		Variable	5 t

Molten slags or alloys pose an obvious immediate hazard. However, they generally cannot be transported beyond the plant boundaries by accidental discharge, because they solidify rapidly. They are innocuous as solids and, therefore, are not included. The solids which are listed in *Table 11* are included because they can be dispersed as airborne particulates.

Although hot, dusty, and toxic by virtue of their composition, carbon monoxide and sulphur-containing gases produced in the dryers, furnaces and converters are present in relatively small amounts. The equipment in which they are produced is normally maintained at slightly sub atmospheric pressure, so that the production of these gases can be stopped rapidly if a release is detected. Reducing gases, containing carbon monoxide, would be burned in waste heat boilers for energy recovery prior to release. All off-gases would be scrubbed, if necessary, to meet emission limits on nitrogen and sulphur oxides.

Oxygen is included in the hazardous materials inventory, because it supports combustion of other materials. Significant amounts of oxygen are held in inventory as pressurized liquid and would vaporise and disperse rapidly if the containment vessel were ruptured or if leaks developed in transfer piping. Fuels are included for obvious reasons, although the in-plant inventory of liquid fuels for vehicles and process uses is small, and its storage is conventional.

The movement of large amounts of fine, dry solids through a pyrometallurgical process plant results in the generation of substantial amounts of dusts and presents a possible hazard from either sudden or chronic releases of particulates. Solids conveyors would be enclosed, and transfer points would be hooded and ventilated to reduce emission to the plant environment. Careful housekeeping would prevent spills from being dispersed. All process exhaust streams (such as dryer or furnace off-gases) and fugitives control streams (as from transfer-point hoods) would be passed through bag-houses, electrostatic precipitators or other devices to remove particulates.

The discontinuous, ferroalloy phase of the pre-reduced crust solids is pyrophoric. Ignition is prevented by maintaining it under reducing conditions. Transfer of molten materials from the smelting furnaces, converters, and ferromanganese reduction furnaces via ladles or launders will result in the production of fine particulates or sulphurous gases fumed from the very high temperature fluids. For process reasons, the furnaces themselves, including charging ports, penetrations for electrodes or lances, etc., would be carefully sealed and hooded to minimize infiltration of air. Tap holes and skim bays would be hooded and provided with high-volume ventilation for control of fugitives; exhaust gases would be passed through bag-houses or precipitators to remove dust, which would be recycled to the extent possible. Slag and matte granulators and cooling pits would also be hooded and ventilated to control vapours and particulate emissions.

The inventory of dried solids, dusts and fume in the plant is relatively small, and the probability of massive release and dispersal is quite small, since these materials are held at atmospheric pressure and mostly within buildings. The major concerns in a pyrometallurgical plant would be the release of noxious gases during upset conditions and/or the chronic release of particulates from a variety of sources.

Coal and coke storage requirements are modest and would be handled in a conventional manner. Anti-dusting agents would be used to control dispersion of particulates during storage and retrieval.

The properties of all of the materials listed in *Table 11* are well known, and all operations in the pyrometallurgical process plant are known from practice for analogous terrestrial ores. It is not likely that new or untested designs would be required or that new standards would need to be developed for the design or operation of the plant described. Based on historical data, expected failure rates of equipment or systems that would lead to uncontrolled releases of these materials would be of the order of 10-3 to 10-6 events per year (see U.S. Nuclear Regulatory Commission, 1975). Therefore, the probability of an accidental release occurring during the 20-year plant operating life is very low.

Hydrometallurgical Plant

For the purpose of this analysis, the hydrometallurgical treatment is considered to be carried out as an integrated process, from ore leaching to metals refining. The in-plant inventory or consumption rate of hazardous materials and the conditions under which they are stored or processed are summarised for the hydrometallurgical process in *Table 12*. The list is not fully comprehensive, since minor and incidental materials commonly used in processing are excluded, as for the pyrometallurgical process. Partially processed crust material is included although; based on analogy with similar types of tailings, the leached solids are not likely to be toxic. The large flow of sulphur dioxide, trioxide-containing gases occurs in the on-site sulphuric acid plant, and the small flow of hydrogen, sulphur, hydrogen sulphide occurs in the on-site hydrogen sulphide plant. The hydrogen sulphide is compressed and used to precipitate the value metals as sulphides; ammonia is used in the cobalt refinery; and hydrogen is generated and stored on site for use in the production of hydrogen sulphide. The gas inventories in the sulphuric acid and hydrogen sulphide plants are small; operating pressures are near ambient; and the production processes are easily controlled. Accordingly, massive releases of these gases are very unlikely. Gas generation can be halted quickly if a release is detected in any of these plants.

Table 12

HAZARDOUS MATERIALS INVENTORY, HYDROMETALLURGICAL PROCESS

Material/Origin/Use	Composition	Condition	Amount
A. Gases (STP)			
1. Sulfuric acid plant	SO_2, SO_3, N_2	~1 atm, 550° C	900 m^3/min
2. H_2S plant	H_2, S_2, H_2S	~1 atm, 400° C	20 m^3/min
3. Hydrogen plant	H_2, CO_2, CO	20 atm, 600° C	20 m^3/min
4. H_2S to process		10 atm, 50° C	13 m^3/min
5. Hydrogen		20 atm, 50° C	3 x 10^3 m
6. NH_3 to process		3 atm, 50° C	1.5 m^3/min
B. Liquids			
1. Leach solution (ore leach plant)	H_2SO_4 dissolved salts	35 atm, 255° C	500 m^3
2. Leach solution (cobalt refinery)	H_2SO_4 dissolved salts	10 atm, 170° C	75 m^3
3. Pregnant liquor	H_2SO_4 dissolved salts	1 atm and 100°–50° C	17 x 103 m^3
4. Neutralized pregnant liquor	dissolved salts	1 atm, 50° C	165 m^3
5. Precipitated sulfide slurry	H_2SO_4 dissolved salts	10 atm, 120° C	165 m^3
6. Neutralized effluent	dissolved salts	1 atm, 50° C	160 m^3
7. Manganese sulfate	$MnSO_4$	1 atm, 50° C	45 m^3
8. Ion exchange	kerosene, reagents	1 atm, 40° C	105 m^3
9. Co tankhouse electrolyte	H_2SO_4 dissolved metal	1 atm, 50° C	1500 m^3
10. Ni tankhouse electrolyte	H_2SO_4 dissolved metal	1 atm, 50° C	750 m^3
11. H_2SO_4		Ambient	200 t
12. H_2S		10 atm, 25° C	25 t
13. NH_3		10 atm, 25° C	50 t
14. Fuels		Ambient	650 t
C. Solids			
1. Sodium hydrosulfide	$NaHS \cdot 2H_2O$	Ambient	20 t
2. Sulfur		Ambient	2.5 x 10^3 t
3. Coal		Ambient	8.5 x 10^3 t
4. Ore undergoing leaching		35 atm, 255° C	200 t
5. Leach residue		1 atm and 50° -100° C	12 x 10^3 t
6. Sulfide precipitate		10 atm, 120° C	1 t
7. Precipitates undergoing leaching		10 atm, 170° C	2 t
8. Sulfide leach residues		1 atm and 50° -100° C	20 t

Substantial inventories of leach liquors are in process under pressure and at moderately high temperatures in the leaching operations of the hydrometallurgical plant and cobalt refinery. Loss of vessel integrity or failure of piping components would result in rapid de-pressurization, with the release of boiling acidic, metal-bearing liquors and the generation of vapors containing acid mists.

Since the leach liquors at reaction temperatures are highly corrosive, the large reaction vessels and their appurtenances would be inspected regularly. The area surrounding the vessels would be diked to contain spills. All components of process piping would be maintained carefully to prevent leakage of these liquors, which would be very corrosive to unprotected equipment.

Much larger inventories of acidic, metal-bearing pregnant liquors, tank-house electrolytes and other aqueous streams and of organic liquid-ion-exchange solutions, reagents and solvents are contained in the plant, but are held at ambient pressure and near-ambient temperatures. Most of these liquids would be in equipment located within individually bermed, sumped, or diked areas or, in the case of thickeners, in in-ground tanks. Therefore, seepage of small amounts is a more likely occurrence than is a large uncontrolled release. Since most of these fluids are flammable or corrosive, as well as toxic to some degree, inspection and maintenance would be carried out on a regular schedule to prevent spillage.

Storage and containment of liquid fuels and sulphuric acid would be in conventional tanks located within diked areas so that catastrophic occurrences such as earthquakes, hurricanes or tsunamis can only result in the localized escape of these materials within the plant itself, where clean-up can be accomplished quickly and with insignificant threat of wider dispersion. Hydrogen sulphide and ammonia, stored as liquids under pressure, would vaporize and disperse rapidly if storage vessel integrity were lost. Both of these materials are very toxic, especially the former. However, they are widely used, and design and operating practices for their safe use are well known.

Except for the inventory of leach residues, or tailings, held in in-ground thickeners, the amount of solids in the hydrometallurgical process plant would be substantially less than in the pyrometallurgical plant. Furthermore, solids within the former are produced and transported as slurries and, so, are not as likely to be dispersed as are dry dusts. Spillage or leakage of small amounts of slurries could, if allowed to dry, result in the release of particulates.

The leach residues (washed free of attendant liquors) are not likely to be hazardous. The smaller amount of precipitated sulphides, on the other hand, will be very finely divided and subject to oxidation and possible combustion. This could lead to the release of fumes or metal-bearing particulates.

Coal storage would be conventional. Sulphur is considered as a hazardous material because it is combustible and, in powder form, is subject to dispersal by dusting. Sodium hydrosulphide is toxic and additionally hazardous because it can generate hydrogen sulphide on hydrolysis or, particularly, if contacted with acidic solutions.

In contrast with the pyrometallurgical plant, normal emissions of gases, dusts and fumes would be very low for the hydrometallurgical plant. Small amounts of acid mist, generated in the cobalt and nickel tank-houses, would be controlled by directed high-volume ventilation. Other process vents and exhausts, being small, would be scrubbed or treated as required. The major concerns in the hydrometallurgical plant would be the uncontrolled release of pressurized, boiling leach liquors or toxic liquids stored under pressure, due to equipment failure or malfunction.

Undetected seepage of acidic, metal-bearing solutions would also be of concern, although the hazard would be less immediate.

As is the case for the pyrometallurgical process, the properties of the identified hazardous materials are well known, and no unusual or new processing operations are involved. Based on historical data, failure rates of equipment or systems leading to uncontrolled releases would be expected to be on the order of 10-3 to 10-6 per year.

Waste Disposal Areas - Summary

The total inventory of materials in the plant's waste disposal areas will increase year by year, but the properties of the waste materials will not change appreciably. Furthermore, normal operating practice is to reclaim filled disposal areas periodically, probably annually, so that the potential for major accidental releases is limited on that account. Proper siting of slag disposal areas and proper construction and maintenance of slurry impoundment areas are the primary design methods used to prevent either uncontrolled or chronic releases.

Smelter slags produced in the pyrometallurgical process are inert and, as already noted, may be used as construction material in a variety of applications. Slag not used in this way would be disposed of in slag piles or dumps. The geotechnical properties of typical slag are such that it is free-draining and not subject to rapid dispersal as fluid slurry. For the most part, slag is coarse and not subject to dispersal by dusting. The smaller amounts of ground slag from the alloy recovery operation could be treated and disposed of separately.

Substrate tailings leach residues and gypsum sludges would be impounded in impervious disposal areas. Although the geotechnical properties of these wastes might differ, reclamation techniques would be essentially the same. The major concerns with accidental discharges from the substrate or tailings disposal areas would be chronic dusting problems or seepage of saline liquids if liner integrity were lost.

Overall, the probability of a catastrophic release of waste material, as in earthquake-induced failure of a dam, for example, should be low for properly sited, designed and maintained disposal structures. In any event, the amount of material involved would probably be limited to the previous year's production that had not as yet been reclaimed: about 350,000 - 900,000 t of substrate and 700,000 t of slags or 1,200,000 t, combined, of leach residues and gypsum slurries.

Noise Emissions

Cobalt-rich crust process plants will contain a large number of equipment items and operations that are sources of noise. The noises will be produced at a variety of levels of intensity, or decibel (dB) level, and with varying frequencies in the spectrum between 20 and 20,000 cycles/s. The noise-generated characteristics of the individual sources in these plants are reasonably well known, as is the effectiveness of various noise suppression measures. Therefore, if the details of a plant design were known, the noise emissions signature could be determined. In the absence of such detailed information, approximations must be made, as described be-low.

Noise is generated in the plants envisioned from the operation of electric motor-driven equipment required for the transportation of fluids and solids; from motor driven size-reduction equipment; from steam turbine driven items of process equipment (particularly large fans or blowers); from the operation of mobile equipment; and from the operation of miscellaneous items of equipment that involve noise, such as removal of skulls from ladles by mechanical actions. In addition to noise emitted by the drives themselves, the fluids or solids may emit sound energy as they are transported through process equipment, particularly if velocities are high or if resonant frequencies are encountered, as may be the case for transport of large volumes of air (for fugitives control) through ducts and flues and for flashing of fluids through let-down valves into separator vessels.

The noise levels may be attenuated by enclosing the drives or equipment within small buildings or housings, as is commonly done for compressors or large blowers. Ducts may be insulated with sound-absorbing materials, and all drives and equipment located within buildings will have noise levels attenuated by 20 dB or so. With careful attention to design and the use of silencers, outside equipment such as cooling towers can also be quietened significantly. In fact, some attenuation will be required to comply with OSHA standards with respect to maximum permissible worker exposure for plant operators.

A rough estimate was made of the expected noise level at the plant boundaries by identifying the number of large and small drives and other noise sources in the plant, the expected in-plant attenuation for each, and summing the contribution of all of these sources on an energy-weighted basis to the ambient noise level at the plant boundary. The plant areas proper were assumed to be 25-50 ha, roughly rectangular, with the noise sources located 300-500 m from the fence lines. The ore elutriation and beneficiation steps were considered to be within the process plant's perimeters for purposes of estimating the noise levels.

Since the waste disposal areas are very large and few items of process equipment are located there, noise levels would not be very far above ambient at the perimeters. Additional noise suppression and visual isolation of the plant can be achieved by planting rows of trees around the perimeter. Therefore, a separate noise-level analysis has not been made for these areas. The cobalt refinery was considered to be an integral part of the hydrometallurgical plant for estimation of noise levels, and a separate analysis was not made for this area.

Pyrometallurgical Plant

There will be approximately 250 small [<75 kilowatt (kW)] and 35 large (>75 kW) motor drives in the pyrometallurgical plant, with approximately 35 of them being unenclosed. The majority of the larger drives are used to move large volumes of air for fugitives control or for carrying off combustion or furnace off-gases. Large diameter flues are in use for these purposes. In addition, approximately 10 items of mobile and outside equipment are involved in slag hauling and movement of other solids. Other operations such as skulls removal, solids grinding and slag granulation are sources of noise.

The estimated noise level at the plant boundary is between 55 and 65 dB, which is comparable to the sound level near a busy freeway. The major contributors to this level of noise are the large drives associated with movement of large amounts of air and off-gases.

Hydrometallurgical Plant

There will be approximately 300 small and 15 large motor drives in the hydrometallurgical plant, with approximately 10 of them being unenclosed. The smaller number of larger drives reflects the greatly decreased amount of fugitives control required in a hydrometallurgical plant. On the other hand, a number of small motors are needed in the cobalt refinery. Also, only about 5 items of mobile and outside equipment will be used in the plant, and the motor sizes of these vehicles will be much smaller than required for slag haulers, for example.

The estimated noise level at the plant boundary is between 50 and 60 dB, measurably lower on average than for the pyrometallurgical plant. This sound level is comparable to that of light traffic from a distance of 30 m, and is typical of that generated in a variety of light manufacturing operations.

Transportation

Three of the four phases of the mining scenario -- Resource Assessment, Mining, and Processing -- proceed in logical sequence. The fourth, Transportation, pervades the entire operation. At the outset, small research vessels are needed to locate and describe promising crust deposits. Once a suitable ore body has been found, a larger class of exploration ship (about 2,000 deadweight tonnes (dwt)) would be called upon for precise bathymetric definition of the mining site and for more detailed geological and metallurgical characterization of the area.

With the advent of the mining ship, the potential impact on the environment becomes more significant. The postulated annual throughput of a million tonnes of manganese crust ore plus co-mined substrate requires a typical mining ship of 65,000 dwt with diesel-electric power propulsion and a capability of dynamic positioning for proper control of the bottom miner. The mining ship on station would be complemented by two or more bulk cargo vessels of perhaps 30,000 dwt to take the combined ore and substrate to the shore-based processing plant. Any potential for removing substrate at the mining site or for processing the ore at sea will have a strong positive effect on the economics of the operation, but these refinements may not be possible in the first generation system.

Port facilities required for the mining operation can be considered in two aspects. First, the overhaul, supply, and home-porting needs of the ships involved, and second, the actual movement of the ore and integral substrate to the processing facilities. The mining ship, though quite large, will not need frequent servicing (perhaps one docking per year) and could use facilities outside of Hawaii (U.S. West Coast, or perhaps Japan). Some crew rotation might be handled by the ore transports.

Large quantities of consumables for the processing plant will be brought in by sea, including such materials as gypsum, coal, diesel oil, coke, and probably sulphur. Some of these can be handled within the framework of the existing Hawaiian container trade between the Islands and from the U.S. mainland. The majority of the tonnage will arrive in bulk to new facilities.

A final problem is the inland transport from the port to the actual processing plant since the plant probably will not be at the water's edge for acceptable Hawaiian locations. If the processing is not done in Hawaii, then about half of the desired economic impact of the crust mining will not be realized locally. The alternatives for inland transport are obvious and are analysed in the mining development scenario (Marine Development Associates, Inc., 1987). They include rail, trucks, and slurry pipelines. More exotic solutions such as a single point buoy for offshore unloading of the slurried crust mixture are also treated in this reference as well as in Jenkins and Brown (1987).

Prospecting and Exploration

In early stages of prospecting, the vessel operator would be looking for large, thick and rich crust deposits. In later stages of the exploration, the vessel's operations are meant to discover the precise range of mineable crust. This means a continuing refinement of the detail secured on each seamount by successive iterations of the sampling process. At the start, the prospector will have limited data available from government and university research vessels, with perhaps 200 or so bottom surface samples on each of up to 100 seamounts. The prospector will eventually need complete delineation of the mineable seamount crust with a precise map of the terrain. Specific features that will be recorded include geophysical, chemical, and photo data.

The research vessel to perform these activities need not be large or sophisticated and can operate out of a few Hawaiian ports on voyages of less than 300-2,000 nautical miles (nm) from port. The prospecting phase will identify seamount areas for further exploration, i.e. broad areas with little crust or poor assay, and permit the business plan to be improved from further analysis of the ore samples.

In a four-week voyage, less than half of a typical seamount could be prospected as described; three voyages would be needed to complete a preliminary map and geological survey of an average seamount crust. Over a year, three seamounts may be evaluated for further exploration while some may not be suitable for commercial mining. Several years prospecting by one research vessel may be necessary to find a sufficient number of suitable seamount crusts. The impacted areas on the seafloor are listed with each of the prospecting activities on *Table 13*, as well as the crude estimate of the number of samples taken.

The next phase of the at-sea search from the research vessel will be considerably more detailed and expensive. Continuous bottom mapping in the areas of interest with better crust coverage will be secured. Geomagnetic sweeping may also be appropriate to better define the bottom layers and crust. As the mining operation needs precise location data, transponder beacons may be set to improve bottom navigation.

These exploration activities will probably require use of a larger research vessel than needed for exploration because of the large number of sea bottom acoustic beacons, large size of towed equipment, and volume of samples to be collected and carried on each voyage. Alternatively, smaller research vessels could perform fewer tasks on each cruise.

The ports at Honolulu represent the most likely base for research vessels. Hilo, 196 nm further to the southeast, does not offer vessel repair and dry docking services, and has less infrastructure (airlines, support services, etc.) than Honolulu. Kauai offers potential ports (Nawiliwili and Port Allen), however like Hilo, the services are limited and little advantage would be secured over the use of Honolulu.

Table 13

RESEARCH VESSEL - CRUST EXPLORATION
(Projected Voyage Activities)

Action	Samples (#)	Time (d)	Bottom Area (m^2)
Transit	1 roundtrip	1 - 5	--
Place bottom acoustic beacons	20		20
Dredge crust samples	20	2	2000
Drill core samples	150	15	1500
Bottom microtopography	20 km	2	not impacted
Bottom photographs	10 km	2	not impacted
Geophysical profiling instruments	5 km	1	not impacted
Sea surface and atmosphere	hourly	concurrent	not impacted
Net trawls	10	2 - 3	1000
Replace bottom monitors	2	1	2
Place current monitors	2	concurrent	2
Totals Per Voyage	--	31 - 38	4,524 m^2
Ten Voyages Yearly	--	315	45,240 m^2
Delays (resupply, maintenance, weather)	--	45	--

Vessels for Mining, Lift and Transport of Ore

The seamount crust mining and transport operation is likely to be relatively small, in the range of 1.4 to 2.0 million t/yr throughput rate. The distances to the receiving port are relatively short, 100-1,200 nm, as compared to ocean-going transport distances.

Because of the small tonnage of crust likely to be moved, and the relatively short distances to land, the transport vessel requirements are modest. At the highest throughput and distance, only 2.3 x 109 t-mi of transport need be provided one way, during the mining ship's productive year.

The most likely prospect for the mining scenario is the combination mining and lift vessel, with a separate vessel being provided for transport to shore. The mining/lift vessel would then have to be large enough to carry almost the full load of the transport ships, which arrive intermittently to receive loads from the mining/lift ship. The crust mining and lift functions could be simplified into one process, without loss of crust. This method is contemplated and has been engineered by the consortia formed for mining manganese nodules, and the similarities to harvesting the seamount crusts are obvious. With a 206 working day year for the mining/lift ship, 6,800 t/d of crust and substrate must be raised at average projected throughput. This is considered quite reasonable and feasible at the shallow water seamount depths, and provides space to lift unwanted substrate material not removed by on-bottom separation.

To accompany the mining/lift ship, transport ships of 23,000-35,000 dwt size are needed, the size depending upon the at-sea transfer and port discharge transfer rates. If going to Hawaii during the loaded voyage time of 100 days, a single crust transport ship at 15 knot (kn) speed need have an average capacity of only 65,000 t of cargo. Alternatively, a pair of slower-speed integrated tug-barges of about 40,000 dwt could keep up with the mining/lift ship, depending upon speed, voyage distance, transfer rates, throughput, etc.

The resource requirements and environmental parameters of this likely vessel combination (a single mining and lift ship and separate transport) are reported. The other vessel alternatives described next will have generally similar resource and environmental effects, except for those differences mentioned at the end of this section.

Mining and Lift Ship Description

The mining/lift ship is sized to accommodate the mining equipment and ore lifting system described above. Over 1 million t annually of wet crust material would be broken free, collected and raised.

Assuming that manganese crust as damp-stowed occupies 29 cubic feet per tonne (ft^3/t), 206 working days for the mining-lift ship, about 6,800 to 9,560 t (some 180,000 to 191,000 cubic feet (ft^3) must be raised in the average working day, to produce 1 million t of crust annually. The lift ship must stow all the production between transport ship visits, and each average day's output occupies a space 50-ft wide, 35-ft deep and 100-ft long - about the size of two ore holds on dry bulk/ore carriers of the size likely to be utilised in this service.

While stowed, the surface water would run off and be pumped through a separator to retain valuable fine particles, and the clean sea water returned to the ocean. This is necessary to prevent the material from becoming thixotropic, or fluid-like, while moving in a seaway, and flowing to one side and tending to heel or even capsize the vessel.

With transfer intervals to the transport depending on the number, speed, transfer rate and transport size, the lift ship and transport hold capacities as shown on *Table 14* below are needed. *Table 14* assumes an exact match of average performance, which is not likely because of variable production rates, and variable transport sailing distances in particular.

Table 14

LIFT SHIP HOLD SIZE

Quantity	Low (25% Substrate)		High (50% Substrate)
Annual (t/yr)			
Undried Crust	1.13×10^6		1.13×10^6
Crust and Substrate	1.41×10^6		1.97×10^6
Daily (t/d)			
Undried Crust	5,000		5,000
Crust and Substrate	6,300		8,800
	Average Hold Size (t)		
Intervals Between Transfers (d)	Low	High	Trips Per Year
4	25,000	35,000	57
6	38,000	53,000	37
8	50,000	70,000	28
10	63,000	88,000	22

This hypothetical mining and lift system requires one small ocean mining ship to mine the one million tonnes of wet crust plus substrate, annually. The ship characteristics are estimated from the equipment and operations about as follows:

LBP	730 ft
Beam	120 ft
Hull depth	70 ft
Draft, loaded	40 ft
Water	10,000 t
Cargo	40,000 t
Fuel	5,000 t
Mining equipment	7,100 t
Basic light-ship weight	15,000 t
Total generator	17,000 diesel-electric
Sea speed, loaded	14 kn
New construction	U.S.A.

The ships are draft-limited when laden because of Hawaiian port limitations, but not when fuelled but light of crust. They are also capable of being seawater-ballasted to full draft, permitting better ship control and surface reference during mining or while transferring crust. The ship holds are strengthened because of the density of the ore.

Handling and stowage of mining equipment aboard the mining ship are significant items. They include a 100 t, 40-ft outreach pedestal crane for the collector, winches and transfer racks for handling the hose used to connect the collector to the dredge pipe, airlift pipe, and handling of the power and signal cables essential to the operation of the system. Other major components are the lift and air pipe stowage, total 1,700 m^3, gimbal platform, and hydraulic pipe lowering/lift system. The heave-compensation system was sized at 2.85 million pound (lb) capacity.

The mining ship air lift system selected consists of multistage, motor-driven, compressors located on the ship. Diesel generators onboard connect through power cabling and connectors to the compressors. A mining control center providing system data readouts, stress monitoring, TV, and a control computer, are included.

Ore handling includes a hose-and-pipe subsystem to accommodate the relative ship/gimbal platform movement while transferring the crust and seawater mixture to a pipeline that distributes the crust material to the specially configured holds, where they are dewatered and drained, and where the water is returned to the sea, with some of the fine material. Brackish water carried by the transport ship is recycled to reclaim crust by slurry jets feeding hoppers and pumps that deliver the crust to the stern, where the crust transfers to the ore transports via hose. Water and fuel hoses for receipts from the transport are included. The following assumptions are made regarding crust treatment on the miner ship:

1. Slurry water brought from shore and transferred to the miner ship has a salinity of about 5 parts per thousand (ppt);

2. Twenty four thousand tonnes (24,000 t) of ore are slurried in a 15 per cent (by volume) slurry for transfer to four separate compartments in the transport hold (this water is recycled for each hold);

3. All of the slurry water is discharged in the immediate vicinity of the mine site;

4. Due to the repeated dilution of the seawater contained in the crust ore, the slurry water salinity is raised to about 25 ppt; and

5. Solids content is similar to the discharge stream for the collection operation, i.e. 50 kg/s.

The slurry water discharge would be approximately the same as the mining discharge and would continue for 6 hours.

The mining lift ship is outfitted with an operating collector and a spare collector stowed on the mining ship to assure continuous operations. Spare pipe of about 25 per cent of the string length, and spare bottom parts, are provided and are stowed on the ship.

Transport Ship Description

The vessels for transportation of crust material from mining-lift ship to shore, whether they are ships, tugs or barges, can be described only in generalities until the specific features of the mining system are delineated, the destination ports determined, and other duties of the transport are defined.

The dense crust may be carried in ore carrier hull types, which restrict the center-line cargo holds to a small part of the available hull space; or in bulk-ore ships which load dense ores in only some of the bulk cargo holds, leaving others empty. In either an ore ship or bulk-or-ore ship configuration, extra steel is needed to provide compartments and adequate hull strength for concentrated loads of dense ore, although all have double bottoms. Combination ships may be able to carry any ore, bulk or oil (OBO) cargo. OBO's may also be utilised for crust transport and are flexible for carriage and pumping of other liquid cargoes. Thus, all three ship types (ore, bulk/ore and OBO) will be considered in this analysis of transport ships or barges. The basic bulk/ore or ore carrier has no cargo handling gear, although many ships are equipped with cranes, and a few have self-unloading conveyors.

The crust and fragments will probably be raised in slurry from the ocean floor in an upward flow of sea water, by a hydraulic system, and could also be transferred to and from ships as slurry. Improved pumping efficiency will be achieved when smaller particles are produced by grinding crusts, either at the sea bottom, on the lift ship, or both. Because of the ease of handling and reduced chance of spillage of either coarse or fine particles, slurry handling on ships is considered most likely. For ship transport, the water should be drained after loading to reduce transported weight, and to assure stable cargoes that do not shift in seaways.

The crust as raised from the seabed may be transferred at sea from the lift ship to the transport ship. Conventional dry bulk handling methods utilizing belt or screw conveyors and buckets may be satisfactory to handle the material as raised. However, reports indicate that crusts tend to disintegrate into small particles, and even dust, when allowed to drip-dry, and when stacked in large piles and in ship holds.

Manganese crusts may also be dried at low temperatures to reduce weight by about 30%. However, grinding and drying consumes much fuel, and produces hot, wet gases that probably cannot be used aboard ship. Also, dried crusts are probably dusty, and more difficult and slower in pneumatic cargo handling. Because of the need to elutriate sea salts, industry probably would not dry crusts to powder form unless transport distances are very long. Selection of transport of dried material is not considered likely unless crusts are transported very much longer distances than the Pacific Ocean voyages analysed in this Appendix. Therefore, dried crusts were not evaluated further in this analysis; only wet, fragmented crusts handled by bucket, conveying, and slurry pumping are examined.

The crust is breakable or removable from the underlying basalt rock or phosphorite, and appears when dry to be a heavy sand-small gravel combination. Ore is wet all the time unless specifically dried. Ore is amorphous and crushing does not release interstitial water. It takes heat at 110 °C for several hours to remove 30% moisture. Crushing should reduce the void fraction which holds water that can drain. Transport ships are sized (*see Table 14*) to carry the assumed tonnages of ore with wet densities described above. Crust is intermediate in density between other metal ores and bauxite.

Transport Routes

The richness of deposits in the United States Exclusive Economic Zones of Hawaii, Johnston and Palmyra were defined by Clark, Johnson, and Chinn (1984). Using their labels, the transport routes and average distances were estimated on the basis of the weighted average of their crust resource tonnage, *Table II* in their report. The distances estimated to Oahu are shown on *Table 15*.

Table 15

TRANSPORT DISTANCES IN AMERICAN EXCLUSIVE ECONOMIC ZONES
(Oahu to Area Center)

Geographic Area	Average Distance (nmi)
Hawaii	
A - Southwest seamounts	270
B - Necker Ridge	760
C - Western seamounts	1,620
G - Hancock seamounts	2,050
H - Musician and unnamed	810
I - Northwest seamount	1,670
Johnston Island	700
Overall Average	1,190

Transport of the crust to Japan, or to the American Pacific Northwest, is possible, since smelting processing plants are located in these areas (*Table 16*). From Honolulu to Kobe, Japan is 3,670 nautical miles (nm), and to Portland, Oregon, is 2,332 nautical miles. These distances modified by distance from seamounts to Honolulu, will be used in estimating transport voyages outside Hawaii.

Thus, the typical Japanese distance is assumed to be 3,700 nm, and 2,900 nm to the U.S. Pacific Northwest, with a range of plus or minus 700 nm depending on the seamount being mined.

Table 16

DISTANCES TABLE

TO	FROM				
	Port Allen	Honolulu	Hilo	Midway	Johnston Island
Pacific Islands[1]					
Midway	1,042	1,150	1,338	--	825
Johnston	656	725	905	825	--
Palmyra	979	959	959	1,606	785
Honolulu	106	--	196	1,150	725
Seamount Areas					
Northwest	1,300	1,500	170		
North-central		700	890	550	
South-central		600	780	500	
Southeast		300	150	130	950
Johnston EEZ		700	820	825	100
Palmyra EEZ		860	860	1,430	100
Pacific Northwest					
Vancouver		2,419	2,396		
Seattle		2,409	2,387		
Portland		2,332	2,296		
Japan					
Muroran		3,314	3,500	2,198	2963
Yokohama		3,397	3,581	--	--
Hiroshima		3,816	3,097	--	--
Nagasaki		3,986	4,159	--	--
Panama Canal		4,685	4,542	5,707	--

[1] Source: U.S. Coast Pilot

For these longer transport voyages, larger crust transport ships are likely to be utilised than if only delivery within the Hawaiian Islands is needed. These larger laden bulk transports could be limited in size by the port or terminal dimensions at the port of discharge. If crust delivery were projected to the U.S. Atlantic or Gulf coasts, or to Europe, transports would transit the Panama Canal and be subject to their size limitation. The controlling harbour dimensions at representative Pacific Ocean ports are listed on *Table 17* to illustrate the range of size limitations, mostly on draft of the laden ship that can be applied to crust transports.

All dry bulk ships are generally described as gearless, house-aft, diesel propelled single screw designs. The ships have multiple cargo holds, increasing with larger size, and power-operated, rolling hatch covers. Bow thrusters are now common for ease of docking operations.

An ore-carrying type ship with reduced hold width and higher hold centre of gravity is needed for proper stability. Whether slurry or dry form, the ore carrying configuration is essential. In addition, transport of fuels, supplies and waste would probably be necessary by the ore carrier.

Table 17

SELECT HARBOR NAVIGATION CHANNEL DIMENSIONS

Location	Low Water Depth (ft)	Width (ft)	Length (nmi)	Tidal Range
Columbia River				
Entrance	48	2600	--	7.5 mean
Astoria, OR	40	500	12	6.7 mean
Longview, WA	40	600	58	3.3 mean
Vancouver, WA	35	600	92	1.3 mean
Portland, OR	40	1000 to 400	97	0 mean
Puget Sound				
Bellingham	30	3600	0.5	8.6 max
Everett	28 to 35	400	1.27	.4 mean
Seattle	34 to 30	800	4.5	10.4 max
Tacoma	40 to 29	200 to 800		8.1 mean
San Francisco Bay				
Entrance	55 to 45	2000	2	5.7 max
Richmond	35 to 30			5.9 max
Susuin Bay	35			5.5
Stockton	35		30	4.5
Sacramento	30	200	79	5
Redwood City	30		2	5
Los Angeles				
Outer Harbor	55	500	1.5	4.6
Inner Harbor	45	500	5+	4.7
Long Beach-Outer	60	700	2.8	4.6
Long Beach-Inner	47	210	4	4.7
San Diego				
Outer Channel	44	800	6	5.0 mean
Inner Channel	34	800	11	5.2
Panama Canal (FW)	37.5 to 40 lock [1]		44	none
Japan				
Niihama, Ehime Pref. in Shikoku Island	24.3	520	2 max	12.1 max
Onahama, Fukushima Prefecture	31.1		--	8.6 max
Hikoshima, Fukushima Prefecture	52.5 to 30	--	--	14.4 max

Table 17 (continued)

Location	Low Water Depth (ft)	Width (ft)	Length (nmi)	Tidal Range
Amagasaki, Hyogo Prefecture	39.4 to 32	720 to 650	2.3+ 1.6	7.5 max
Muroran, Hokkaido Island	54	980	3	5.2 max
Hibi, Okayama Prefecture	39.4	--	--	7.8 max
Hososhima, Miyazaki Prefecture	32.8	--	--	12.5 max
Miyako, Iwate Prefecture	39.4 to 29.5	--	--	5.0 max
Hawaii				
Honolulu	40 to 35	--	1.2	1.9
Barbers Pt (1987)	38	450	1.0	2.0
Hilo	35	--	--	2.4
Kawaihae	40 to 35	400	0.65	2.0
Port Allen	35 to 27	--	0.25	1.7
Nawilwili	40 to 35	--	0.33	1.8
Midway Island	?	--	N.A.	1.2
Kahului	35	--	--	2.3

[1] Panama Canal lock length limitation is 900 feet

Note: Salt water vessel unless labeled FW for fresh water

The slurry-pumping ship is basically an ore-oil ship with the water jets and discharge pumps installed in the lower compartment under the cargo holds, and additional piping is installed for slurry loading, sea water handling, and dewatering and decanting of the slurry holds.

Ship dimensions are presented in *Table 18* as a function of ship size as measured by deadweight tonne. Dimensions given are typical of vessels that tend toward shorter length and a more shallow draft, which are representative of recent designs and new construction since the early 1979 fuel oil price increase.

Table 18
TYPICAL COMBINATION SHIP DIMENSIONS

Dwt	Length BP		Beam-Moulded		Depth-Moulded		Draft SW	
(t)	(m)	(ft)	(m)	(ft)	(m)	(ft)	(m)	(ft)
15,000	146	480	20.4	67	11.1	36.5	8.4	27.5
20,000	163	535	23.2	76	12.7	41.5	9.2	30.0
25,000	179	588	25.0	82	13.7	45.0	9.8	32.1
30,000	186	610	26.8	88	14.5	47.5	10.2	33.5
35,000	192	630	28.4	93	15.1	49.5	10.6	34.7
40,000	200	655	29.9	98	15.7	51.5	11.0	36.0
45,000	204	630	31.1	102	16.3	53.5	11.3	37.0
50,000	210	690	32.6	107	16.8	55.0	11.6	38.0
55,000	215	706	33.8	111	17.2	56.5	11.8	38.7
60,000	220	720	34.8	114	17.7	58.0	12.0	39.5
65,000	223	732	36.0	118	18.1	59.5	12.2	40.1
70,000	227	745	36.9	121	18.6	61.0	12.5	41.0
80,000	233	765	39.6	128	19.4	63.5	12.8	42.0
100,000	247	810	42.1	138	20.6	67.5	13.4	44.0

Notes: Dwt - deadweight tonne, Length BP = length between perpendiculars (approx. at the waterline); SW = salt water; and Beam and Depth are moulded dimensions inside steel plating.

A 55,000 dwt ship with beam less than 32 metres (105 feet) and laden draft in fresh water less than 11.9 metres (39 feet) is about the largest able to transit the Panama Canal, fully laden. These sizes, up to about 75,000 dwt that can fit in the locks and are not fully laden, are called "Panamax" size. Bulk carriers designed especially for maximum cargo loads through the Panama Canal are longer and narrower than typical designs. When not limited by Canal draft restrictions, they can carry even larger cargoes at deeper drafts.

Generally the water depth available inside major U.S. harbours is about 40 to 45 feet in salt water at low tide (*see Table 17*). Allowing for tidal rise and deeper dredging at berths, about 40 to 45 ft draft ships would be the maximum size that could be fully laden and still transit most large U.S. harbours. These are equivalent to about 65,000 dwt, to over 100,000 dwt for recent proposed shallow draft designs. Deadweights are typically less for older ships with higher speeds and relatively deep drafts.

The Hawaiian ports of interest are 35 to 40 feet depth, with problem areas at specific channels and berths of as little as 30 feet depth, and small tidal rise of about 2 feet. Therefore local transports moving crust to shore for processing will be more restricted (than sending the crust to the American mainland for processing) to about 40,000 dwt or less.

Japanese ports where imported ores are received for processing are usually small, private wharfs of limited depth, and equipped with slow cargo handling gear. The shallow, 30 ft drafts limit the size of vessels at several Japanese terminals to ships of about 15,000 dwt or less. By careful negotiation, and perhaps some dredging, the few larger receiver terminals with 35 ft drafts can be selected, but these dimensions still limit vessel size to smaller capacity than desired for economic transport. For purposes of describing the transport ships, their resources consumption and potential for pollution, a range of sizes from 25,000 to 65,000 dwt capacity has been selected.

The cargo holds for carrying any dense cargo that is wet must be shaped to prevent shifting and thus off-center weight. Strong, hopper holds able to carry the weight of the ore plus a water head, and high enough to avoid excessive metacentric height, are essential. No matter how the crust is handled, the "ore and oil" configuration will be part of the crust transport design, and many conventional bulk carriers will not be usable for this service. The U.S. merchant fleet has only two ships basically suitable for this service, 82,000 dwt steam turbine powered OBO's owned by Apex Marine.

A standard gearless bulk carrier will not be suitable for crust transport. If crust slurry discharge is required, installation of an onboard slurry pump in each hold, and on-deck overboard discharge piping and valves, will also be needed, at great expense for installation and repair, too. If dry crust loading is selected, distribution conveyors from the hoppers, rather than piping, will be installed. Both loading options are relatively simple compared to the discharge options. Cranes could be installed aboard ship for dry crust discharge, and even self-unloading conveyors, Great Lakes style, could be installed because of the short and frequent transport voyages to Hawaii, and the fast discharge rates desired for a dense ore can easily be achieved. However, self-unloading by conveyor is incompatible with slurry loading.

Since slurry loading and discharge of crusts by short equipment at the port is cheapest, this option is considered most likely.

Port Operations

The principal activity of the transport ship while in port is the discharge of the cargo load of crust material. While in port, the transport will be refuelled for its diesel propulsion and generator plants; be resupplied with fresh provisions, water, preserved and refrigerated foods; and be re-equipped with repair parts. Vessel maintenance will require in-place and ashore rebuilding and cleaning of engines, pumps, valves and piping, motors, switches and cable, and navigation and electronic equipment. Some cleaning and painting between cruises, and above-water repairs will also be performed in the day, or few days, of each port call. When nearby seamounts are being mined, the ship may spend as much as one-third time in port. When distant seamounts are mined, rapid turn-around is essential.

Because of the intense activities while in port, both the crew returning from sea and those few replacements preparing to depart on the next voyages will be in port at the same time and compare notes on vessel operations.

Transit sheds, can be provided for the very small volume of goods delivered direct to shipside, rather than warehoused by the transport company. Fuel for a transport is available by pipeline to the shipside generally in Honolulu, but not elsewhere, so it must be trucked or barged to the transports. Minimum barge loads of about 1,000 t of fuel would be taken on most port calls, or about every other week in larger amounts.

Vessel crew may live either in their own homes or apartments in the islands, or in rented accommodations. New housing construction should not be necessary anywhere, except by personal desire. Alternating crews, half time at sea, would also work on ship in the port during the call of the transport.

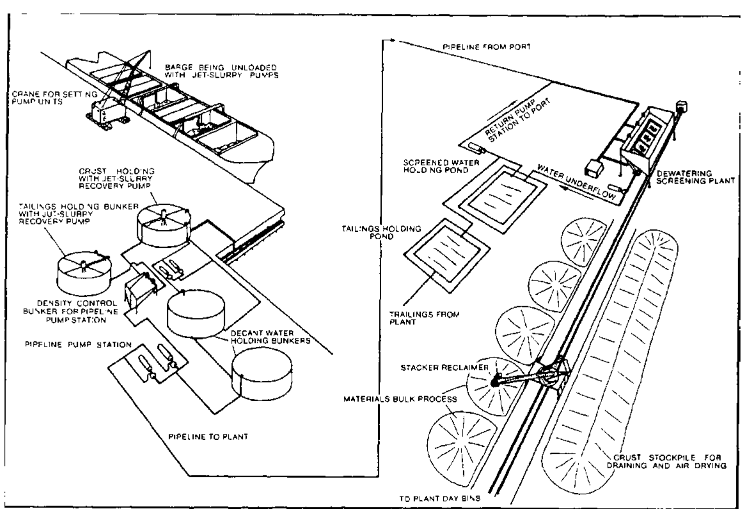
Slurry Handling

Crust material may be removed from the transport ship by pumping slurry of spent process water or fresh water, to remove the salts. The pumps may be located either on transport, or on the pier to permit better maintenance. Experience has found that the high cost of shipboard slurry pump and maintenance results in shore side pump installation as being more reliable and cheaper.

Slurry terminals in deep water harbours are generally comparable to tanker terminals. Essential elements of this type of crust terminal would include the dock, wharf or pier, mooring dolphins, pipeline connections, an access trestle, a shore receiving pond, and a pumping station. Portable shore side slurry discharge units can be lifted by a small crane and held in place in each hold of the transport for shore discharge. Portable units are necessary when a conventional ship is utilised for slurry transport. Provision for handling ore as slurry may be included in any new single-purpose terminal, since crust slurry pipeline systems may be lower cost than conventional dry bulk conveyor systems to deliver the crust to the plant.

The terminal receiving slurry pond should have capacity equivalent to several ship-loads -- 70,000 t of material minimum, about ten days' receipts, but preferably more. Often, capacity many times this amount would be provided for buffer stock storage. If the processing plant is nearby, the plant stockpile of two or three month's production may be advantageously located at the terminal if space is available. Each 35,000 dwt ship load represents a 10 m deep pond by 85 m/side after dewatering, or 1.6 acres per ship load. A process or fresh water recycling tank of very large capacity is also needed. About 10,000 t of fresh water would provide for start-up and an hour's operation. The basic features of the necessary slurry receiving facilities are illustrated in *Figure 9*.

Figure 9 Slurry terminal schematic



A pumping station for on land slurry movement and a pipeline to the processing plant would take perhaps one acre. Utilities and parking would take another acre. As a minimum, a total 7.5 acres of land would be required for a slurry terminal.

Dry Bulk Commodity Terminal

Depending upon the crust process plant design, a substantial volume of supplies, reagents and fuels must be brought into the plant from a variety of sources. On the mainland, most of these items would arrive at the plant in regular shipments of barges, box cars or tank cars. On Hawaii, these specialised and sometimes hazardous cargoes are unusual and must arrive by ship.

Demand for a 4-metal pyrometallurgical crust processing plant, bulk commodities such as coal, gypsum, lime, silica flux, and coke may require 800,000 t annually if all electric power is purchasable, and about 1.0 million t of these items if power is to be produced from coal as primary fuel. Use of coal assures fuel independence and protects against cost increases, but requires more expensive plant and emission controls, fuel handling, and ash disposal. Other bulk materials are each used in amounts that are less than the coal tonnage, but still are amounts large enough to be cheaper if handled in bulk like coal and coke (and properly segregated or protected), rather than carried in containers. Lime, difficult to handle, may be replaced by a coal burn of limestone, but would entail carriage of over double the total tonnage.

For the receipt of all these dry bulk commodities, a terminal similar to that described for dry whole crust handling is appropriate. Considering the tonnage of crust handled, the same terminal can easily and most efficiently be expanded to transfer over two million to three million t of the mixture of commodities, with the commodity separation needed. Except for the crust, coal, lime and silica flux, shipments of the other bulks would be less than about 80,000 t/yr, and arrive in only three or four shipments. The larger coal bulk volumes would arrive in 20,000 or 30,000 t shiploads every three to four weeks. Therefore, the total number of bulk ships calls would be approximately as shown in *Table 19*.

The maximum 3 million t of 68 commodities in 106 calls could easily be handled in about 160 to 200 port days, at an average transfer rate of about 15,000 t/d and about 50 per cent berth occupancy. The ferromanganese product of 200,000 t/yr may also be loaded into bulk ships.

Because coal and coke are not dense, larger size bulk carriers may fill up their volume before being laden down to their draft marks. Therefore, the bulk berth must be longer for vessels up to about 750 feet. As before, the berth should permit full-laden vessels to lie afloat, that is, should be dredged to about 40-feet depth in Hawaii.

In Japan, fuels and supplies are distributed by small feeder ships. In the U.S. Pacific Northwest, these items will arrive by barge, rail, pipeline or truck. So this discussion is largely limited to the Hawaiian application.

Table 19

VESSEL TRAFFIC SUMMARY
(Calls Per Year)

Small Craft at Kauai, Midway or Oahu Ports	Construction	Operations
Research Vessel	11	11
Crew-supply	0	26
	---	---
Total	11	17
Ship Calls Projected For Island of Hawaii or Barbers Point	**Construction**	**Operations**
Miner-Lift	0	0
Transport*	1	60
Container	52	52
Tanker*	12	12
Bulk Carrier*	4 (?)	102
General Cargo or Barge	4	1
	---	---
Total (Barbers Point or the Island of Hawaii)	73	227

*Maximum, assuming maximum fuel oil for tanker calls, and maximum coal fuel for bulk carrier

The wharf in Hawaii for large ships in the 35 feet deep harbour should be about 670feet long, and if 40feet deep, about 740feet, plus mooring dolphins at each end, some 100 feet each way. The pier or wharf can be pile or fill supported, and must carry crane tracks, conveyors and pipelines.

Dry bulk handling systems utilise mechanical equipment to unload the vessel, move the material to port storage, recover the material from storage, and transfer it to the plant. The major mechanical elements of the system described here are the unloaders, distributing conveyor, reclaimer unit, and mainline conveyors. These are typical in the port industry. However, the operator may use different equipment adapted to specific requirements, such as continuous bucket unloaders.

In such a dry bulk handling system, the two travelling clamshell unloaders would traverse the pier on rails. They would dig the material from the ship's holds and carry it to a crane-mounted hopper, which would discharge through a belt feeder to the dock conveyor. Crust or other dense bulk materials can be unloaded at an aver-age rate of 500 to 1,500 t/hr.

A cross-belt conveyor would elevate the material to the upper level of a covered storage building. The cross-belt conveyor would be equipped with a tripper to distribute the material in the storage structure. This storage could simultaneously hold shiploads of crust and shiploads of coal in separate compartments. The minimum size of the enclosed and outdoor storage areas is estimated as 14 acres for all dry bulk commodities.

The material would be recovered from live storage and deposited on the plant conveyor by a travelling scraper-reclaimer, which automatically pulls the material onto the belt by boom-mounted scraper, The mainline conveyor system would move the crust or other dense bulk materials to the plant at a rate of about 500 t/hr, and low density commodities such as coal, at a slower rate. The conveyor system would consist of two or more conveyor sections in sequence, depending on the right-of-way alignment and the topography. The crust and other bulk materials would primarily be stockpiled at the process plant.

Crust and coal have similar dust problems, require the use of enclosed conveyors and walled or covered live storage. Dust collecting units and water sprays would be used at critical locations to mitigate dusting. Unloaders can be partly enclosed, and equipped with air curtains as well as water sprays to suppress dust. Proper dust control would prevent possible explosive concentrations of coal dust. The short residence time in port live storage would prevent fires due to spontaneous combustion. The coal may be enclosed in structures from the time it leaves the clamshell bucket in the unloader until it arrives at the plant, to keep it dry.

Other facilities at the dry bulk terminal would include a 60 feet x 20 feet office and warehouse building; a 50,000 barrels (bbl) fuel oil tank for refuelling transport ships; petroleum products storage; freshwater supply for dust control and transports; a 4,000 kilovolt ampere (kVa) substation; and a 40,000 square feet paved parking area. The marine terminal may require 23 acres. The total area would not all have to be contiguous to the pier; fuel, water, ship office, and parts storage could be near-by.

Inland Transportation

Slurry and fuel pipelines are considered the most likely for haul distances in the range considered here. They also demonstrate environmental and safety advantages. Truck haul for large volumes of dry bulk can be eliminated mainly on the basis of cost and adverse safety and environmental effects. Rail systems can be eliminated mainly on economic reasons. A conveyor system is most economical for very short distances only. The practicality of a conveyor is questionable, especially in a developed area such as is expected in the vicinity of a major port. The anticipated conditions may require that the conveyor jog around existing structures, and cross streets and utilities. This may prove difficult to permit, construct, operate and maintain. Industry would probably select pipeline transport even for very short distances, since the crust could be transported hydraulically without fine crushing. The same pipeline may also be used for tailings transport.

Thus, a slurry pipeline is the system that industry is most likely to select for onshore transport of crust material in Hawaii.

The large volume of dry bulk commodities including coal for fuel may well be adequate to support a belt conveyor between port and plant if the distance is only a few miles. Since such proximity to a port may be realistic, the likely scenario includes a minimal size and speed conveyor if any coal at all is used for power co-generation. If power is generated by fuel oil on-site, a fuel oil pipeline is proposed on the same right-of-way as the slurry pipeline. The remainder of the supplies, general cargo products, liquid bulks, and minor dry bulks will then move by tractor-trailer, mostly inside containers.

Potential Lease Tracts

The EEZ adjacent to Hawaii and Johnston Island has been divided into ten potential lease tracts (*Figure 2*). The permissive areas found in each tract (or logical mining unit) are presented in *Table 20*. From the assumptions of in-place ore abundance, production rates and mining efficiency, we expect a mining operation to mine an area of about 600 square kilometres during the first twenty-year operational phase. We assume further that about one-third of the EEZ permissive area is mineable. Therefore a logical mining unit, defined here as an area large enough to support one twenty-year mining operation, must contain at least 1,800 square kilometres of per-missive area. The potential tracts in *Figure 2* have been constructed using this size as an absolute minimum from the original study areas in the EEZ adjacent to Hawaii and from a separate evaluation of the EEZ adjacent to Johnston Island. It should be noted that the tract boundaries in *Figure 2* are not exact, but the allocation of seamounts among these tracts (see *Table 2*) is the ultimate criterion for inclusion in any particular tract.

Table 20
POTENTIAL LEASE TRACT PERMISSIVE AREAS

Tract ID	Permissive Area (lan^2) *
(see Figure 2)	(see Table 2 for Individual Seamounts)
A	2,004
B	2,792
(7G	2, 670
HI	3,194
K	2,612
L	890
M	4,113
N	1,204
0	2,157
P	5,276
Total Permissive Area	26,912

*Permissive area is seafloor in water depths of 800 to 2,400 metres

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Summary of the presentation

Dr. Morgan said that in 1984 he was retained by the U.S. Government to assist it in preparing offshore leases for ferromanganese crusts deposits within the EEZ of the United States, in particular in marine areas surrounding the Hawaiian Islands and the Johnston Atoll to the south-west of the Hawaiian Islands. Dr. Morgan explained that at that time the United States was very interested in trying to develop these resources and to promote commercial activity on its Outer Continental Shelf (OCS). He said he had worked for four years on this project and had prepared a programmatic environmental impact statement which included economic feasibility; demographic impact; biological impacts and the development of a mining scenario according to certain assumptions for a commercial system. Now, 20 years later, Dr. Morgan noted that to his knowledge, no further efforts have been made toward commercial development of these deposits. He said that following an invitation by the Authority, he tried to synthesise and distill this older work to extract information which could be useful to the Authority's endeavours.

Dr. Morgan outlined the primary discussion items for his presentation. He said that these were: the purpose for developing a hypothetical mining operation for ferromanganese crusts deposits; the limitations of such a model, the characterisation of the deposits as well as the issue of substrate collection. He said that the issue of substrate collection related to the development of a seafloor mining system, and the selection of a possible mining site. Dr. Morgan said that the mining model that he would propose, also considered the following:

- Technical considerations for lift and buffer systems

- At-sea beneficiation
- Transportation
- Metallurgical processing, and
- Hazardous materials generated by the system

In relation to the technology for use as subsystems, he listed them as:

- Lift and buffer system
- At sea beneficiation
- Transportation
- Metallurgical processing, and
- Hazardous materials.

Dr. Morgan noted that some of components of his scenario were based on old technologies, pointing out that metallurgical processing schemes have been greatly improved in the past 20 years. However, he said some technologies like the lift and buffer systems were similar to those used today.

With regard to the purposes of his mining scenario, Dr. Morgan pointed out two incentives; the identification of key development issues for a mining operation and the establishment of baselines for impact analysis and policy making. He stated that impact assessments and defining the limits of possible mining activities were essential for a regulatory body in order to develop policies e.g. with respect to defining monitoring requirements.

The study presented by Dr. Morgan was funded by the United States Department of the Interior through the state of Hawaii. The study on "*Proposed Marine Mineral Lease Sale: Exclusive Economic Zone Adjacent to Hawaii and Johnston Island*" was published in 1990. In his present deliberations, Dr. Morgan stated that the major limitations of the study were that it was specifically drafted for the Outer Continental Shelf Act, which governed offshore development in the United States but might not be fully relevant to tasks of the International Seabed Authority. In addition, he noted that the considerations in his study were site specific; and that some of the information about the deposits could apply to other places

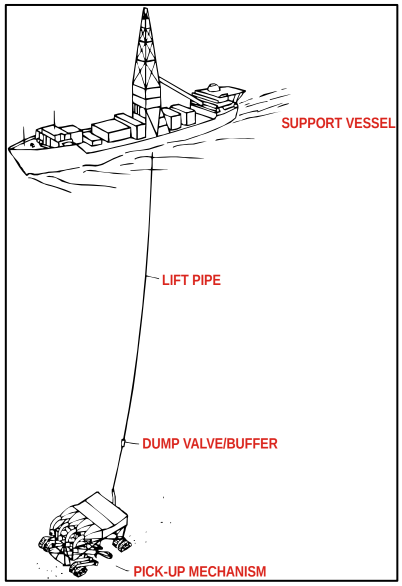
In relation to deposit characterisation Dr. Morgan introduced the table below, indicating major parameters, expected value ranges of these parameters and the values used in his scenario:

Parameter	*Expected Range*	*Scenario Value*
Mean Crust Thickness	< 1 – 15 cm	3.5 cm
Crust Specific Gravity	1.95 (wet)	1.95 (wet)
Cobalt	0.8 – 1.1%	0.9%
Nickel	0.4 – 0.6%	0.5%
Manganese	20 – 25%	22%
Pt	0.4 grams/ton	0.4 grams/ton
Seamount Slope	5 - 20°	10°
Crust Coverage	60 – 90%	75%
Water Depth	800 – 2,400 m	800 – 2,400 m
Recovery Percentage	50 – 70%	70%
Production (dry t/yr)	550,000 – 1,000,000	700,000

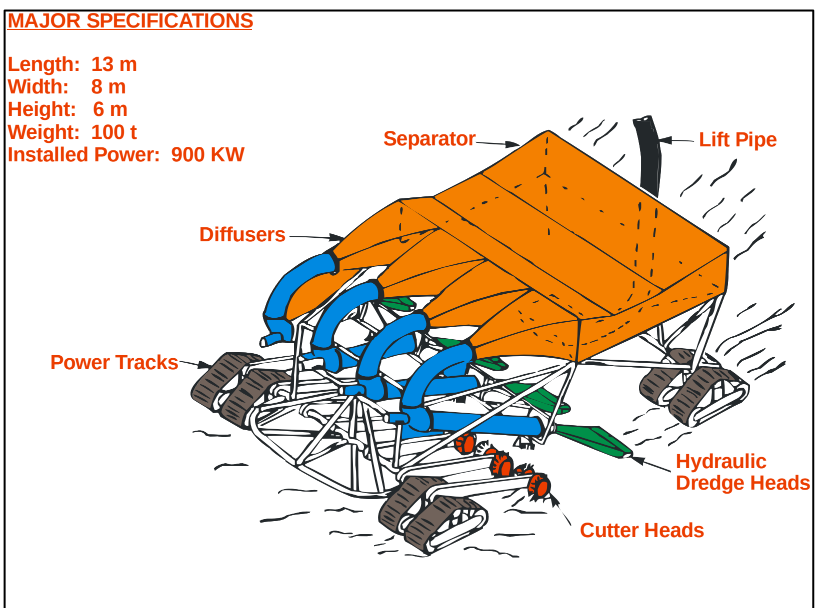
Supporting Dr. Hein's analysis of the field work that had been done in the Central Pacific Ocean, Dr. Morgan noted that the best commercial potential, particularly in terms of crusts thickness, could probably be located on the large guyots and not on archipelagos like the Hawaiian Archipelago. He said that some of the values used in the scenario, for example, a crust thickness of 3.5 centimetres, may be pessimistic. He noted that other values were chosen to minimise the penetration of cobalt production into the cobalt market on the one hand, and to ensure a production rate that can sustain investment and operating costs on the other. With regard to market penetration, he added that producing a major fraction of the world's demand for cobalt would impact the price for cobalt, which would automatically decrease as a result of likely countermeasures from competing land-based cobalt producers. He said that in his scenario a maximum of about 10 per cent market penetration was set as a limit resulting in range of 6,300 tons of annual cobalt production from crusts. Given global cobalt production of about 52,000 tonnes in the 2005, this would be a market penetration of about 12 per cent which, according to Dr. Morgan, could be a cause for concern to investors in terms of price stability. Summarising, he stressed that market penetration was a key limitation to cobalt-crusts mining operations.

With respect to the required mining area, Dr. Morgan said that compared to mining polymetallic nodules, a cobalt crusts mining venture would require a relatively small area to fulfil its needs. According to his estimates, he said that a mine site area of 400km² would be sufficient to sustain a 20-year crusts mining operation.

Utilizing the diagram below, Dr. Morgan illustrated the basic mining system for crusts. He described the system as consisting of the pick-up mechanism, the lift system and the support vessel. Dr Morgan noted that the lift system was originally specified as an air lift system. He noted, however, that nowadays direct hydraulics lifts have proved to be better designed.



He said that for all components, except the pick-up mechanism and actual miner, a future cobalt-crusts mining industry could take advantage of the latest developments in the oil industry. With regard to a pick-up system for mining cobalt crusts, Dr. Morgan described a system designed by the mining engineer John Halkyard, as depicted below.



MANGANESE CRUST MINER (HALKYARD 1987)

Dr. Morgan said that Dr. Halkyard, the designer of the system, worked for one of the manganese nodule consortia in the 1970s and that later, was very successful in completion of mining systems for the oil industry. Dr. Morgan described the basic elements of the crusts miner as:

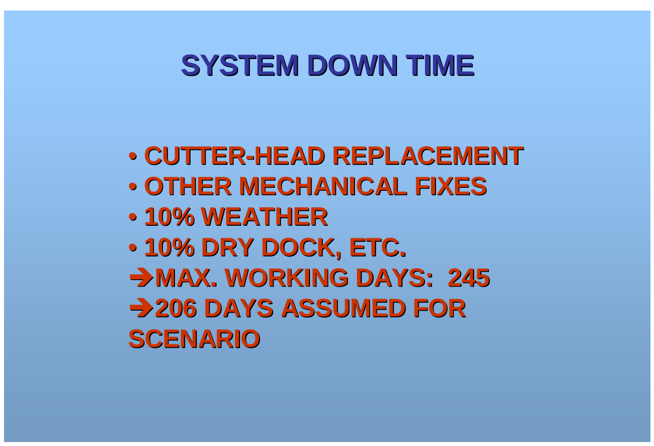
- Cutter heads which will fragment the material and which needs to be self-powered to ensure precise operation;

- A pick-up device or hydraulic dredge heads, and

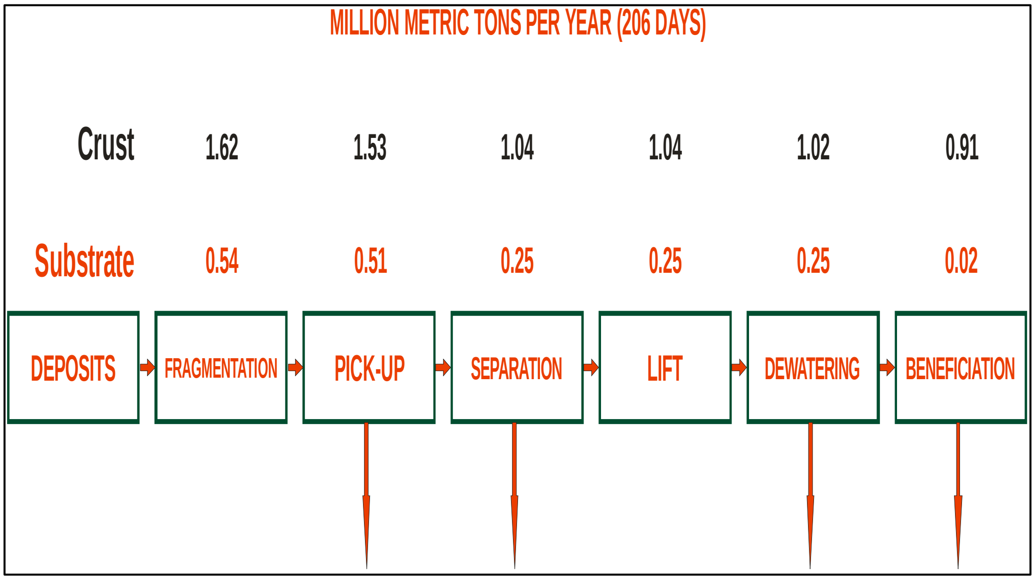
- A separator, whose efficiency depends on the difference in densities between substrates and crusts.

Supporting Mr. Yamazaki's comments on the substrate issue, Dr. Morgan said that there was no guarantee that the substrate would be different in density from the crust itself and that prospectors should be as interested in the density of the substrate and the physical strength of the substrate as they are in the thickness of the crusts. He suggested that this would be a prerequisite for efficient separation of crusts from substrate. He said that any major fraction of substrate entrained in the lift pipe which has to be handled would increase operating costs. In this respect, he noted that the density of the substrate could be a key factor in the feasibility of the mining operation.

With regard to the number of operational days on site by the system, Dr. Morgan said that limiting factors in this regard are the time for replacing the cutter-head and programmed maintenance periods. In his scenario Dr. Morgan considered additional downtime due to weather conditions (10 per cent) as well as for dry dock time (10 per cent) and unforeseen breakdowns. Taking these considerations into account, Dr. Morgan assumed a maximum 245 days that system could be operational per year. For his scenario, he then assumed 206 days per year as the number of days during which the system would be in operation. He used this estimation to determine the production rate and the sizing of the mining operation.



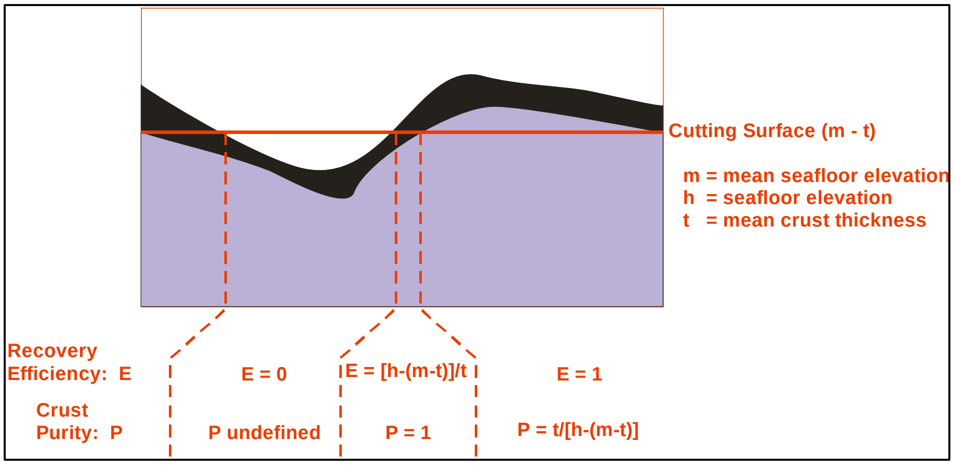
With regard to material flow, from ore fragmentation to beneficiation, Dr. Morgan provided participants with the following illustration:



He noted that most of the values and recovery efficiencies as contained in the scenario were engineering guesses and were not from detailed investigations. Dr. Morgan said that assuming a targeted production rate of 1.6 million metric tonnes of crusts per year, this initial amount of material would be reduced in quantity during crusts pick-up at the mine site; in the separation stage; in the lift-up stage and in the de-watering stage on the surface vessel. He also said that additional losses would occur during ore beneficiation, including froth flotation, which would further reduce the amount of ore to about 0.9 million wet tonnes. He said that he therefore used 700,000 dry metric tonnes of ore as the actual annual production in his model. He added that these throughputs formed the basis for the subsequent environmental impact statement in terms of impacts on the seafloor and further impacts during ore processing and waste management.

Dr. Morgan again emphasised the importance of separating substrate from crusts. He said that in order to estimate substrate recovery, a model had been developed to predict the entrainment of the substrate as a function of the thickness of the crusts and the roughness of the terrain. In this regard, he said that the model assumes that cutting is constant in the horizontal dimension, i.e. the cutter is set to cut at the mean elevation where the machine is driving minus the mean thickness of the crusts.

Substrate Entrainment



Using the figure above Dr. Morgan described the model to determine 'recovery efficiency (E)' and 'crust purity (P)', the latter describing the proportions of crust and substrate in the recovered material. He said that crust purity of 1 meant that pure crust was recovered, and that a value of 0.5 meant that the recovered material was half substrate and half crust. He also said that if no material was recovered, P was undefined and E was 0. Elaborating on the model, Dr. Morgan said that if the miner only cuts crust, the recovery efficiency depends upon how deep the miner cuts into the crust. In general, he said that if the cutter was set to operate at a deeper level within the crusts, recovery efficiency could improve although at some point the collected crusts would be diluted with substrate.

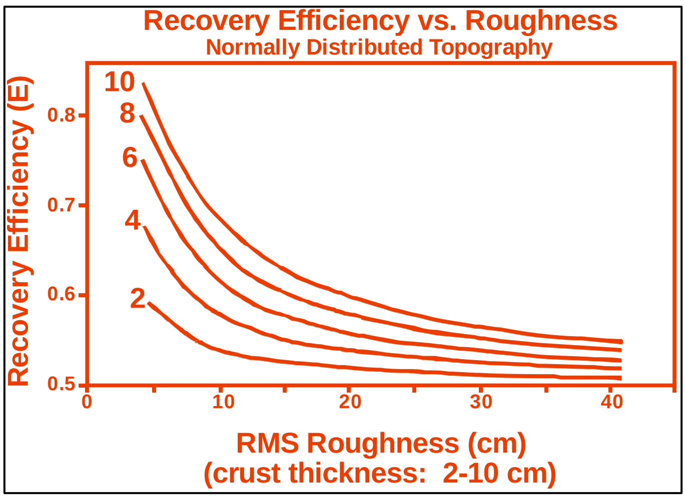
In order to apply this model to the real world, Dr. Morgan disclosed that micro topography models of the surface had been generated for a number of seamounts. He said that this had been done to measure the actual roughness of the surface and to predict how much substrate would be collected. He illustrated some results from this model in the table below using efficiency and crust purity from eight selected sites.

Mining Simulation: Cross Seamount

RMS Roughness (cm)	*Recovery Efficiency (%)*		*Crust Purity (% crust)*	
	20 cm	*50 cm*	*20 cm*	*50 cm*
8	76	63	72	52
9	80	68	78	64
10	80	66	79	62
12	85	71	85	69
14	82	71	82	68
16	72	63	67	46
38	66	57	58	36
43	65	56	55	32

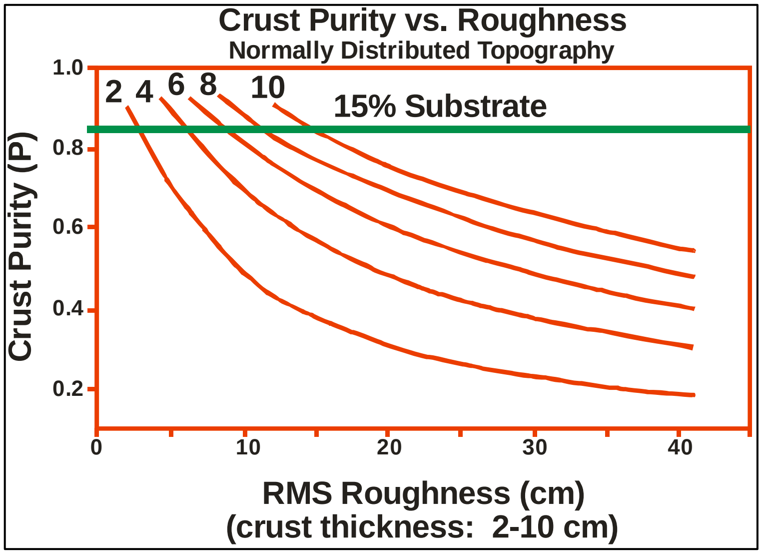
Dr. Morgan said that a crust thickness of 4 centimetres was assumed for all eight sites. He said that the results were given for two different cuttings heads with tools of 20 centimetres and 50 centimetre widths. He noted that the broader cutting head would be less sensitive and entrain more substrate. He also said that the root meant square (RMS) roughness was the standard deviation of the elevation, and that it ranged from about 8 centimetres on the smoothest surface to 40 centimetres on the roughest surface.

Dr. Morgan extended the model results to different thicknesses of crusts, showing the ratio between recovery efficiency and roughness for thickness values of 2, 4, 6, 8 and 10 centimetres using the following graph:



He said that the thicker the crust, the higher the recovery efficiency would be. He explained that compared to smooth surfaces the differences were less significant in rough areas. Similarly, he said that in the case of a 10 centimetre thick crust a higher roughness can be tolerated. Consequently, he said, for commercial mining operations it was critical to identify areas with thick crusts and smooth terrain structures.

Dr. Morgan said the model was rather simple and that the tensile strength of the substrate as well as improved technologies for the cutter head allowing for selective recovery of crusts and substrate needed to be taken into account in the model. He said that if there was a substantial difference in tensile strength between the crust and the substrate, it would be possible to design cutter heads with some discrimination which would be able to reduce the amount of recovered substrate. He added that he was convinced that it was technically possible to develop a cutter head which was more selective and efficient than the one assumed in his model. He stressed that in this respect the characteristics of substrate in terms of its density compared to the crusts would be essential. Dr. Morgan continued to say that the perfect mine site would be one with thick crusts, smooth topography and very hard substrate. He said that prospectors would be able to identify such areas and limit substrate recovery to a tolerable fraction such as 15 per cent. With another graph, he showed the above discussed relationships for crust thicknesses of 2, 4, 6, 6 and 10 centimetres and depicted the 15 per cent substrate limit in terms of terrain roughness.



Dr. Morgan summarised the key conclusions of the scenario that he had presented. He said that a future mining operation would cover a relatively small area compared to a polymetallic nodules mining operation because of the limitations that were imposed by the world cobalt market and by nature. Dr. Morgan noted that ferromanganese cobalt-rich crusts deposits were relatively concentrated in space. He said that because mining would take place in areas with thick crusts to avoid collection of substrate as far as possible, it would reduce the size of the area for mining operations even more. He emphasised that since cobalt production from crusts mining would constitute a significant percentage of world production, any investor would take this into account before starting an operation. He also emphasised that the incorporation of substrate in crusts mining would be a key consideration and could be a critical factor in prospecting and exploring for these minerals.

Dr. Morgan noted that his presentation did not cover all aspects of his study in detail. He also noted that even though the study was relatively old, it was probably the most significant work that has been done in this field. He concluded that the LTC would be well advised to consider this development scenario for further deliberations on the draft Regulations.

Summary of the discussions

There were no discussions following Dr Morgan's presentation

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Chapter 9: Technological issues associated with commercializing polymetallic sulphides deposits in the Area.

Mr Tetsuo Yamazaki, Senior Researcher, National Institute of Advanced Industrial Science and Technology (AIST), Japan

Abstract

The Kuroko-type seafloor massive polymetallic sulphides (SMS) in the western Pacific Ocean have received much attention as sources for the economic recovery of gold (Au), silver (Ag), copper (Cu), zinc (Zn), and lead (Pb). Since the end of the 1980s, the Kuroko-type SMS have been found in the back-arc basin and on oceanic island-arc areas. In the Okinawa Trough [1] and on the Izu-Ogasawara Arc [2] are typical representatives in the Japan's EEZ. They yield a higher concentration in gold (Au) and silver (Ag) than the SMS found in ocean ridge areas [3]. Similar formation processes with the Kuroko ore deposits on-land in Japan have been expected and outlined by many researchers [4, 5]. The higher gold (Au) and silver (Ag) contents in one of the areas have increased the chances for a profitable mining operation, which is under consideration by a private company [6].

A preliminary technical and economic resource evaluation, and sensitivity analyses are conducted using a special model for examining the potential of the Kuroko-type SMS in the Japan's EEZ with some important assumptions. The very attractive features for the commercial development of the Kuroko-type SMS in the Japan's EEZ have been clarified from the evaluation and analyses. Although available information about polymetallic sulphides in the international seabed area (the Area) is insufficient, some technological issues induced from the discussions for the Kuroko-type SMS development are introduced.

Information on the targeted polymetallic sulphides deposits such as:

- the amount of polymetallic sulphides contained in this ore body,
- the internal structure,
- the mean metal yields, and
- the geotechnical properties,

are necessary for a technical and economic resource potential analysis for this development.

The Sunrise Deposit of Myojin Knoll on the Izu-Ogasawara Arc in the Japanese EEZ was selected as a target for the preliminary technical and economic resource evaluation, and sensitivity analyses of the Kuroko-type SMS development. The relatively higher amount of information on its resource potential is the reason why the deposit was selected. A technical and economic evaluation model, which examines the economic potential of the Kuroko-type SMS, was developed by the author [7] on the basis of previous feasibility reports for deep-sea mineral resources [8, 9].

The primary geophysical and geological factors used for creating the technical model for the Sunrise Deposit are summarized in *Table 1*. Among the factors, the location and depth are exact data [2]. The ore density, water content, and compressive and tensile strengths are the average or ranges of measured data from the Kuroko-type SMS samples [10]. Both the amount of ore, introduced from an estimated value [2], and metal yields, introduced from average values of the supplied Kuroko ore into a froth floatation plant in Japan are assumed and uncertain. If the Kuroko-type SMS has similar formation processes with the Kuroko ore deposits on-land in Japan, which is expected by many researchers [4, 5], the metal yields are expected to be not significantly different.

TABLE 1: GEOPHYSICAL AND GEOLOGICAL FACTORS USED FOR CREATING THE TECHNICAL MODEL

Name of factor	Factor used for model and evaluation
Site location	N32°06', E139°52'
Site depth	1,400 m
Amount of ore body	9,000,000 metric tons in wet weight
Metal yields	1.66 % in Cu, 10.5 % in Zn, 2.45 % in Pb, 1.4 ppm in Au, and 113 ppm in Ag in dry weight
Ore density	3.2 in wet bulk
Ore water content	0.128 in weight
Ore compressive strength	3.1-38 MPa
Ore tensile strength	0.14-5.2 MPa

The production scale of 300,000 t/y in wet weight results from the duration of production (approximately 20 years) and the amount of ore body (9,000,000 metric tons in wet weight, where it is assumed that two-thirds will be recovered). Basic subsystems for the Sunrise Deposit development are chosen and identified with reference to the ones for cobalt-rich ferromanganese crusts [9]. Because of the compressive and tensile strengths of the ore in Table 1, mechanical excavation tools are expected to be applicable to the Kuroko-type SMS. The froth floatation ore dressing subsystem is considered to be the same as for the Kuroko ore except the on-board one uses seawater. The possibility of desalting with a simple physical method, crushing the ore and soaking the products in distilled water, was tested [7]. The results strongly suggest that the desalting method and use of existing customer smelters for the development of Kuroko-type SMS could be implemented. A desalting plant beside the Zn customer smelter is assumed in the model. In the model, all concentrates are unloaded at the desalting plant and they are sold to existing customer smelters after desalting. The outline of a basic model and important recovery efficiencies for each subsystem are shown in *Figure. 1*.

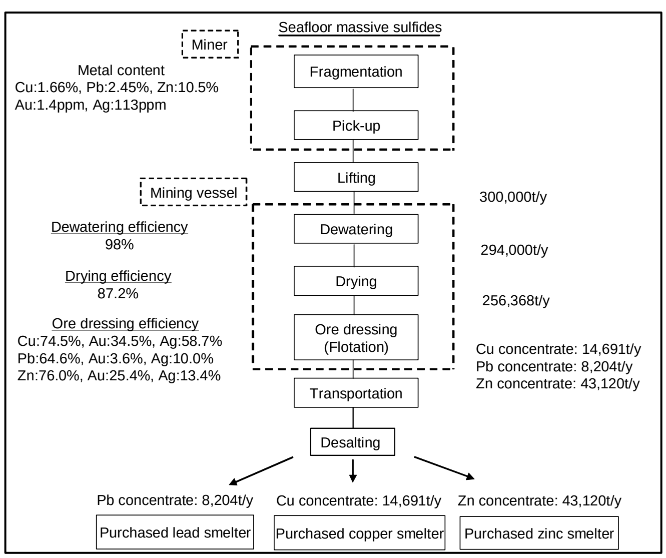

Figure 1 Outlines of basic model, 300,000 t/y in production scale, and the ore flowchart

The average prices during 1995-1999 were: copper (Cu): US$ 1.0/lb, lead (Pb): US$ 0.45/lb, zinc (Zn): US $0.55/lb, gold (Au): US$ 336.4/oz and silver (Ag): US$ 5.2/oz are used for the economic evaluation. The calculated investment costs for development of the deposit are summarized in *Table 2*.

TABLE 2: RESULTS OF INVESTMENT COST CALCULATION

Item	Production scale: 300,000 t/y	
	Capital costs	Operating costs
Mining system	55.0	6.6
Mineral processing	19.5	2.2
Transportation	9.6	3.4
Sub-total	84.1 M$	12.2 M$
Continuing expenses	18.9	
Working capital	9.1	
Total investments	112.1 M$	

The total investments are significantly lower than those for cobalt-rich ferromanganese crusts and manganese nodules which were US$645.8 million and US$1158.6 million respectively. [9]. The smaller production scale with no construction for metallurgical processing subsystem are the main reasons. The results obtained from the economic evaluation are introduced in *Table 3*. Three measures of economic return are provided in the table. They are the payback period, the net present value (NPV), and the internal rate of return (IRR). A discount rate of 8 per cent is used for the NPV calculation.

TABLE 3: RESULTS OF ECONOMIC EVALUATION

Sensitivity factor	Production scale: 300,000 t/y		
Purchase price	Payback periods (year)	NPV($)	IRR(%)
Metal sales in 75%	9.4	23M	13.2
Metal sales in 70%	10.5	13M	11.1

Though the amount of the Kuroko-type SMS ore body and the mean metal yields are the most two important factors for the economic evaluation, both are assumed ones. It is also strongly suggested that the following information for the economic resource evaluation of polymetallic sulphides in the Area are acquired:

- Vertical extent of the massive ore body
- Metal concentration contour lines in the massive body

Some metal-rich zones were recognized in on-land Kuroko deposits in Japan. The gold and silver contents affect the economic evaluation of targeted polymetallic sulphides, though they are byproducts. Some structural questions for polymetallic sulphides are summarized in *Figure 2*.

Key words: Benthic multi-coring system, Customer smelter, Desalting, Economic analysis, Geophysical survey, Kuroko, Massive ore body, Polymetallic sulphide, Sensitivity analysis

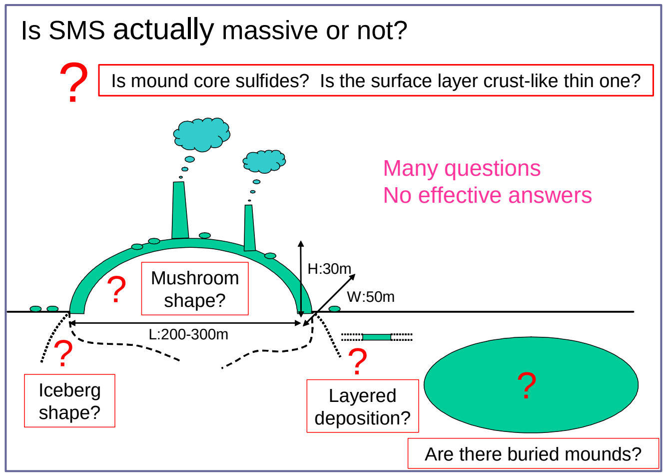

Figure 2: Structural questions for polymetallic sulphides

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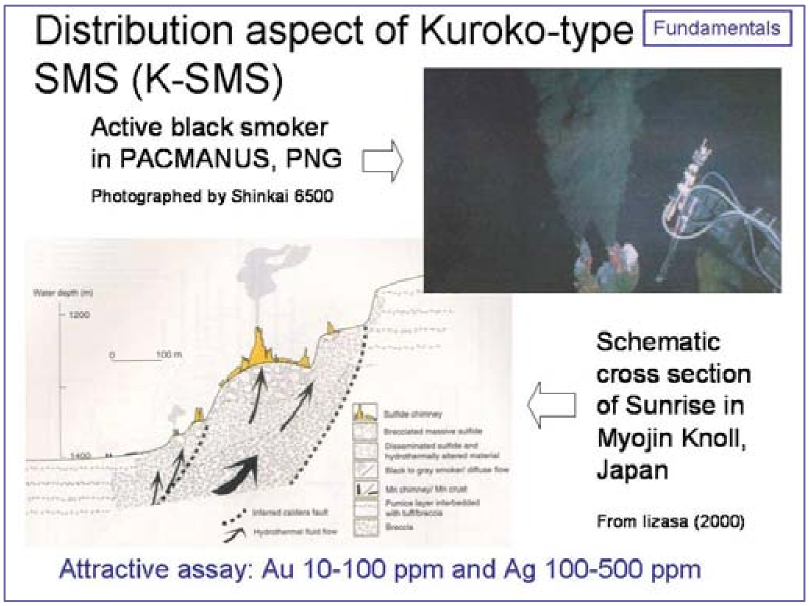
Summary of the presentation

In his introductory remarks, Mr. Yamazaki said that he had recently learned that an existing custom smelter for sulphides ore accepted some chlorine in the concentrates that it bought from mining companies. He also said that through a simple experiment that he had conducted, he found out that it is possible to physically desalt seafloor polymetallic sulphides. He further noted that sampling results from a recent benthic multicore of a seafloor sulphides deposit revealed that a richer zone could be found within the orebody. He said that based on these findings, he had developed a mining model for a prototype seafloor massive sulphides deposit.



Mr. Yamazaki showed participants a slide illustrating a schematic cross section of the sunrise sulphides deposit in Myojin knoll in Japan's EEZ

He said that the Myojin Knoll is on the Izu-Ogasawara Oceanic island arc, about 470 kilometres south of Tokyo, at a depth of 1,400 metres, and covers an area 600 metres wide and 600 metres in length. He said that based on the horizontal dimensions and height of the mound at the deposit, it had been estimated to contain about 9 million tons of sulphides. He said that he had used the location, depth and amount of ore in the deposit to develop his model. He also said that he had used some of the geotechnical properties from samples collected from the deposit for model development.

Mr. Yamazaki showed two other slides that provided data on the geotechnical properties of the deposit. He said that the first slide was based on data collected in 1989, and the second on data collected in 2002. He indicated that the number of samples (14) was insufficient, but said that he found some interesting characteristics.

Geotechnical properties of K-SMS in Japan's EEZ #1

Fundamentals

Engineering properties	A	B	C	D	E	F
Bulk wet density (g/cm3)	3.298	4.022	3.1406	2.801	2.914	2.387
Water content	0.1155	0.0384	0.1467	0.165	0.141	0.207
Solid density (g/cm3)	4.63	4.55	4.49	4.25	4.17	3.64
Porosity (%)	37	15	39	45	40	48
P-wave velocity (km/sec)	3.4	3.5	3.1	1.9	2.3	1.8
Compressive strength (MPa)	24	38.2	21	3.45	6.37	3.13
Tensile strength (MPa)	2.23	4.09	3.04	0.61	0.8	0.14
Young's modulus (GPa)	21.9	35.2	18.5	5.7	7.8	22.5
Poisson's ratio	0.15	0.28	0.47	0.31	0.27	0.31
Shore hardness	10.2	18.3	14.6	1.6	9.4	5.2
Micro-Vickers hardness	162	218	154	0	59	0

From Yamazaki et al., 1990

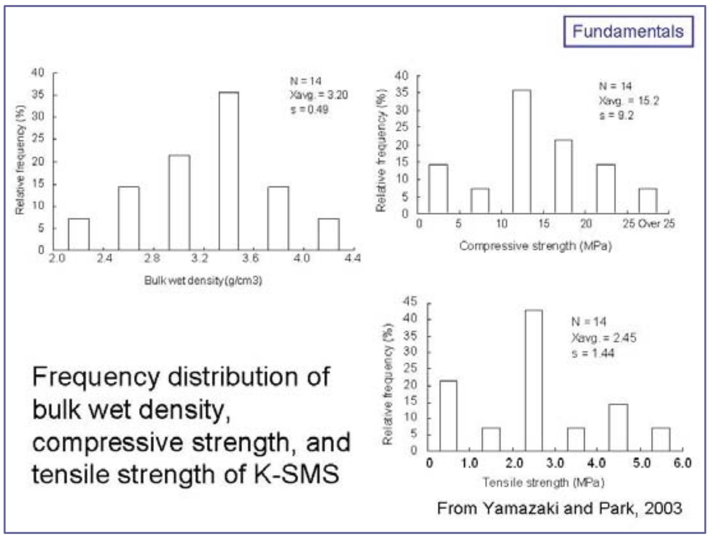
Geotechnical properties of K-SMS in Japan's EEZ #2

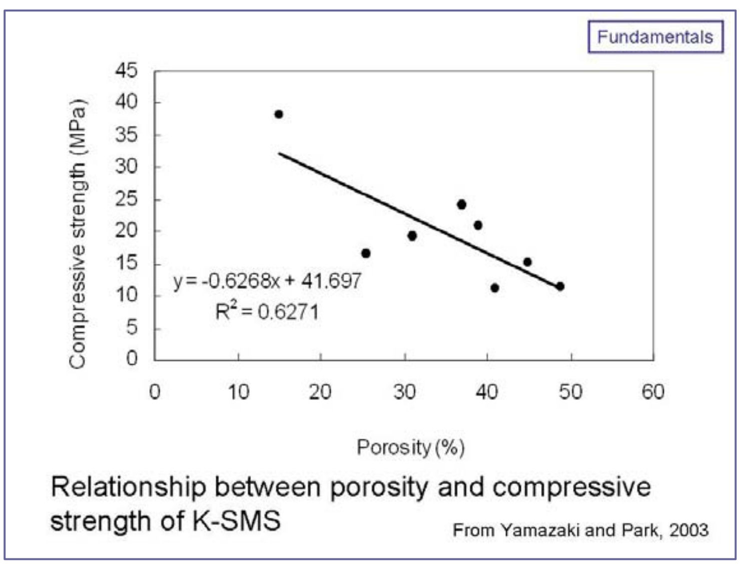
Fundamentals

Engineering properties	G	H1	H2	I1	I2	J1	J2	K
Bulk wet density (g/cm3)	3.358	2.554	2.668	3.861	3.682	3.388	3.349	3.364
Water content	0.126	0.214	0.174	0.059	0.081	0.128	0.148	0.095
Solid density (g/cm3)	4.976	4.273	4.008	4.66	4.765	5.095	5.49	4.413
Porosity (%)	41	53	45	22	29	42	48	31
P-wave velocity (km/sec)	3.55	2.76	2.49	3.2	2.93	2.45	2.65	2.56
Compressive strength (MPa)	11.05	10.26	12.58	18.1	14.93	18.52	11.69	19.22
Tensile strength (MPa)	2.4	2.54	1.81	4.54	2.42	5.21	2.18	2.33
Young's modulus (GPa)	1.448	1.794	3.836	4.51	5.108	4.859	1.745	5.813
Poisson's ratio	-0.022	0.009	0.133	0.025	0.053	0.032	0.01	0.039
Shore hardness	39.01	1.8	7.65	23.32	14.41	12.3	16.94	10.54
Micro-Vickers hardness	635	137	0	188	0	0	0	291

From Yamazaki and Park, 2003

Mr. Yamazaki said that the tensile strength of the Kuroko-type sulphides deposit is the key factor in fracturing and cutting of the ore. He also said that bulk wet density was another important factor. He noted important correlations between factors such as porosity and compressive strength, and total metal percentage and bulk wet density, and explained that this is the reason why gravity type in situ separation is possible for sulphides ores.





He provided a summary of the pertinent geotechnical and geological factors used in his model.

Name of factor	Factor used for model and evaluation
Site location	N32°06', E139°52'
Site depth	1,400 m
Amount of ore body	9,000,000 metric tons in wet weight
Metal yields	1.66 % in Cu, 10.5 % in Zn, 2.45 % in Pb, 1.4 ppm in Au, and 113 ppm in Ag in dry weight
Ore density	3.2 in wet bulk
Ore water content	0.128 in weight
Ore compressive strength	3.1-38 MPa
Ore tensile strength	0.14-5.2 MPa

Mr. Yamazaki informed participants that in Japan, all Kuroko mines are closed and that existing associated smelters have become custom smelters that buy concentrate for processing from other mines. He said that under the current circumstances some of the smelters accept shredded printed circuit boards and mobile phones, which are processed along with concentrates. He said that up to 15 per cent of the processed material comprise the recycled material. Noting that the recycled material contains fluorides, he said that seafloor polymetallic sulphides could be processed along with concentrate.

Mr. Yamazaki described a physical desalting experiment that he had conducted. He said that he had put 5 to 6 centimetres diameter sulphides samples in distilled water and stirred the mixture for about 15 seconds. He said that he had measured the salinity of the mixture after 5 minutes. He said that after a number of cycles, all of the salt in the sulphides ore was removed. He concluded that physical desalting of seafloor sulphides was actually relatively easy.

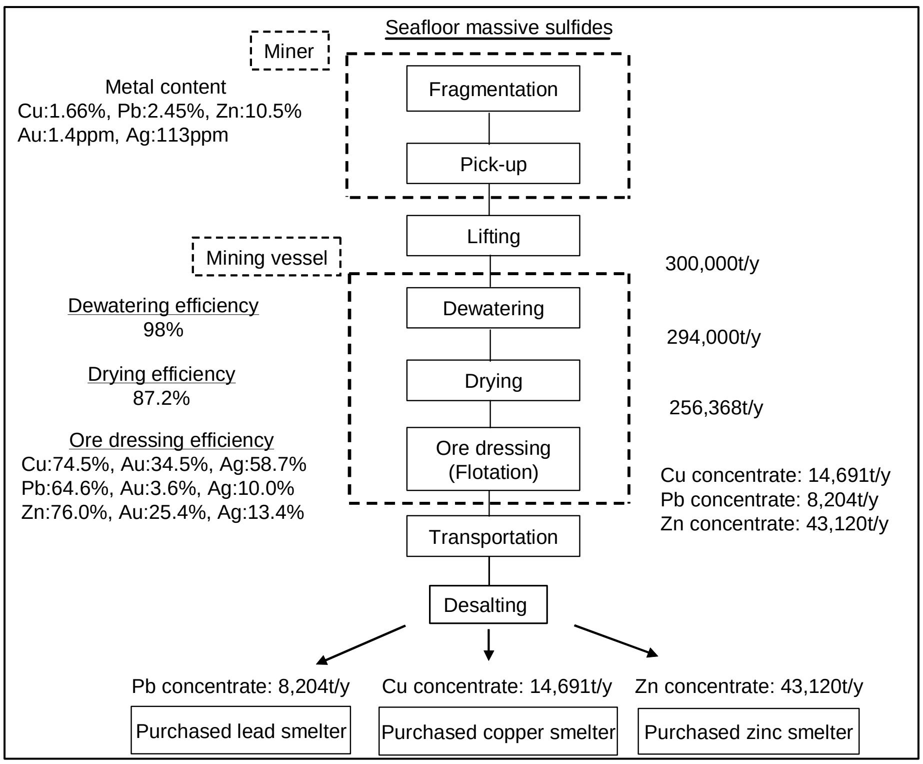
He also showed participants a slide containing a drill core obtained with a Japanese benthic multi-coring system. He said that the total core drilled was about 7 metres, the recovered core was 146 centimetres and the actual sulphides recovered about 100 centimetres. He said that the core revealed high contents of copper and silver. He noted that because of the wide tensile strength variation of the sulphides some parts of the ore body are easily fractured during the coring operation. He said that this causes a low ratio of core recovery and causes deeper coring to be difficult.

With regard to his model, he said that he used metal content data from a mined-out land-based Kuroko deposit, whose average grades were 1.6 per cent copper; 1.4 parts per million gold, and 113 parts per million silver. He informed participants that many researchers believe that marine Kuroko type deposits will have grades similar to terrestrial Kuroko type deposits.

He said that he based the production rate in the model on the Myojin Knoll sulphides that are estimated to contain 9,000,000 tons of ore. Starting with this estimate, Mr. Yamazaki said that he assumed a 20 year mining operation and recovery efficiency on the seafloor of 67 per cent of the in situ tonnage. Therefore, the total amount that would be recovered from the seafloor would be 6,000,000 tons, or 300,000 tons per year for twenty years. He also said that he considered the option of mining only the richer zones located inside the ore body. In this case, he said that the small-scale nodule mining system that India is developing was appropriate. He also said that he obtained the construction cost of the system from Siegen University. He recalled that the prototype miner was tested at 410 metres water depth and worked successfully. He said that he also incorporated the miner and the flexible riser tube system for this scale mining model.

He described the mining system as one originally designed for crusts mining; a self-propelled miner with a mechanical excavation unit. Mr. Yamazaki said that because the sulphides ore is massive and a little bit stronger than crusts, the miner excavating tools themselves are modified to fit the distribution and geotechnical features of this ore. He also said that a gravity separation unit was incorporated in the mining system.

Mr. Yamazaki showed participants a flow chart of his model. He noted that the important aspect of his model is that the operator would produce concentrate after desalting for sale to a custom smelter. He emphasized that in his model, the operator would not be required to construct a metallurgical processing plant.



With regard to the economic factors used in his model, Mr. Yamazaki said that he used 75 and 70 per cent of metal prices. In this regard, he noted that between the late 1990s and 2004, lead and zinc had experienced price decreases while copper, nickel, gold and silver had seen price increases. Mr. Yamazaki showed the results of his economic evaluation. First he outlined the investment costs.

Results of investment cost calculation

Item	Production scale: 300,000 t/y	
	Capital costs	Operating costs
Mining system Mineral processing Transportation	55.0 19.5 9.6	6.6 2.2 3.4
Sub-total	84.1 M$	12.2 M$
Continuing expenses Working capital	18.9 9.1	
Total investments	112.1 M$	

He then illustrated the results of his economic evaluation

Results of economic evaluation

Sensitivity factor	Production scale: 300,000 t/y		
Purchased price	Payback periods (year)	NPV($)	IRR(%)
Metal sales in 75%	9.4	23 M	13.2
Metal sales in 70%	10.5	13 M	11.1

He said that his preliminary economic evaluation of Kuroko-type seafloor massive sulphides mining indicates that the following issues had been clarified:

1. The mechanical excavation of the ore body and in-situ gravity separation of mined ore are applicable for the mining system,

2. Existing sulphides custom smelters can accept polymetallic sulphides after physical desalting, and

3. A small-scale production rate is applicable for mining of Kuroko-type seafloor massive sulphides in Japan's EEZ because no new metallurgical processing plant is required.

He reiterated that the average metal content of the ore body is assumed, and that a number of other factors in his model had not been proven. In this regard, he said that the information required for improving his technical model and the economic evaluation of sulphides mining were:

1. The vertical extent of the massive body, and

2. Metal concentration contour lines in the massive body.

He noted that in the case of terrestrial Kuroko deposits mining the important parameter to make mining feasible is information on the economic reserves. He further noted that an effective method of getting this information for seafloor sulphides is a combined analysis of geophysical surveys and BMS core data.

Mr. Yamazaki identified the following as technical problems to be solved in future sulphides surveys:

1. Combined analysis of the geophysical survey data and survey coring results. He said that only Nautilus Minerals has this data right now, so their report could be very useful.

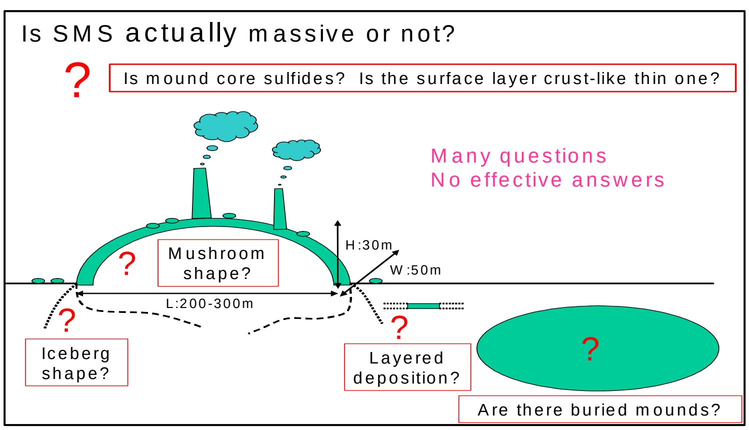
2. Improving the capability of the in-situ coring system. In this regard, he suggested as optional functions for the basic multi-coring system, seismic well drilling (SWD - VSP) and cuttings recovery to enable analysis of the average metal content of the whole length of the core.

Mr. Yamazaki said that because of the fracturing of the rock during coring, some acoustic holes are created. He said that by using a bit of noise and analyzing the record of geophones structural data may be obtained.

Mr. Yamazaki provided another example of an optional data collection system that he described as the cuttings recovery system, comprising a sampling hose and storage revolver tubes installed on an ROV. He said that by using the manipulator on the ROV, seafloor sampling is possible and that with a suction pump, material can be pumped up and stored in plastic tubes. Mr. Yamazaki also said that in the case of the benthic coring system, usually cuttings come out from the coring mouth to the seafloor surface.

Mr. Yamazaki informed participants that Nautilus Minerals has started this kind of trial in the Papua New Guinea EEZ, through geophysical surveys in the area, and by deploying a drilling vessel to undertake drilling of the deposits.

Mr. Yamazaki concluded this part of his presentation showing a figure that he said summarizes the many questions about seafloor massive sulphides that are yet to be answered. These include: are these deposits massive or not? Are they mushroom shaped, or iceberg shaped? He said these were important characteristics required to estimate the amount of ore in the deposits.



In concluding his presentation, Mr. Yamazaki noted that mining technology required for polymetallic sulphides is the most obtainable from among the three mineral resources of the Area, if the sulphides are massive.

He also said that to facilitate the development of seafloor polymetallic sulphides, effective surveying techniques are required together with advancements in the ability to estimate the tonnages and reserves of such deposits.

Summary of the discussions

The discussions following Mr. Yamazaki's presentation focussed on the issues of core recovery, lifting technology, tensile and compressive strengths of ore, the effectiveness of the small scale mining plan that he had talked about and its potential impact on the environment, whether or not there were other deposit shapes, and the applicability of the SWP-VSP techniques to marine sulphides deposits.

A participant, indicating his agreement with Mr. Yamazaki that the critical problems for development of hydrothermal sulphides is not from mining, but from exploration engineering because the grade is so high, the area small and the possible environmental pollution limited, pointed out that at less than 15 per cent as compared with 100 per cent on land, core recovery is a critical problem to overcome. The participant wanted to know what could be done to improve core recovery to 50 per cent. In response to the statement about the small sizes of deposits, Mr Yamazaki said that one could start mining on a small scale, sell the concentrate to a custom smelter and reduce the capital investment involved in constructing a smelter. He described this situation as the big advantage of sulphides mining. In relation to the comment about core recovery, Mr Yamazaki proposed the cuttings recovery system. He said that this would mean recovering the pulverized particles and from an analysis of the powder, estimate the average metal content for the entire ore body.

Another participant asked whether moving the mining operation from one ore body to another is a significant factor in the process. This participant made the observation that to mine several small sites is less efficient, and wanted to know about the environmental aspects of clearing out a large number of sites rather than a single large one. In response, Mr Yamazaki said that in the case of sulphides ore, because of its very high bulk wet density, if an ore bin were placed on the miner, the weight of the miner could be regulated by storing the ore in it. He said that the environmental aspect would be very difficult in the case of the active sulphides area. He defined the active hydrothermal activity and the background eco-system differing considerably from surrounding areas. In this regard, he sated that knowledge of the background of the ecosystem is required to estimate the impact. However, he pointed out that we do not know anything about the background ecosystem.

Mr. Yamazaki was asked if the excavating miner would be appropriate for the different kinds of sulphides deposits, and how deep could it excavate. In this regard it was mentioned that he had identified the mushroom type and iceberg type of deposits. It was pointed out that there is probably a third type where there is very little surface expression, but mostly underground. He was asked if the 9 million ton deposit in the Izu Arc used in his model is sitting inside a caldera. In response Mr Yamazaki said it is on the slope of a caldera. With regard to the excavating miner, Mr Yamazaki said that in the first step of the mining process, the ROV-type characteristics are required for the mining tool. He pointed out that the ROV and cutting tools are necessary to make a flat surface after which a heavy duty-type of operation could be applied to mine the sulphides. He emphasized that the second step in mining the sulphides is quite easy compared to crusts and nodule mining because the floor is stable and strong enough to support the excavating machine-weight.

With regard to lifting the ore, Mr Yamazaki was asked whether he proposed the use of pumping or airlift. He was also asked what estimates he used for the tensile and compressive strengths of the ore given the wide ranges contained in his table. In response to the first question, Mr Yamazaki said he would propose pumping since airlift was less efficient. In response to the second question, he said that for the mining machine the hardest one is the maximum design criteria. He said that within the range it was better to imagine the strongest one, which was not as strong as the land-based ore.

Finally, Mr Yamazaki was asked how the SWD-VSP, usually used for oil drilling could be applied to massive sulphides. He said that many trials must be done before sufficient information would be obtained.

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Chapter 10: Global Exploration Models for Polymetallic Sulphide Deposits in the Area – Possible Criteria for Lease Block Selection under the Draft Regulations on Prospecting and Exploration for Polymetallic Sulphides.

Mark Hannington and Thomas Monecke, University of Ottawa(Document ISBA/12/C/3 - Part II. Presented by James Hein

Introduction

More than 300 sites of submarine hydrothermal venting and associated mineralization are known on the ocean floor. About 100 of these are host to polymetallic sulphides (*Figure 1* and *Table 1*).

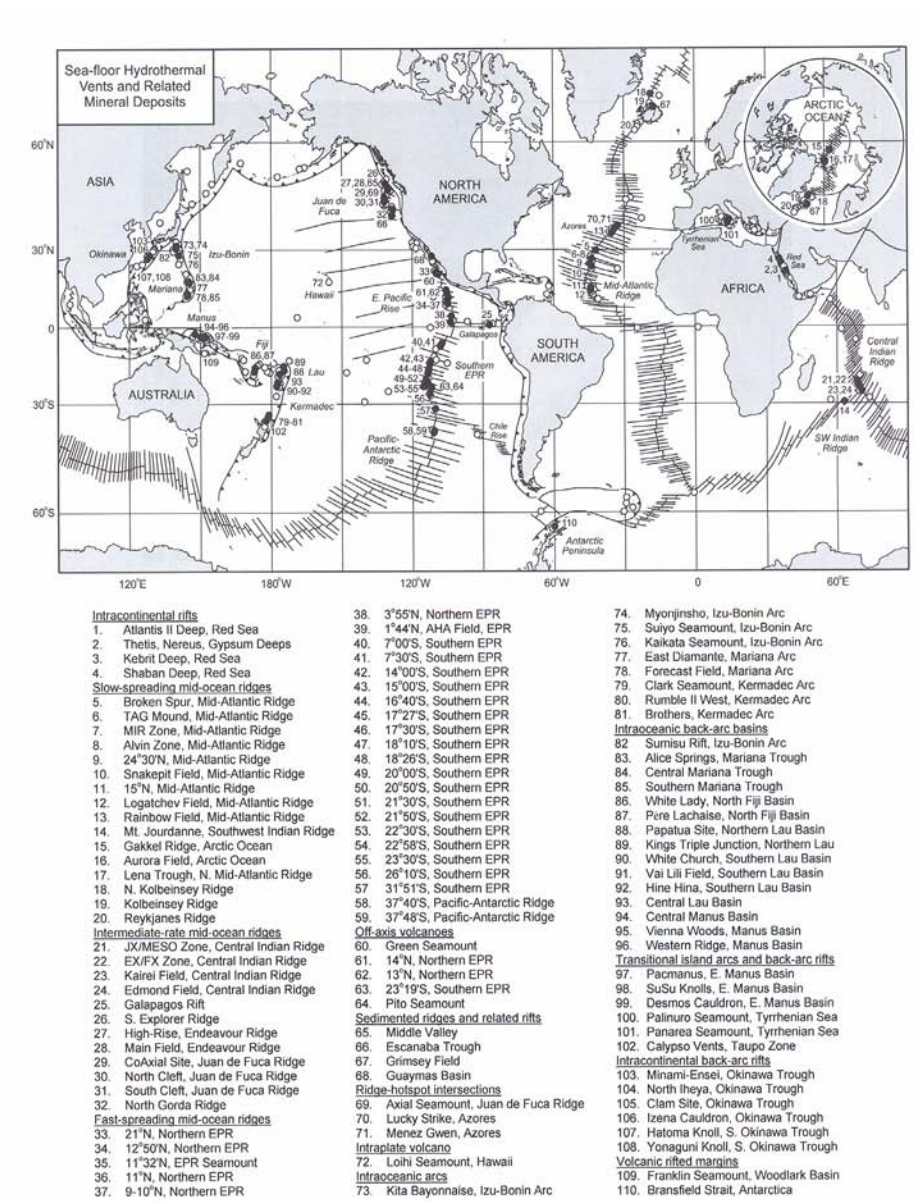

Figure 1. Distribution of seafloor hydrothermal vents and occurrences of seafloor polymetallic sulphides (Hannington et al., 2005). Numbers refer to occurrences listed in table 1. Other low-temperature hydrothermal vents and Fe-Mn crusts or metalliferous sediments are indicated by open circles. Major spreading ridges and subduction zones (volcanic arcs and back-arcs) are indicated.

Table 1

Table 1. High-Temperature Hydrothermal Vents and Related Sea-floor Sulfide Deposits (1965-2005).

No.[1]	Deposit	Regional Setting	Spreading Rate (cm/yr)[2]	Volcanic Setting	Host Rocks[3]	Depth[4] (m)	Temp.[5] (°C)
A. Oceanic Spreading Centers and Related Rifts							
Intracontinental rifts:							
1.	Atlantis II Deep (21°22'N)	Red Sea	1.5	rift graben, brine pool	E-MORB, evaporites, sediments	2,200	66
2.	Thetis, Nereus, Gypsum (22°30'-24°30'N)	Red Sea	1.0-1.5	rift graben, brine pool	E-MORB, evaporites, sediments	1,700	low-T
3.	Kebrit Deep (24°43'N)	Red Sea	0.9	rift graben, brine pool	E-MORB, evaporites, sediments	1,600	low-T
4.	Shaban Deep (26°14'N)	Red Sea	<0.8	rift graben, brine pool	E-MORB, evaporites, sediments	1,600	low-T
Slow-spreading mid-ocean ridges:							
5.	Broken Spur (29°10'N)	Mid-Atlantic Ridge	2.3	rift valley floor	MORB	3,090	364
6.	TAG Mound (26°08'N)	Mid-Atlantic Ridge	2.4	rift valley floor	MORB	3,650	366
7.	MIR Zone (26°09'N)	Mid-Atlantic Ridge	2.4	rift valley wall	MORB	3,500	na
8.	Alvin Zone (26°10'N)	Mid-Atlantic Ridge	2.4	rift valley wall	MORB	3,500	na
9.	24°30'N, Mid-Atlantic Ridge	Mid-Atlantic Ridge	2.4	rift valley floor	MORB	3,900	na
10.	Snakepit Hydrothermal Field (23°22'N)	Mid-Atlantic Ridge	2.4	rift valley floor	MORB	3,480	366
11.	15°N, Mid-Atlantic Ridge	Mid-Atlantic Ridge	2.6	rift valley floor	MORB	3,500	na
12.	14°43'N, Logatchev Field	Mid-Altantic Ridge	2.6	rift valley wall	MORB, serpentinite, gabbro	2,950	>300
13.	36°14'N, Rainbow Field	Mid-Atlantic Ridge	2.1	rift valley wall	MORB, serpentinite, gabbro	2,300	362
14.	Mt. Jourdanne (27°51'S)	Southwest Indian Ridge	1.4	rift valley floor	MORB, E-MORB, ±ultramafic	2,960	na
15.	Gakkel Ridge, 86°N	Gakkel Ridge, Arctic Ocean	1.1	rift valley floor	MORB, E-MORB, ±ultramafic	>4,000	na
16.	Aurora Field (82°54'N)	Gakkel Ridge, Arctic Ocean	1.3	rift valley floor	MORB, E-MORB, ±ultramafic	>4,000	na
17.	Lena Trough (81°22'N)	Northern Mid-Atlantic Ridge	1.3	rift valley floor	MORB, E-MORB, ±ultramafic	>4,000	na
18.	69°N, Kolbeinsey Ridge	Northern Mid-Atlantic Ridge	1.7	rift valley floor	MORB	<1,200	na
19.	67°N, Kolbeinsey Ridge	Northern Mid-Atlantic Ridge	1.7	rift valley floor	MORB	100	<185
20.	63°06'N, Reykjanes Ridge	Northern Mid-Atlantic Ridge	1.7	rift valley floor	MORB	300	low-T
Intermediate-rate mid-ocean ridges:							
21.	JX/MESO Zone (23°24'S)	Central Indian Ridge	4.5	rift valley floor	MORB, minor E-MORB	3,300	na
22.	EX/FX Zone (21°15'S)	Central Indian Ridge	4.4	rift valley floor	MORB, minor E-MORB	3,000	plume
23.	Kairei Field (25°19'S)	Central Indian Ridge	4.8	off-axis, rift valley wall	MORB, minor E-MORB	2,460	365
24.	Edmond Field (23°53'S)	Central Indian Ridge	4.6	off-axis, rift valley wall	MORB, minor E-MORB	3,390	382
25.	Galapagos Rift, 86°W	Galapagos Spreading Center	6.3	axial volcanic high	MORB, low-K oceanic andesite	2,550	na
26.	Southern Explorer Ridge (49°45'N)	Northern Juan de Fuca	5.7	axial zone, central high	MORB, minor E-MORB	1,850	306
27.	High-Rise, Endeavour Ridge (47°58'N)	Juan de Fuca Ridge	5.7	axial volcanic high	E-MORB	2,170	342
28.	Main Field, Endeavour Ridge (47°57'N)	Juan de Fuca Ridge	5.7	axial volcanic high	E-MORB	2,200	380
29.	CoAxial Segement (46°10'N)	Juan de Fuca Ridge	5.6	axial volcanic high	MORB, E-MORB	2,060	294
30.	North Cleft, Monolith (44°59'N)	Juan de Fuca Ridge	5.6	axial volcanic high	MORB	2,300	330
31.	South Cleft, Plume (44°39'N)	Juan de Fuca Ridge	5.6	axial volcanic high	MORB	2,300	342
32.	North Gorda (42°45'N)	Northern Gorda Ridge	5.6	off-axis, rift valley wall	MORB	2,700	304
Fast-spreading mid-ocean ridges:							
33.	21°N, Northern EPR	East Pacific Rise	9.2	axial rift zone	MORB	2,600	355
34.	12°50'N, Northern EPR	East Pacific Rise	10.5	axial rift zone	MORB	2,600	380
35.	11°32'N, EPR 87D1 Seamount	East Pacific Rise	10.7	near-axis seamount	MORB	2,090	na
36.	11°N, Northern EPR	East Pacific Rise	10.9	axial rift zone	MORB	2,500	347
37.	9-10°N, Northern EPR	East Pacific Rise	11.1	axial rift zone	MORB	2,550	403
38.	3°55'N, Northern EPR	East Pacific Rise	12.0	axial rift zone	MORB	2,600	plume
39.	1°44'N, AHA Field, EPR	East Pacific Rise	12.3	axial rift zone	MORB	2,850	active
40.	7°00'S, Southern EPR	East Pacific Rise	13.6	axial rift zone	MORB	2,600	active
41.	7°30'S, Southern EPR	East Pacific Rise	13.7	axial rift zone	MORB	2,750	340
42.	14°00'S, Southern EPR	East Pacific Rise	14.4	axial rift zone	MORB	2,630	374
43.	15°00'S, Southern EPR	East Pacific Rise	14.5	axial rift zone	MORB	2,600	plume
44.	16°40'S, Southern EPR	East Pacific Rise	14.6	axial rift zone	MORB	2,600	active
45.	17°27'S, Southern EPR	East Pacific Rise	14.6	axial rift zone	MORB	2,600	active

46.	17°30'S, Southern EPR	East Pacific Rise	14.6	axial rift zone	MORB	2,600	active
47.	18°10'S, Southern EPR	East Pacific Rise	14.7	axial rift zone	MORB	2,670	305
48.	18°26'S, Southern EPR	East Pacific Rise	14.7	axial rift zone	MORB	2,635	374
49.	20°00'S, Southern EPR	East Pacific Rise	14.6	axial rift zone	MORB	3,000	active
50.	20°50'S, Southern EPR	East Pacific Rise	14.8	axial rift zone	MORB	2,600	plume
51.	21°30'S, Southern EPR	East Pacific Rise	14.9	axial rift zone	MORB	2,835	402
52.	21°50'S, Southern EPR	East Pacific Rise	14.9	axial rift zone	MORB	2,600	active
53.	22°30'S, Southern EPR	East Pacific Rise	14.9	axial rift zone	MORB	2,600	plume
54.	22°58'S, Southern EPR	East Pacific Rise	14.9	axial rift zone	MORB	2,600	active
55.	23°30'S, Southern EPR	East Pacific Rise	15.0	axial rift zone	MORB	2,600	active
56.	26°10'S, Southern EPR	East Pacific Rise	15.0	axial rift zone	MORB	2,600	active
57	31°51'S, Southern EPR	East Pacific Rise	9.4	axial rift zone	MORB	2,300	370
58.	37°40'S, Southern EPR	Pacific-Antarctic Ridge	9.4	axial rift zone	MORB	2,200	active
59.	37°48'S, Southern EPR	Pacific-Antarctic Ridge	9.4	axial rift zone	MORB, andesite, dacite	2,200	active
Off-axis volcanoes:							
60.	Green Seamount (20°48'N)	Larson Seamounts, N. EPR	(9.2)	small, off-axis seamount	MORB, E-MORB	2,000	na
61.	14°N, Northern EPR	East Pacific Rise	(10.3)	small, off-axis seamount	MORB, E-MORB	2,600	na
62.	13°N, Northern EPR	East Pacific Rise	(10.5)	large, off-axis seamount	MORB, E-MORB	2,650	na
63.	23°19'S, Southern EPR	Easter Microplate, S. EPR	(14.9)	small, off-axis seamount	MORB, E-MORB	2,200	--
64.	Pito Seamount (23°19'S)	Easter Microplate, S. EPR	(14.9)	small, off-axis seamount	MORB, E-MORB	<2,000	--
Sedimented ridges and related rifts:							
65.	Middle Valley (48°27'N)	Juan de Fuca Ridge	5.4	sediment-covered rift valley	MORB, minor E-MORB, sediment	2,425	276
66.	Escanaba Trough (41°00'N)	Southern Gorda Ridge	2.4	sediment-covered rift valley	MORB, sediment	3,200	217
67.	Grimsey Hydrothermal Field (66°36'N)	Mid-Altantic Ridge, Iceland	1.8	sediment-filled pull-apart basin	MORB, E-MORB, sediment	400	250
68.	Guaymas Basin (27°18'N)	Gulf of California	3.8	sediment-filled pull-apart basin	MORB, sediment	2,000	315
Ridge-hotspot intersections:							
69.	Axial Seamount (45°56'N)	Juan de Fuca Ridge	5.6	axial volcano, caldera	MORB, E-MORB	1,540	348
70.	Lucky Strike (37°17'N)	Mid-Atlantic Ridge, Azores	2.2	axial volcano, rift zone	E-MORB	1,670	333
71.	Menez Gwen (37°50'N)	Mid-Atlantic Ridge, Azores	2.0	axial volcano	E-MORB	850	284
Intraplate volcano:							
72.	Loihi Seamount	Hawaiian Hotspot	na	hotspot volcano	OIB	980	<200
B. Volcanic Arcs and Bac-arc Basins							
Intraoceanic arcs:							
73.	Myojin Knoll, Kita Bayonnaise (32°06'N)	Izu-Bonin Arc	na	arc front volcano, caldera	IAB, low-K andesite, dacite, rhyolite	1,300	278
74.	Myonjinsho (31°53'N)	Izu-Bonin Arc	na	arc front volcano, caldera	IAB, low-K andesite, dacite, rhyolite	900	na
75.	Suiyo Seamount (28°35'N)	Izu-Bonin Arc	na	arc front volcano, caldera	IAB, low-K andesite, dacite	1,300	317
76.	Kaikata Seamount (26°42'N)	Izu-Bonin Arc	na	arc front volcano, caldera	IAB, low-K andesite	900	na
77.	East Diamante (15°56'N)	Mariana Arc	na	arc front volcano	IAB, low-K andesite(?)	345	240
78.	Forecast Field (13°26'N)	Mariana Arc	na	arc-backarc volcano	IAB, BABB, low-K andesite	1,470	202
79.	Clark Seamount (36°27'S)	Kermadec Arc	na	arc front volcano, summit	IAB, minor BABB, med-K andesite	950	na
80.	Rumble II West (35°21'S)	Kermadec Arc	na	arc front volcano, caldera	IAB, minor BABB, med-K andesite	1,300	active
81.	Brothers Seamount (34°52'S)	Kermadec Arc	na	arc front volcano, caldera	IAB, minor BABB, med-K andesite	1,600	active
Intraoceanic back-arc basins:							
82	31°06'N, Sumisu Rift	Izu-Bonin	na	nascent back-arc rift	BABB, minor rhyolite	1,600	<150
83.	18°13'N, Alice Springs Field	Mariana Trough	2.6	back-arc basin, rift valley floor	MORB, minor BABB	3,650	287
84.	18°02'N, Central Mariana Trough	Mariana Trough	2.6	back-arc basin, rift valley floor	MORB, minor BABB	3,675	active
85.	13°24'N, Southern Mariana Trough	Mariana Trough	3.5	back-arc basin, rift valley floor	MORB, minor BABB	3,000	--
86.	16°59'S, White Lady and Kaiyo	North Fiji Basin	7.0	back-arc basin, rift valley floor	MORB, E-MORB, minor BABB	1,960	290
87.	16°57'S, Sonne99 and Père Lachaise	North Fiji Basin	7.0	back-arc basin, rift valley floor	MORB, E-MORB, minor BABB	1,980	active
88.	15°17'S, Papatua Site	Northern Lau Basin	8.5	back-arc basin, rift valley floor	BABB, MORB, low-K andesite	2,100	--
89.	15°20'S, Kings Triple Junction	Northern Lau Basin	8.5	back-arc basin, rift valley floor	BABB, MORB, low-K andesite	2,000	--
90.	21°58'S, White Church Field	Southern Lau Basin	6.0	back-arc basin, rift valley floor	BABB, MORB, low-K andesite	1,850	na

91. 22°19'S, Vai Lili Field	Southern Lau Basin	6.0	back-arc basin, rift valley floor	BABB, MORB, low-K andesite	1,750	342
92. 22°35'S, Hine Hina Field	Southern Lau Basin	6.0	back-arc basin, rift valley floor	BABB, MORB, low-K andesite	1,850	40
93. 18°36'S, Central Lau Basin	Central Lau Basin	4.0	back-arc basin, rift valley floor	BABB, MORB, low-K andesite	2,000	--
94. Central Manus Basin (150°10'E)	Central Manus Basin	>5.0	back-arc basin	MORB, minor BABB	2,500	--
95. Vienna Woods (150°17'E)	Central Manus Basin	>5.0	back-arc basin	MORB, minor BABB	2,500	302
96. Western Ridge (147°20'E)	Western Manus Basin	>5.0	Back-arc basin	MORB, minor BABB	<1,000	--
Transitional island arcs and related back-arc rifts:						
97. Pacmanus (151°43'E)	Eastern Manus Basin	1.4	back-arc volcanic ridge	BABB, MORB, med-K andesite, dacite	1,650	276
98. SuSu Knolls (152°08'E)	Eastern Manus Basin	1.4	back-arc volcanic ridge	BABB, MORB, med-K andesite, dacite	1,460	220
99. Desmos Cauldron (151°52'E)	Eastern Manus Basin	1.4	back-arc caldera	BABB, MORB, med-K andesite	1,925	120
100. Palinuro Seamount (14°42'W, 39°32'N)	Aeolian Arc, Tyrrhenian Sea	na	arc volcano, summit	CA basalt, high-K andesite	600	na
101. Panarea Seamount (15°06'W, 38°38'N)	Aeolian Arc, Tyrrhenian Sea	na	arc volcano, summit	CA basalt, high-K andesite, rhyolite	80	low-T
102. Calypso Vents (37°41'S)	Taupo Zone, White Island	na	arc volcano, flanking rift	Med-K andesite, dacite, rhyolite	170	200
Intracontinental back-arc rifts:						
103. Minami-Ensei Knolls (28°23'N)	Central Okinawa Trough	2.0	back-arc volcano	basalt, high-K andesite, dacite, sediment	700	278
104. North Iheya Ridge (27°47'N)	Central Okinawa Trough	2.0	back-arc volcanic ridge	basalt, high-K andesite, dacite	970	311
105. Iheya Ridge, Clam Site (27°33'N)	Central Okinawa Trough	2.0	back-arc volcanic ridge	basalt, high-K andesite, dacite, sediment	1,390	220
106. Jade Site, Izena Cauldron (27°16'N)	Central Okinawa Trough	2.0	back-arc caldera	basalt, high-K andesite, dacite, rhyolite	1,400	320
107. Hatoma Knoll (24°51'N, 123°50'E)	Southern Okinanwa Trough	4.0	back-arc volcano	basalt, high-K andesite, dacite, sediment	1,460	310
108. Yonaguni Knoll (24°51'N, 122°42'E)	Southern Okinanwa Trough	4.0	back-arc volcanic ridge	basalt, high-K andesite, dacite, sediment	1,350	195
Volcanic rifted margins:						
109. Franklin Seamount (151°50'W, 9°54'S)	Western Woodlark Basin	2.7	rift volcano	MORB, andesite	2,275	30
110. Bransfield Strait (62°11'S)	Western Antarctic Peninsula	<1.0	rift volcanoes	basalt, high-K andesite, rhyolite, sediment	1,070	na

1. Data summarized from Hannington et al. (2004) and references therein, including Butterfield et al. (2000) and Ishibashi and Urabe (1995).
2. Spreading rates for oceanic spreading centers are full spreading rates from NUVEL-1A plate motion calculations of DeMets et al. (1994). Numbers in brackets refer to spreading rates of adjacent ridge segments.
3. MORB = mid-ocean ridge basalt, E-MORB – enriched MORB, BABB = back-arc basin basalt, IAB = island-arc tholeiite, OIB = ocean island basalt, CA = calc-alkaline
4. Depths are not precisely known for some locations where samples were collected by dredging.
5. Reported temperature is maximum measured temperature. na = inactive, plume = evidence of high-temperature plume, active = black smokers of unknown temperature, low-T = low-temperature vents, -- = unknown

References:

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Ishibashi, J., and Urabe, T., 1995, Hydrothermal activity related to arc-backarc magmatism in the Western Pacific, *in* Taylor, B., ed., Backarc Basins: Tectonics and Magmatism: Plenum Press, New York, p. 451-495.

High-temperature, ~350°C, black smoker vents are the most recognizable features of these sites, but a wide range of different styles of mineralization also has been found. Approximately 40 per cent of the known sites are located in the Area. For a number of reasons, including both legal and technical, recent commercial exploration of seabed polymetallic sulphides has been restricted to occurrences within established Exclusive Economic Zones, or EEZs (*Figure 2*). The present paper considers criteria and possible models for allocation of lease blocks for exploration in the Area. It provides the scientific rationale for the selection of areas for prospecting and for a schedule of relinquishing lease blocks during the exploration phase.

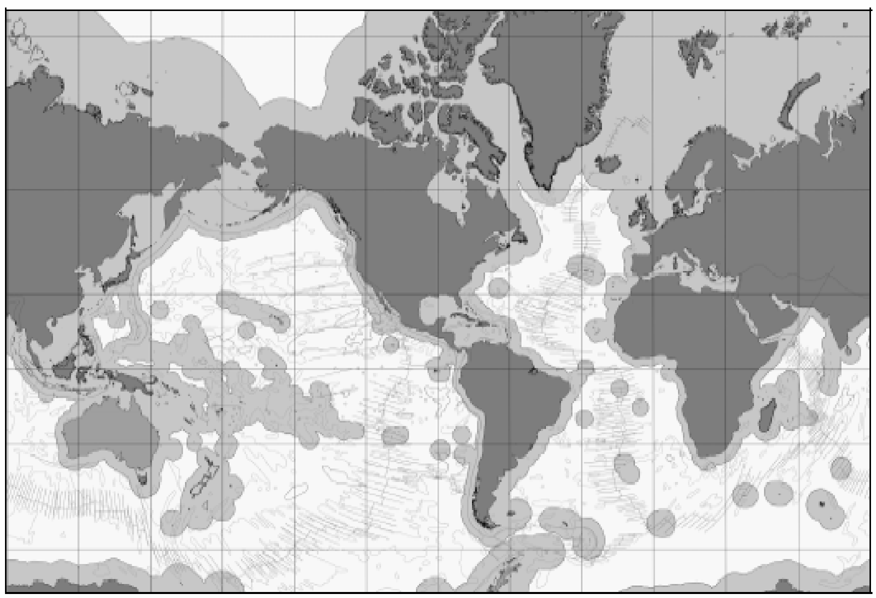

Figure 2. Distribution of seafloor hydrothermal vents and occurrences of seafloor polymetallic sulphides (Hannington et al., 2005). Numbers refer to occurrences listed in Table 1. Other low temperature hydrothermal vents and Fe-Mn crusts or metalliferous sediments are indicated by open circles. Major spreading ridges and subduction zones (volcanic arcs and back-arcs) are indicated.

Practical illustrations are provided for the allocation of lease blocks in areas of known sulphide occurrences using both "contiguous blocks" and "clusters of contiguous blocks". From a range of possible selection criteria and procedures, we compare two models for the allocation of exploration licences in 32 different areas in which at least one occurrence of polymetallic sulphides is known, including 12 in the Area (*Figure 3*). The performance of the exploration models, in terms of their efficiency in selecting known areas of polymetallic sulphides (and relinquishing areas that do not contain polymetallic sulphides) is examined at the global, regional, and site-specific scales, beginning at the prospecting stage and ending with the selection of the most favourable blocks to be retained at the end of exploration. The models take into account:

(a) Geological limitations on prospective areas;

(b) The known distribution of polymetallic sulphides;

(c) The characteristics of individual sulphide occurrences. Other models that may be more appropriate also can be tested using the data presented in the paper.

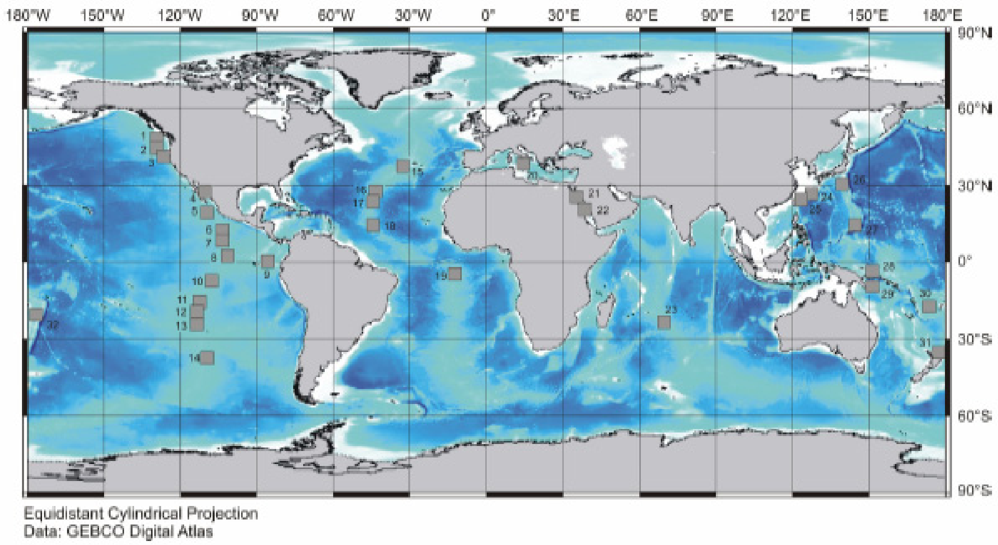

Figure 3. Locations of national EEZs (shaded areas correspond approximately to the 200 nm limit). The distribution of mid-ocean ridges in "the Area" is also shown.

Polymetallic sulphides have a number of important attributes that are dramatically different from crusts and nodules, in terms of their geological settings, distribution, and continuity that must be considered in area selection. Individual occurrences may have dimensions of no more than a few tens of metres up to hundreds of metres, whereas crusts cover larger areas of the seabed with greater physical continuity (e.g., kilometre scales: Hein et al., 1999). These differences require fundamentally different approaches to exploration.

The analysis given in the paper is based on the present state of knowledge of the sizes and distribution of polymetallic sulphide occurrences. No assumptions are made about possible economic or technical limitations on exploration for polymetallic sulphides at the locations discussed. The models proposed here consider only the exploration phase and do not consider actual mining, beyond estimating the minimum sizes of blocks that may be required for multi-year exploitation. Examples of possible lease blocks used in the present paper do not represent an economic evaluation of specific occurrences or areas of the seabed. Sulphide occurrences that meet possible commercial criteria may be mentioned, but no economic valuations are considered or inferred. All cited examples are strictly for illustration purposes and in no way imply that resources suitable for commercial exploitation may actually be present in any given area. Information provided in the paper, including area x thickness of contiguous sulphide bodies, bulk density, grade of metals, or other mineralogical and metallurgical characteristics cannot be used to infer a resource and no such resources are implied, except as hypothetical examples and only insofar as information may be available to justify such examples. Any references to commercial enterprises involved in exploration for seabed polymetallic sulphides are also for illustration purposes only and are not meant to endorse the activities or programmes of these companies or to recommend them as possible models for implementation in the Area. Consistency with the Convention or the proposed draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area (ISBA/10/C/WP.1/Rev.1*) is not addressed, except in the design of the exploration models.

Terminology

For the purposes of the present paper and in the models presented below, the following terminology is used:

(a) *Prospecting area* – A preliminary area that may contain seabed polymetallic sulphides or an area permissive for the occurrence of sulphides, a portion of which may be allocated for exploration as defined in the draft regulations. In the 32 examples discussed in the paper, a prospecting area is arbitrarily defined as an area of less than 5 degrees by 5 degrees and containing at least one known sulphides occurrence or other positive indication of mineralization. In reality, a prospecting area may be identified solely on the basis of permissive geology, in the absence of any indication of mineralization.

(b) *Exploration area* – A "licence" or tenement within a prospecting area and comprising multiple contiguous or non-contiguous blocks reserved for advanced exploration. This is typically an area of not more than 1 degree of longitude by 1 degree of latitude and containing at least one known sulphides occurrence or other positive indication of mineralization. In the models presented herein, the size of an exploration area corresponds to 100 blocks of 10 kilometres x 10 kilometres each, as specified in the draft regulations.

(c) *Lease block* – A portion of an exploration area, measuring approximately 10 kilometres x 10 kilometres and no greater than 100 square kilometres, as defined in the draft regulations.

(d) *Permissive area* – A portion of a prospecting area having a number of geological attributes that are considered to be essential for the formation of polymetallic sulphides. In defining the limits of a permissive area, two key indicators that are commonly used are evidence of tectonic activity and seafloor volcanism. Typically, these are required to drive hydrothermal circulation and to focus hydrothermal fluids to the seafloor where metals may be deposited. A permissive area may include occurrences of polymetallic sulphides or other positive indications of mineralization, but this is not a requirement.

(e) *Most prospective area* – An area chosen for advanced exploration and usually containing at least one sulphides occurrence. In the models presented here, the most prospective areas are generally those blocks that contain more than one sulphides occurrence.

(f) *Sulphides occurrence* – A discrete body of polymetallic massive sulphide (e.g., chimney or mound) or a cluster of such bodies within a defined area (e.g., a chimney field), commonly but not necessarily associated with active hydrothermal venting. Where an occurrence consists of more than one sulphide body, some degree of continuity or clustering is implied (e.g., a collection of chimneys or mounds within an area that is smaller than the distance to the next nearest cluster). The most prospective areas in an exploration licence contain at least one such occurrence.

The present paper makes no legal or technical distinction between "prospecting", which typically does not entail exclusive rights as defined in the draft regulations, versus "exploration" with exclusive rights. Prospecting might be carried out in multiple areas, a subset of which could be allocated under a plan of work for exploration, as illustrated in the models below. The term "deposit" is not used in the paper, except in reference to massive sulphide deposits that have been mined economically on land. This is to avoid confusion about what constitutes a deposit on the seabed. In the scientific literature, the term "deposit" has been variably applied to a variety of entities, including individual sulphide mounds, entire vent fields, or whole geographical regions.

Other terms used in the present paper are as defined in the draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area.

Database

The areas chosen for analysis in the present paper were selected from a global database of seafloor polymetallic sulphides and associated hydrothermal systems (Hannington et al., 2002, 2004). The database is available in two parts that were prepared separately for the Central Data Repository of the International Seabed Authority in 2002 and 2004. The first is a digital database of locations and descriptive information on more than 300 occurrences of seafloor polymetallic sulphides and related hydrothermal activity. The second is a compilation of published geochemical analyses of more than 2,600 samples of seafloor polymetallic sulphides (61,000 records). From these data, 32 permissive areas were selected to test models for the allocation of exploration licences, including 12 in the Area.

Bathymetric data used to define initial prospecting areas were derived from the GEBCO 1-minute gridded digital atlas of the seafloor (General Bathymetric Charts of the Oceans, British Oceanographic Data Center, 2003). Although the standard GEBCO contour interval is 500 m, a contour interval of 1,000 m was used here for ease of plotting. Similar regional maps also can be created from the global predicted bathymetric data of Smith and Sandwell (1997). This 2-minute gridded data, based on satellite gravity measurement, has the advantage of coverage over more remote and inaccessible regions of seafloor.

Areas permissive for polymetallic sulphides were selected from 5 deg. x 5 deg. maps. These maps are provided in Appendix 3. Maps illustrating the application of exploration models at this scale are shown in Appendix 4. A grid with a spacing of 0.1 degree is overlain on each map in the areas considered to be permissive for polymetallic sulphide occurrences and where prospecting might be carried out. This grid corresponds to block sizes of approximately 10 kilometres x 10 kilometres each (0.1 x 60 nautical miles (nm) x 1.852 kilometres = 11.11 kilometres grid spacing). Decimal-degrees are used for ease of plotting sulphides locations. In each case, the placement of the grid is based on a number of different criteria discussed in Appendix 2.

Several examples of 30 minutes (min) x 30-minute maps (100-metre contour interval) illustrate the distribution of sulphides occurrences in selected areas where more detailed bathymetric information may be available. These maps are provided in Appendix 5. This more detailed bathymetry can be used to significantly reduce the initial size of a permissive area, but the data are not available for all parts of the oceans.

Models for lease block selection

Permissive areas for the occurrence of polymetallic sulphides were selected in 32 map areas of 5 degrees by 5 degrees, based on the broad geological attributes of each area as outlined in Appendix 2 (e.g., areas encompassing ridge crests, off-axis seamounts, volcanic arcs, back-arc basins, etc.). A range of physical characteristics of seafloor polymetallic sulphides were considered, including the spacing between deposits and the sizes of likely discoveries. For more information, the reader is referred to Appendix 2 and to overview papers on this topic by Hannington et al. (1995, 2005) and Herzig and Hannington (1995, 1999 and 2000). Additional information also can be obtained from Technical Study No. 2 on Polymetallic Massive Sulphides and Cobalt-rich Ferromanganese Crusts – Status and Prospects, published by the International Seabed Authority. The selection process is limited, to some extent, by the bathymetric detail in the plotted maps. In the 1,000-m contour data from GEBCO, large areas at the edges of prospective geological features (e.g., flanks of ridges) are included in the initial area selection, owing to uncertainty in the seafloor geology. Higher-resolution bathymetry can be used to help reduce the selection of permissive areas, as discussed further below (see Results).

In Appendix 4, a number of models are presented that illustrate how these areas might be reduced to the minimum number of exploration lease blocks according to the schedule of relinquishment proposed in the draft regulations (50 per cent of the allocated area after year 5, 75 per cent after year 10, and a maximum of 25 blocks after year 15). In a successful exploration exercise, the final allocation of 25 blocks is expected to contain enough polymetallic sulphide to sustain multi-year exploitation, herein defined as exploitation at commercially reasonable rates for a period of more than one year. Various models have been proposed for multi-year exploitation (e.g., ranging from 1 to 2 million tonnes per year), although grades, production rates, and other technical aspects have not been specified. The proposed exploitation models are based on comparisons with commercial mining operations on land. This is a reasonable approach, as it must be assumed that any future seabed exploitation would have to compete with land-based mining.

Accumulations in excess of 1 million tonnes might be contained in one large occurrence (e.g., TAG, Middle Valley) or, more likely, in multiple occurrences within a larger area. The size of an area likely to contain this amount of massive sulphides is not known. It might correspond to 20 blocks containing 50,000 tonnes each, 2 blocks containing 500,000 tonnes each, or 1 block containing more than 1 million tonnes. Based on comparisons with fossil deposits, however, we estimate that the median tonnage in the most prospective block of 10 km x 10 km will be no more than 500,000 tonnes (see Appendix 2). Few blocks of this size would be expected to contain more than 1 million tonnes, and the majority would be expected to contain no more than 50,000 tonnes. Of the 100 occurrences considered in the present study, excluding the Atlantis II Deep, only two have been shown by drilling to contain more than 1 million tonnes of massive sulphides. Fewer than five others have dimensions that could be consistent with tonnages exceeding 1 million tonnes. Of these, only two are located in the Area (TAG and 13°N East Pacific Rise).

Mapping of sulphides occurrences on the seabed has shown that, individually, they cover areas of no more than 1 kilometre in diameter, and exploitation of any given sulphides occurrence would not be expected to extend beyond an area of these dimensions. In no cases are the expected dimensions of a single occurrence larger than the minimum 10 kilometre x 10 kilometre block. In the majority of cases, blocks where exploitation might take place would not be arranged contiguously and may not be a subset from a single original exploration area. Blocks considered for exploitation may need to be selected from several non-contiguous exploration areas and split between two or more tenements. The following examples illustrate how contiguous and non-contiguous blocks might be allocated at the exploration stage.

Exploration model 1 (contiguous blocks)

In this model, areas of permissive geology, physically bounded by ridge segments or other geological features of similar scale and containing at least one occurrence of polymetallic sulphide or other positive indication of mineralization, were selected in each 5-degree by 5-

degree area (see *Appendix 3*). Each permissive area corresponds to approximately 500 contiguous blocks of 10 kilometres x 10 kilometres each (50,000 square kilometre). This is approximately 20 times the size of the final allocation for exploitation as defined in the draft regulations (20 x 25 blocks = 500 blocks).

A single exploration area comprising 100 contiguous blocks of 10 kilometres x 10 kilometres each (10,000 square kilometres) was selected for advanced exploration, such as might be defined in a work-plan. In this model, an exploration area was chosen that contains at least one of the known sulphide occurrences in the 5-degree by 5-degree area (e.g., *Figure 4*) and represents no more than 20 per cent of the original prospecting area. In each case, 100 of the most prospective blocks (arranged in square blocks of 25) were selected to include as many of the known sulphide occurrences as possible. This mimics the selection process that would be expected in a permissive area during the first phase of exploration. This area is reduced to 50 contiguous blocks after year 5 and 25 contiguous blocks after year 10 (*Figure 4*).

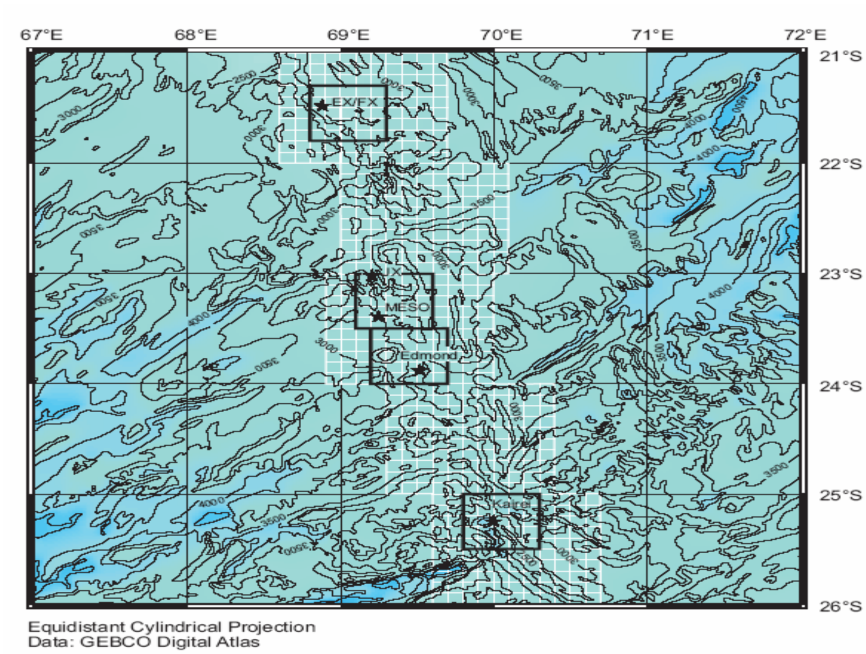

Figure 4. An application of model 1 in the Central Indian Ridge, showing 100 contiguous blocks of 10 km x 10 km each that were leased for exploration and contain at least one known sulphide occurrence or other positive indication of mineralization in the 10,000 km^2 area. Fifty per cent of the exploration area is relinquished in the first exploration stage (5 years), leaving 50 contiguous blocks of 10 km x 10 km each, containing three of the 5 known sulphide occurrences in a 5,000 km^2 area. In the final stage of exploration, 25 contiguous blocks of 10 km x 10 km each are retained, containing two of the known sulphide occurrences in a 2,500 km^2 area. In this model, two occurrences were left outside the initial exploration area and a third occurrence had to be relinquished in order to retain only contiguous blocks in the final selection of 25.

A single area of 25 contiguous blocks of 10 kilometres x 10 kilometres each (2,500 square kilometres) and containing at least one known sulphide occurrence was selected as the final lease within the exploration area. In this model, the final lease blocks were selected to contain the maximum number of known sulphide occurrences in an area representing no more than 25 per cent of the original exploration area (*Figure 4*).

Exploration model 2 (non-contiguous blocks)

In this second model, the exploration area is split into 4 clusters of 25 blocks each, with each cluster containing a known sulphide occurrence or other positive indicator of hydrothermal activity in a total combined area of 10,000 square kilometres (e.g., *Figure 5*). During the exploration phase, portions of each cluster of contiguous blocks would be relinquished in multiple stages, eventually leaving 25 non-contiguous blocks of 10 kilometres x 10 kilometres each that contain all of the known sulphide occurrences in the original 10,000 square kilometres. Although not considered here, the optimum lease blocks in some areas would need to be chosen from more than one exploration area of 10,000 square kilometres. There is no guarantee that the most prospective blocks would be correctly identified in the exploration phase, but it is a reasonable expectation that explorers will be able to apply appropriate criteria to maximize the selection of clusters of blocks that contain sulphides.

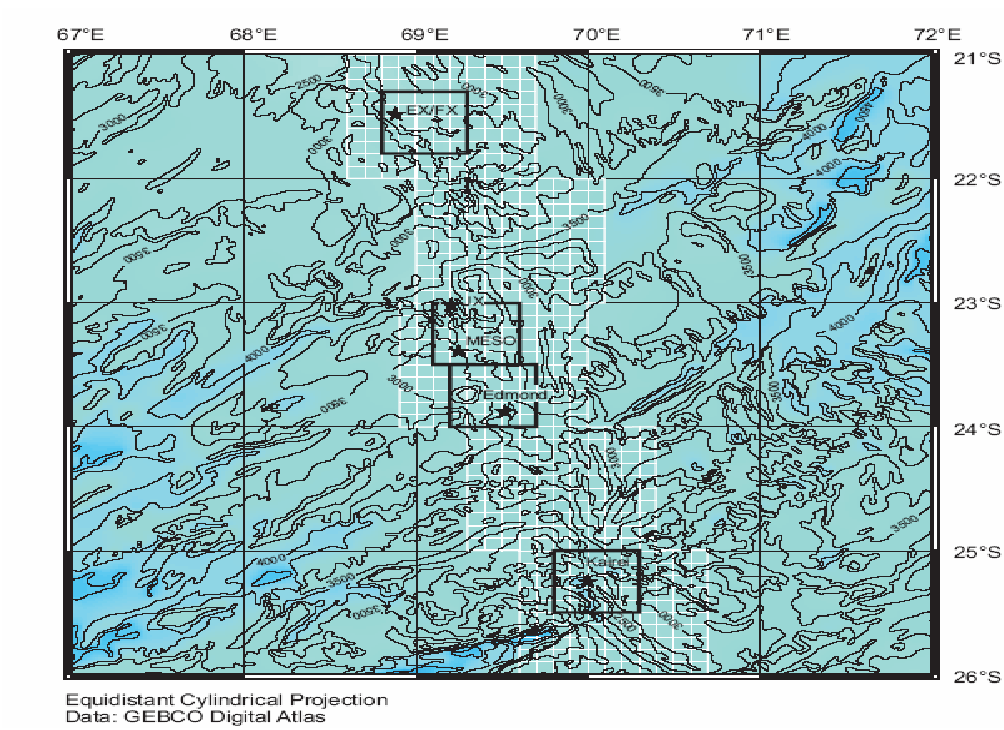

Figure 5. An application of model 2 in the same areas as Figure 4, showing 100 non-contiguous blocks of 10 km x 10 km each, split between 4 clusters of 25 contiguous blocks of 2,500 km^2 each, containing all of the known sulphide occurrences in a total combined area of 10,000 km^2. There is no guarantee that the most prospective blocks would be correctly identified in the exploration phase, but it is a reasonable expectation that explorers will be able to apply appropriate criteria to maximize the selection of clusters of blocks that contain sulphides. The initial area for exploration may need to be significantly larger than 10,000 km^2 in order to secure all of the sulphide occurrences in the final stage of exploration.

Results

Selection of permissive areas and areas for exploration

Of the 32 areas of 5-degrees by 5-degrees considered in the present study, the average area with permissive geology for the occurrence of polymetallic sulphides is 55,000 square kilometres (*Table 2*). Areas of roughly equal size were selected in the 20 examples of national EEZs and in the 12 examples from the Area. The permissive areas in some EEZs are smaller, owing to the proximity to land and large numbers of islands. In other EEZs the permissive areas are larger, owing to the selection of both back-arc areas and arc-front volcanoes. The variance in the size of permissive areas selected in examples from the Area is lower than in many EEZs, as the mid-ocean ridge spreading centers in the Area tend to be geologically less complex. In all cases, the areas chosen as being permissive for polymetallic sulphides are significantly larger than the 10,000 square kilometres that would be encompassed by a single exploration area of only 100 blocks of 10 kilometres x 10 kilometres each.

Table 2. Analysis of permissive areas, numbers of known sulfide occurrences, and spacing between occurrences in 32 areas (5 deg. by 5 deg.).

	Five Degree Map Area	Estimated Permissive Area (km^2)	Number of Occurrences In the Area (N=106)	Max. Number of Occurrences in 100 Contiguous Blocks*	Max. Number of Occurrences in a Final 25 Blocks	Average Spacing (km) Between Occurrences
	In "the Area"					
1.	EPR, 13°N	80,000	8	6	3	54
2.	EPR, 9°N	50,000	4	4	3	23
3.	EPR, AHA Field	50,000	1	1	1	--
4.	EPR, 7°S	40,000	2	2	2	10
5.	EPR, 17°S	60,000	4	3	2	120
6.	EPR, 18°S	60,000	9	6	3	55
7.	EPR, 37°S	50,000	2	2	2	15
8.	MAR, TAG and Broken Spur	50,000	2	1	1	300
9.	MAR, 24°N and Snakepit	45,000	2	1	1	175
10.	MAR, 14°N and Logatchev	60,000	3	2	2	87
11.	MAR, 5°S	60,000	2	2	2	--
12.	Central Indian Ridge	50,000	5	3	2	108
	National EEZs					
1.	N. Juan de Fuca Ridge	56,000	3	2	1	86
2.	S. Juan de Fuca Ridge	40,000	4	4	3	40
3.	Gorda Ridge	50,000	4	3	3	67
4.	Guaymas Basin	40,000	1	1	1	--
5.	Galapagos Rift	50,000	1	1	1	--
6.	EPR, 21°N	50,000	3	3	3	10
7.	EPR, 23°S	110,000	4	2	2	250
8.	MAR, Lucky Strike, Menez	75,000	4	3	1	100
9.	Tyrrhenian Sea	35,000	3	3	1	70
10.	N. Red Sea	50,000	3	2	1	180
11.	S. Red Sea	52,000	1	1	1	--
12.	N. Okinawa Trough	60,000	4	4	2	53
13.	S. Okinawa Trough	45,000	3	2	1	75
14.	Izu-Bonin Arc	65,000	4	3	2	123
15.	Mariana Trough and Arc	75,000	3	2	1	165
16.	Eastern Manus Basin	25,000	6	3	3	48
17.	Woodlark Basin	40,000	1	1	1	--
18.	N. Fiji Basin	40,000	3	2	2	95
19.	S. Lau Basin	50,000	4	3	2	133
20.	Southern Kermadec Arc	70,000	4	2	1	110
	Average	55,000	3.4	2.5	1.8	98

*10,000 km^2 arranged in square blocks of 25

Interpolation and gridding of the GEBCO data at 500-metre contour intervals and a 1-minute spacing can recover additional seafloor details that may be useful in selecting smaller permissive areas, potentially reducing the areas selected in the first pass by as much as 50 per cent. This is illustrated by the example of the Northeastern Pacific, in which the permissive area selected from the GEBCO data is 55,000 square kilometres, whereas a permissive area of about 25,000 square kilometres might have been chosen at a contour interval of 100 m (*Appendix 5*). Even with the higher resolution bathymetry, it is not always recommended to exclude deep or flat areas flanking the ridges. An example of this problem is the Middle Valley occurrence, which, owing to its location off-axis from the spreading center, might not have been included in an initial selection of permissive areas even at a 100-m contour interval. Thus, a tenfold *increase* in the resolution of the bathymetry at the scale of 5 degrees by 5 degrees does not necessarily result in a tenfold decrease in the area selected as being permissive for polymetallic sulphides. Restricting exploration to shallow water depths (e.g., less than 2,500 metres), for as yet unspecified technological reasons, also would exclude many areas that are highly prospective for polymetallic sulphides, including most of the Area. Whereas a high proportion of the known polymetallic sulphides in national EEZs occur at water depths of less than 2,500 metres, many in the Area are as deep as 4,000 metres (*Figure 6* and *Table 1*).

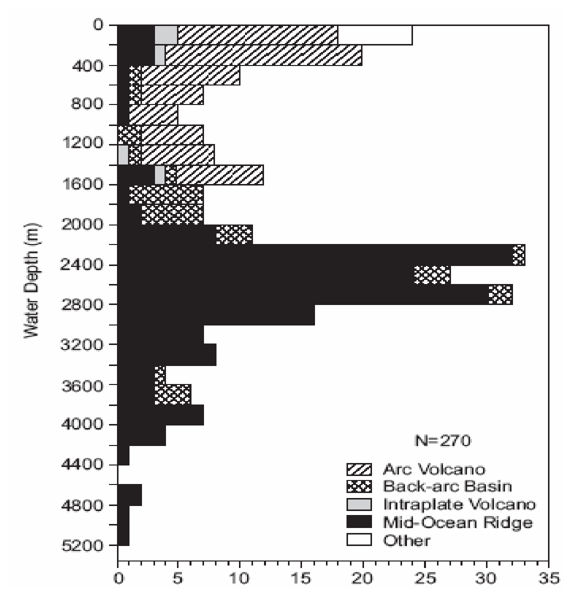

Figure 6. Depth distribution of seafloor hydrothermal vents in different volcanic and tectonic settings (from Hannington et al., 2005, modified after Massoth et al., 2003).

The average number of sulphides occurrences in each of the ca. 55,000 square kilometres permissive areas is 3.4 (*Table 2*). A slightly higher average number (3.7) was found in the examples from the Area, reflecting the number of small sulphide occurrences that characterize fast-spreading ridges. From an analysis of all 106 sulphides occurrences in *Appendix 3*, the average spacing between occurrences in each 5-degree by 5-degree area is 98 kilometres (*Table 2*). In the Area, the average spacing is 95 kilometres (n = 43). Although the spacing is greater on the slow-spreading ridges (167 kilometres) than on the fast-spreading ridges (46 kilometres), the individual sulphide occurrences on the slow-spreading ridges are larger on average. These data suggest that an exploration licence of only 10,000 square kilometres will likely include only a fraction of the known occurrences in an area. Given the wide distribution of vents, lease blocks may be required at a number of separate locations within discrete and possibly separate permissive areas. Although unfavourable areas could be systematically relinquished in such a way as to preserve a contiguous arrangement of retained blocks, it is more likely that explorers will rapidly identify the most favourable sites and that a number of non-contiguous prospective blocks would be established.

Comparison of Model 1 and Model 2

In model 1, the average number of sulphide occurrences in 100 of the most prospective blocks, or 10,000 square kilometres, is 2.5. A slightly higher average number of occurrences (2.7) was found in the examples chosen from the Area. On average, an exploration area that comprises 100 contiguous blocks encompasses 73 per cent of the known sulphide occurrences in the permissive area. In the example shown in figure 4, two occurrences were left outside the initial exploration area and a third occurrence had to be relinquished in order to retain a contiguous arrangement of blocks in the final selection. In this example, the final 25 contiguous blocks contain only 2 of the 4 sulphide occurrences in the original permissive area. On average only 53 per cent of the known sulphide occurrences in a permissive area are contained in the final 25 blocks (*Table 2*).

In model 2, the exploration areas were split into 4 sub-areas, each comprising 25 of the most prospective blocks (for the same total area of 10,000 square kilometres). In this case, it was possible to capture 97 per cent of the known sulphides occurrences within the 100 most prospective blocks. In the few cases where sulphide occurrences were left outside the 100 most prospective blocks, the total number of occurrences was larger than could be contained in the 4 sub-areas. In the majority of the 5-degree by 5-degree areas, non-contiguous blocks would be required to encompass all of the known sulphide occurrences in the permissive area.

Conclusions and recommendations

The draft regulations for prospecting and exploration likely could not be applied equally to crusts and polymetallic sulphides. The permissive areas for polymetallic sulphides are large, but the occurrences are more localized and the areas likely to be considered for exploitation are smaller than for crusts. Unlike crusts, which are mainly restricted to seamounts that can be readily identified in bathymetric surveys, large areas may be selected for initial stages of prospecting for polymetallic sulphides. Such areas can be rapidly reduced to the most highly prospective sites within the first 5 to 10 years, but more areas may need to be explored to ensure that sufficient exploitable resources are eventually identified. In the majority of cases, a single exploration area of 10,000 square kilometres is too small to encompass all of the polymetallic sulphides that may occur within a prospective area of 5 degrees by 5 degrees. For larger areas, the proposed schedule of relinquishment may not allow adequate assessment of all areas in enough detail to ensure that prospective blocks are not abandoned prematurely.

Given the known distribution of polymetallic sulphides in the Area, it is likely that separate clusters of contiguous blocks would be needed to encompass all of the known sulphide occurrences in an exploration licence. The use of contiguous blocks, as defined in the draft regulations, likely would not allow a contractor to secure adequate opportunities for multi-year exploitation, and applications for multiple 100-block licences would almost certainly be required to cover the permissive geology. Because of the spacing between occurrences in a given area, 100 contiguous blocks in a plan of work for exploration is unlikely to be sufficient for the discovery of multi-year resources. Splitting the exploration areas into clusters of non-contiguous blocks would be required to ensure that the final clusters can be spread over a large enough area to contain such resources. The final 25 blocks selected for exploitation may not originate from the same initial allocation of 100 blocks in a single exploration licence. In most applications of model 1, at least one occurrence was left outside the initial exploration area and a second occurrence had to be relinquished in order to preserve a contiguous arrangement of the final 25 blocks. The regulations should allow licensing of areas for exploration that are large enough to contain a reasonable number of occurrences, or provide other rights at the prospecting stage to secure enough prospective areas that might contain exploitable resources. Applications for licences comprising non-contiguous blocks should be permitted throughout the exploration and exploitation stages.

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Appendix 1:
Relevant paragraphs of the draft Regulations

Regulation 12
Total area covered by the application

1. The area covered by each application for approval of a plan of work for exploration shall be comprised of not more than 100 blocks.

2. For polymetallic sulphides or cobalt crusts the exploration area shall consist of contiguous blocks. For the purposes of this regulation two blocks that touch at any point shall be considered to be contiguous.

3. Notwithstanding the provisions in paragraph 1 above, where a contractor has elected to contribute a reserved area to carry out activities pursuant to annex III, article 9, of the Convention, in accordance with regulation 17, the total area covered by an application shall not exceed 200 blocks.

Regulation 17
Data and information to be submitted before the designation of a reserved area

1. Where the applicant elects to contribute a reserved area, the area covered by the application shall be sufficiently large and of sufficient estimated commercial value to allow two mining operations. The applicant shall divide the blocks comprising the application into two groups of equal estimated commercial value and composed of contiguous blocks. The area to be allocated to the applicant shall be subject to the provisions of regulation 27.

Regulation 27
Size of area and relinquishment

1. The contractor shall relinquish the blocks allocated to it in accordance with paragraphs 2, 3 and 4 of this regulation.

2. By the end of the fifth year from the date of the contract, the contractor shall have relinquished:

(a) At least 50 per cent of the number of blocks allocated to it; or
(b) If 50 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

3. By the end of the tenth year from the date of the contract, the contractor shall have relinquished:

(a) At least 75 per cent of the number of blocks allocated to it; or
(b) If 75 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

4. At the end of the fifteenth year from the date of the contract, or when the contractor applies for exploitation rights, whichever is the earlier, the contractor shall nominate up to 25

blocks from the remaining number of blocks allocated to it, which shall be retained by the contractor.

5. Relinquished blocks shall revert to the Area.

6. The Council may, at the request of the contractor, and on the recommendation of the Commission, in exceptional circumstances, defer the schedule of relinquishment. Such exceptional circumstances shall be determined by the Council and shall include, inter alia, consideration of prevailing economic circumstances or other unforeseen exceptional circumstances arising in connection with the operational activities of the Contractor.

Appendix 2
Model parameters

A range of physical characteristics of seafloor polymetallic sulphides and the geological environments in which they are found are considered here as guides for the selection of prospecting areas. Following is a brief review of the main parameters used for mid-ocean ridges. A thorough review of other geological settings listed in table 1 is beyond the scope of the present paper but should be the subject of any further consideration of global exploration for seafloor polymetallic sulphides. For more information, the reader is referred to overview papers on this topic by Hannington et al. (1995, 2005) and Herzig and Hannington (1995, 1999, 2000). Additional information also can be obtained from Technical Study No. 2 on Polymetallic Massive Sulphides and Cobalt-rich Ferromanganese Crusts – Status and Prospects, published by the International Seabed Authority.

1. Geological considerations

Polymetallic massive sulphides are products of high-temperature (ca. 350^{o}C) black smoker vents that occur in areas of active or recently active volcanism on the seafloor, including deep-sea mid-ocean ridges, sedimented ridges, mid-plate seamounts, arc volcanoes, and back-arc rift environments. The hydrothermal precipitates consist of massive accumulations of metallic minerals, including mainly pyrite, pyrrhotite, chalcopyrite and sphalerite that occur at and below the seafloor around hydrothermal vents. Most sulphide accumulations are associated with ongoing hydrothermal venting, but about 20 per cent of these sites are no longer active.

About 65 per cent of known sulphides occurrences are located at mid-ocean ridges; the remainder are in back-arc basins (22 per cent), on submarine volcanic arcs (12 per cent), and on intraplate volcanoes (1 per cent). The distribution of vents is roughly proportional to the lengths of the ridges and arcs; mid-ocean ridges have a combined length of 55,000 km, and island arcs and adjoining back-arc basins have a combined length of 22,000 km. The sulphides are found on a variety of different substrates, including mid-ocean ridge basalt, ultramafic intrusive rocks, and more evolved lavas associated with volcanic arcs, as well as within sediments overlying both oceanic and continental crust. Permissive areas for the occurrence of polymetallic sulphides include areas of intense faulting and seafloor eruptions, which commonly can be identified from regional bathymetry. Black smokers are most abundant on fast-spreading mid-ocean ridges, which reflect the high heat flow and voluminous seafloor volcanism in this environment. However, the most abundant sulphides are not always associated with the highest spreading rates; the largest sulphide occurrences are located at intermediate- and slow-spreading centers, at ridge-axis volcanoes, in deep back-arc basins, and in sedimented rifts adjacent to continental margins. The lack of known sulphides occurrences in some parts of the oceans (e.g., the Polar Regions and Southern Ocean) mainly reflects the difficulties of marine research at these latitudes. Recent discoveries of hydrothermal plumes and massive sulphides in the high Arctic and in Antarctica confirm that seafloor hydrothermal activity in remote parts of the oceans is little different from that observed elsewhere.

In the Area, mid-ocean ridges and intraplate volcanoes are the dominant volcanic features that host polymetallic sulphides (e.g., southern East Pacific Rise or EPR, Mid-Atlantic Ridge or MAR, Central Indian Ridge or CIR: Figure 1). The different types of mid-ocean ridges are discriminated on the basis of spreading rate and morphology, which vary in response to regional tectonic stresses and rates of magma supply. Fast-spreading ridges (full spreading rates of 6-10 cm/yr) occur in relatively thin oceanic crust and are characterized by abundant volcanic eruptions; intermediate-rate (4-6 cm/yr) and slow-spreading (1-4 cm/yr) ridges occur in relatively thick crust and are characterized by only intermittent volcanism between long periods of essentially a magmatic, tectonic extension and/or intrusive activity. Fast-spreading ridges account for about 25 per cent of the total length of the ridges, whereas 15 per cent of the ridges are classified as intermediate-rate and 60 per cent are slow-spreading. Super fast-spreading centers, such as the southern EPR (up to 17 cm/yr), and ultraslow-spreading centers, such as the Arctic and Southwest Indian ridges (<1 cm/yr), are also recognized. The rate of magma supply, the depth of the sub axial magma, and the extent of magmatic versus tectonic extension influence the size and vigour of hydrothermal convection on the ridges. There is a general correlation between the spreading rate and the incidence of hydrothermal venting; however, as noted above, the largest sulphides occurrences are commonly found where volcanic eruptions are episodic and alternate with long periods of intense tectonic activity.

Ridges (and back-arc basins) are physically segmented at scales of tens to hundreds of kilometres by a variety of discontinuities, including transform faults, overlapping spreading centers, and other non-transform offsets. These features affect the distribution of magmatic heat and convective hydrothermal circulation, providing natural boundaries on the areas that are likely to be selected for exploration of polymetallic sulphides. At the scale of major ridge segments, high-temperature venting commonly occurs along the shallowest portions of the ridge at the middle of the segments, whereas the ends of segments are typically starved of magma and heat.

On fast-spreading ridges, such as the southern EPR, lavas are extruded onto the seafloor faster than the rate of extension, so the flows accumulate as local volcanic highs up to 100 m above the surrounding seafloor. The eruptive fissures typically occupy a narrow axial graben (~1 km wide), and this is the most common location for hydrothermal vents. Venting correlates closely with the areas of most recent volcanic eruptions. However, frequent eruptions can disrupt the flow of hydrothermal fluids and bury sulphides occurrences that are localized along the eruptive fissures. As a result, the vent complexes at fast-spreading ridges tend to be small (less than a few thousand tonnes, dry weight) and the sulphide occurrences may be rapidly displaced from their heat source by the high spreading rates.

Slow and intermediate-rate spreading centers, such as the MAR and CIR, are characterized by lower rates of magma supply and greater structural control on hydrothermal upflow than at fast-spreading ridges. Slow-spreading ridges, in particular, are characterized by a wide (up to 15 km) and deep (up to 2 km), fault-bounded axial valley. Here, eruptions occur only very rarely or at intervals of hundreds to thousands of years. At the slowest spreading rates, eruption intervals may be as long as tens of thousands of years. Until 1984, it was generally accepted that hydrothermal activity on slow-spreading ridges would be limited because of the lack of near-seafloor magmatic heat. Following the discovery of the TAG Hydrothermal Field on the Mid-Atlantic Ridge, it became apparent that slow-spreading ridges may host some of the largest hydrothermal systems on the seafloor. These may be located well off-axis, where the substrate is stable enough to have supported growth of sulphides mounds for many hundreds of years, in contrast to younger vent fields near the neovolcanic zone that have not had sufficient time to accumulate massive sulphides. Hydrothermal venting at slow-spreading ridges is commonly focused along the walls of the rift valley. Because of large buoyancy forces acting on the hydrothermal fluids, it is not uncommon for high-temperature venting to occur on top of structural highs many kilometres from the center of the rift. For this reason, exploration of slow-spreading ridges must include large areas adjacent to the rift.

Off-axis volcanoes also may be sites of hydrothermal activity. These volcanoes are typically located 5 to 10 km from the ridges. They range in size from a few kilometres across to larger edifices up to tens of kilometres in diameter. A few large sulphide occurrences are known where these volcanoes are close to the ridge (e.g., at 13°N EPR). However, most off-axis volcanoes are characterized by only low-temperature, Fe-Mn oxide precipitates. This may reflect the small sizes of the associated magma bodies or the lack of deeply penetrating faults associated with the off-axis volcanism.

Most mid-ocean ridge vents occur at water depths of between 2,000 and 3,000 m, but a large number are also known at water depths of as much as 4,000 m (figure 6 and table 1). The deepest vents occur on slow- or ultraslow-spreading centers that lack the crustal buoyancy associated with large volumes of sub axial magma. However, at a regional scale, most hydrothermal venting is focused at the summit regions of volcanic edifices (shallowest portions of mid-ocean ridge spreading centers; summits of off-axis seamounts). More locally, sulphide occurrences may be found in volcanic or tectonic depressions that are superimposed on the volcanic highs (e.g., rift grabens at the summit of a ridge segment; summit calderas of arc volcanoes). The deeper outer flanks of ridges or volcanoes are less prospective areas for hydrothermal activity and are less likely to host significant polymetallic sulphides, except where major structures may be present to focus hydrothermal up flow.

Unlike areas where crusts might be exploited, sediment cover should not discourage exploration for polymetallic sulphides unless the cover is so thick as to prevent hydrothermal fluids from reaching the seafloor. However, some heavily sedimented environments, such as sedimented ridges and rifted margins, may be specifically targeted for sediment-hosted polymetallic sulphides, especially where other indicators of mineralization are present (e.g., high heat flow, evidence of sub seafloor hydrothermal activity or alteration of the sediment). One of the largest known occurrences of polymetallic sulphides (Middle Valley on the Juan de Fuca Ridge) is in an area of almost 100 per cent sediment cover, although hydrothermal manifestations are evident and indicate near-sub seafloor mineralization. In the models presented in the present paper, sediment cover is not considered in the selection of permissive geological environments, but this criterion, together with the presence or absence of hydrothermal indicators, will likely be used by explorers in the selection of blocks with limited volcanic activity to be released from tenements following an initial phase of exploration.

11. Prohibitive bathymetric relief can be expected in many areas of recent volcanic and tectonic activity. This may be a positive indicator of magmatic and hydrothermal processes that can lead to concentrations of polymetallic sulphides, but extremes of relief or poor ground stability which may be an impediment to any future exploitation. The walls of rift grabens or summit calderas of recently active volcanic edifices are inherently unstable and rugged, although the bottoms of rifts and calderas may include locally flat areas where polymetallic sulphides may accumulate. Typical relief at fast-spreading centers is tens to hundreds of metres over distances of 1 km; relief at slow-spreading centers may be hundreds of metres up to 1 km over horizontal distances of 1 km. In some places, ongoing volcanic eruptions may be an impediment to exploration or exploitation of sulphides. Some arc volcanoes are off-limits to navigation owing to volcanic hazards.

2. Other considerations

Biological communities associated with active hydrothermal venting are typically located at or near occurrences of polymetallic sulphides. Regulations may prohibit any disturbance of such communities so that a large proportion of the known sulphide occurrences may be excluded from any commercial exploration at an early stage. Inactive sulphides chimneys and mounds are typically not associated with living biological communities, and therefore are potential candidates for exploitation, but they commonly occur in close proximity to active vents (within 1-2 km) and are almost always associated with the same geological features. The disturbance of inactive sulphides accumulations adjacent to active sites is likely to have an unknown impact on nearby active systems and their associated biological communities.

At some sites entanglement hazards may be presented by abandoned gear (cables, dredges, fishing gear, scientific instrumentation). For example, the TAG mound, which was drilled at 17 different locations within an area of less than 250 m, has numerous abandoned holes, including drill pipe.

3. Sizes of exploration areas

The expected number and distribution of high-temperature hydrothermal vents on the mid-ocean ridges will limit the optimal size of an exploration area. Generally the spacing of vents is not known, but a variety of geophysical measurements provide an indication of the possible numbers of vents on the ridges. For example, heat loss from the axial zones of the global mid-ocean ridges is on the order of 1.8+0.3 x 1012 W (Mottl, 2003). About 10 per cent of this heat is discharged at black-smoker temperatures. Assuming a heat flux of 2 to 5 MW for a single black smoker vent (e.g., discharge rates of 1 to 2 kg/s: Converse et al., 1984), the estimated flux of high-temperature fluids to the seafloor (10 per cent of 1.8+0.3 x 1012 W) would be equivalent to about 50,000 to 100,000 black smokers (i.e., at least one black smoker for every 1 km of ridge). However, the number of known black smokers is extremely small by comparison, and their distribution is far from uniform. A single large vent field may contain as many as 100 black smoker vents having a total heat output of 200 to 500 MW (e.g., Becker and Von Herzen, 1996). Thus, one vent field every 50 to 100 km could potentially account for the estimated high-temperature discharge at mid-ocean ridges. Although this estimate does not consider large-scale variations in heat flux according to spreading rate and other factors, it is a useful first-order guide for choosing the size of an area to explore along a given segment of ridge crest.

Independent estimates based on the actual distribution of known vent sites suggest that the spacing of sulphide occurrences along segments of mid-ocean ridges might be quite regular at the regional scale. From an analysis of 100 known sulphide occurrences in 32 areas 5 deg. by 5 deg. considered in the present study, the average spacing between occurrences is 98 km (table 2). Among those in the Area (n = 43), the average spacing is 95 km. Although the spacing is greater on the slow-spreading ridges (167 km) than on the fast-spreading ridges (46 km), the individual sulphide occurrences on the slow-spreading ridges are larger on average.

Given the wide distribution of vents, lease blocks may be requested at a number of separate locations within discrete and possibly separate permissive areas requiring extensive assessment work. Although unfavourable blocks could be systematically relinquished over the 15-year time period specified in the draft regulations, it is more likely that explorers will rapidly identify the most favourable sites and that a minimum number of non-contiguous prospective blocks could be established quickly. This possibility is considered in the model of non-contiguous blocks.

4. Sizes of exploration targets

The minimum size of an exploration area is determined by the size of the expected discovery and the geological features that control its location. Larger clusters of sulphides occurrences are mainly controlled by geological features that can be readily identified in bathymetric surveys (rift grabens or calderas with maximum dimensions of a few tens of kilometres). More local controls may include faults, dike swarms, lava lakes, or other eruptive features with dimensions of a few hundreds of metres up to several kilometres. Individual sulphide occurrences may consist of single mounds or groups of chimneys and mounds that cover areas of the seafloor ranging from tens to hundreds of metres in diameter. These may be separated by hundreds of metres up to several kilometres, commonly with intervening areas of barren sediment or lava. On the Endeavour segment of the Juan de Fuca Ridge (*Figure A1*), 30 different sulphide complexes are distributed among 8 vent fields along a 10-kilometre segment of the axial valley. The main vent fields are evenly spaced, 2 to 3 kilometres apart (*Figure A2*). In the TAG Hydrothermal Field, the three main massive sulphides mounds (TAG, MIR, Alvin) are located within an area of about 25 square kilometres (F*igure A3*). Based on these observations, areas of the seafloor that are likely to be considered for the most advanced exploration, which may include high-resolution bathymetric mapping, bottom photography or other seafloor observations and sampling, are not expected to exceed 100 quare kilometres.

Of the more than 100 sites of high-temperature hydrothermal venting and polymetallic sulphides occurrences considered in this paper, only about one third have accumulations of polymetallic sulphide on the order of tens to hundreds of metres in diameter (Hannington et al., 1995; Fouquet, 1997). Most are incompletely surveyed, and reported dimensions commonly include large areas of discontinuous sulphides outcrops or barren substrate between the chimneys and mounds. The continuity of sulphides bodies is difficult to assess, even with the most detailed surveys. A number of examples illustrate that preliminary estimate of the surface areas of such occurrences cannot be used to reliably determine the volume of sulphides on or near the seafloor. Only drilling can provide this information, although future developments in geophysical methods might provide additional tools for this purpose.

When polymetallic sulphides were first discovered at Explorer Ridge, in the North-eastern Pacific (*Figure A1*), the largest sulphide mound was estimated to be 250 metres x 200 metres in size, based on submersible observations. Recent high-resolution surveys have shown that this area comprises mainly lava covered by discontinuous Fe-stained sediment, with only four 50-metre diameter clusters of chimneys, covering less than 25 per cent of the area originally considered to be massive sulphide (http://oceanexplorer.noaa.gov/explorations). In a similar survey of the Sunrise occurrence, on the Myojin Knoll submarine volcano, Izu-Bonin arc, an area of sulphides mineralization measuring 400 metres x 400 metres was reported (*Figure A4*). Based on a relief of 30 metres and a bulk density of 1.9 gm/cm^3, a total accumulation of 9 million tonnes of massive sulphides was calculated (Iizasa et al., 1999). Three important assumptions are implicit in this calculation: (i) the sulphide outcrop was considered to cover 100 per cent of the outlined area (i.e., including areas between sulphide ridges and mounds that are concealed by sediment); (ii) the observed relief is due entirely to the accumulation of massive sulphides on a flat seafloor and not due to faults or buried volcanic features (e.g., lava domes); (iii) the bulk density is uniform and represents the entire volume used in the calculation. In *Figure A4*, no more than 5 line-kilometre of surveys cover the 400 metres x 400 metres outlined area, providing visual coverage of not more than 30 per cent (e.g., surveys based on submersible observations or camera tows typically have a maximum field of view of not more than 10 m beyond the survey track). Visually identifiable sulphides outcrops, such as active or inactive sulphides chimneys, are shown to cover only about 25 per cent of the area. Given the limitations of the visual surveys and the uncertainties inherent in the calculations, the value of such estimates of bulk tonnage is questionable.

Drilling provides the necessary confidence to extrapolate surface observations to depth and to judge the continuity of sulphide outcrop. Two examples of sediment-hosted sulphides occurrences illustrate the importance of drilling. At Middle Valley on the Juan de Fuca Ridge and Escanaba Trough on the Gorda Ridge, the seafloor is marked by numerous uplifted blocks of sediment, up to several 100 metres in diameter and 50 metres high. Drilling and other detailed surveys showed that most of these mounds are mainly buried volcanic sills. However, drilling of one mound at Middle Valley (Bent Hill, which has a surface expression of 90 metres x 60 metres) intersected 95 m of massive sulphides below the seafloor, and a second smaller sediment-covered mound 300 m away (ODP (Ore Drilling Programme) mound), also was shown to comprise mainly massive sulphides (Davis et al., 1992). In contrast, drilling of similar mound-like features at Escanaba Trough (270 metres x 100 metres) indicated that massive sulphides is restricted to a small area only 5 to 15 metres deep (Zierenberg and Miller, 2000).

Reliable estimates of the sizes of sulphides accumulations have been possible in only a few cases where drilling information is available. At the TAG mound (200 metres x 45 metres) on the Mid-Atlantic Ridge, 17 holes drilled to a maximum depth of 125 m indicated a bulk tonnage of 2.7 million tonnes of massive sulphides averaging 2 wt. per cent Cu and 1.2 million tonnes of stockwork mineralization at 1 wt. per cent Cu (Hannington et al., 1998). At Bent Hill and ODP mound in Middle Valley, four deep drill holes indicated a combined bulk tonnage of between 10 and 15 million tonnes (Fouquet et al., 1998; Zierenberg et al., 1998). The next largest occurrences on the mid-ocean ridges, based on apparent surface areas, may be on the order of 100,000 up to 1 million tonnes, but no information is available from drilling. However, the great majority of known sulphide occurrences are much smaller. Individual sulphides structures and mounds rarely exceed a few tens of metres m in diameter, with bulk tonnages of no more than a few thousands of tonnes each. At Endeavour Ridge, the 30 sulphides edifices along 10 kilometres of the ridge total no more than about 50,000 tonnes. For the most part, sulphides occurrences in back-arc rifts and on volcanic arcs of the western Pacific are similar in size to those on the mid-ocean ridges.

The accuracy of estimates of bulk tonnage is further subject to considerable uncertainty about the physical properties of the sulphides mounds and chimneys. Hannington et al. (1998) used a bulk density of between 3.5 and 4 for the tonnage calculation of the TAG mound, based on shipboard density measurements of drill core. However, the bulk dry densities of sulphides chimneys, crusts, and sediments from other occurrences are much lower. Sulphides chimneys from the East Pacific Rise have a dry density of only 1-2 gm/cm^3 and an *in situ* water content of 25-50 per cent (Crawford et al.). Higher densities owing to compaction, open-space filling, and hydrothermal recrystallization of the sulphides might be expected in the interiors of mounds, but it is clear that these effects are not uniform.

5. Comparisons with land-based mining

Although there are considerable uncertainties in estimates of the sizes of sulphides accumulations on the seafloor, the range is expected to be similar to that of certain types of fossil sulphide deposits that have been mined on land. There are two potentially relevant models. So-called Cyprus-type massive sulphide deposits have long been considered to be the best ancient analogs of polymetallic sulphides that occur on the mid-ocean ridges and in mature back-arc basin environments (e.g., Hannington et al., 1998, and references therein). The “kuroko” deposits of Japan are analogs of polymetallic sulphides that occur in volcanic arc environments. The use of ancient analogs for predictive purposes assumes that the conditions of ore formation have been uniform over geological time, since the fossil record includes deposits of all ages. Nevertheless, it is unlikely that anything will be found on the present-day seafloor that is dramatically different from what is already known from these land-based deposits. Therefore unique grade and tonnage models for modern seafloor polymetallic sulphides are probably not required.

The data for Cyprus-type deposits indicate a median size of 1.6 million tonnes (figure A5). These data are skewed towards larger deposits because tonnages and grades are only known or reported for those deposits of sufficient size to have been mined economically. The vast majority of sulphides occurrences are either too small or of too low grade to be mined, and large numbers of small deposits are not included in the published reserves. Among the Cyprus-type deposits, this includes more than 90 undeveloped prospects containing <100,000 tonnes each, and probably many more much smaller occurrences that were never considered to be prospects (Hannington et al., 1998, and references therein). This situation is analogous to the many small isolated chimneys and mounds that are found on active segments of the mid-ocean ridges. When undeveloped prospects are included, the curves are shifted towards significantly lower tonnages (figure A5). In the case of the Cyprus-type deposits, the median size including uneconomic occurrences is expected to be less than 500,000 tonnes.

During mining of the "kuroko" deposits of Japan, careful records were kept of the physical dimensions of the mined ore bodies. Of the 44 mined deposits in the Hokuroku basin, the average surface area of the ore bodies was about 200 metres x 200 metres (Tanimura et al., 1983). Ore clusters typically occupied less than 100 square kilometres and contained up to 10 ore bodies. Sangster (1980) showed a similar distribution of ore bodies in massive sulphides mining districts in Canada, which have an average of 12 deposits in an area of 84 square kilometres. In these areas, the single largest deposit typically accounts for 60-70 per cent of the total metal reserves; the second largest deposit may contain only 10-20 per cent. The next nearest area with another large deposit may be located tens to hundreds of kilometres away. While these comparisons are potentially useful in defining target sizes for exploration of seafloor polymetallic sulphides, it is important to recall that the areas represented in ancient mining districts typically include deposits that are exposed at a number of different stratigraphic levels (i.e., many more deposits may be exposed on eroded surfaces on land than are likely to be exposed on a flat seabed).

The size distribution of sulphides occurrences in most areas of the seafloor suggests that rates of exploitation comparable to those employed at mining sites on land would exhaust the resource in 2,500 square kilometres within one year. Except in very rare cases, additional resources to sustain multi-year exploitation would need to be sought in other areas.

6. Comparison with commercial seabed exploration in Exclusive Economic Zones

Commercial exploration licences that have been granted to two corporations (Nautilus Minerals in the Eastern Manus Basin of Papua New Guinea and Neptune Minerals in the Tonga-Kermadec arc region of New Zealand) provide cogent examples of the limitations of different models for exploration and lease block selection. The original prospecting licences of Neptune Minerals in New Zealand were 33,000 square kilometres in 1999 and were reduced to a tenement of 7,790 square kilometres (24 per cent) in 2003. Nautilus Minerals' exploration licences in Papua New Guinea totalled 15,000 square kilometres in 1996. The two most prospective sites now being explored in the Eastern Manus Basin occur within an area of 2,500 square kilometres (17 per cent). In the tenements of both Neptune Minerals and Nautilus Minerals, the known sulphides occurrences could not have been captured in a single exploration licence of 100 contiguous blocks.

Appendix 3
Figures

Location of the SouthernExplorer, Middle Valley and
Endeavour sulphides occurrences

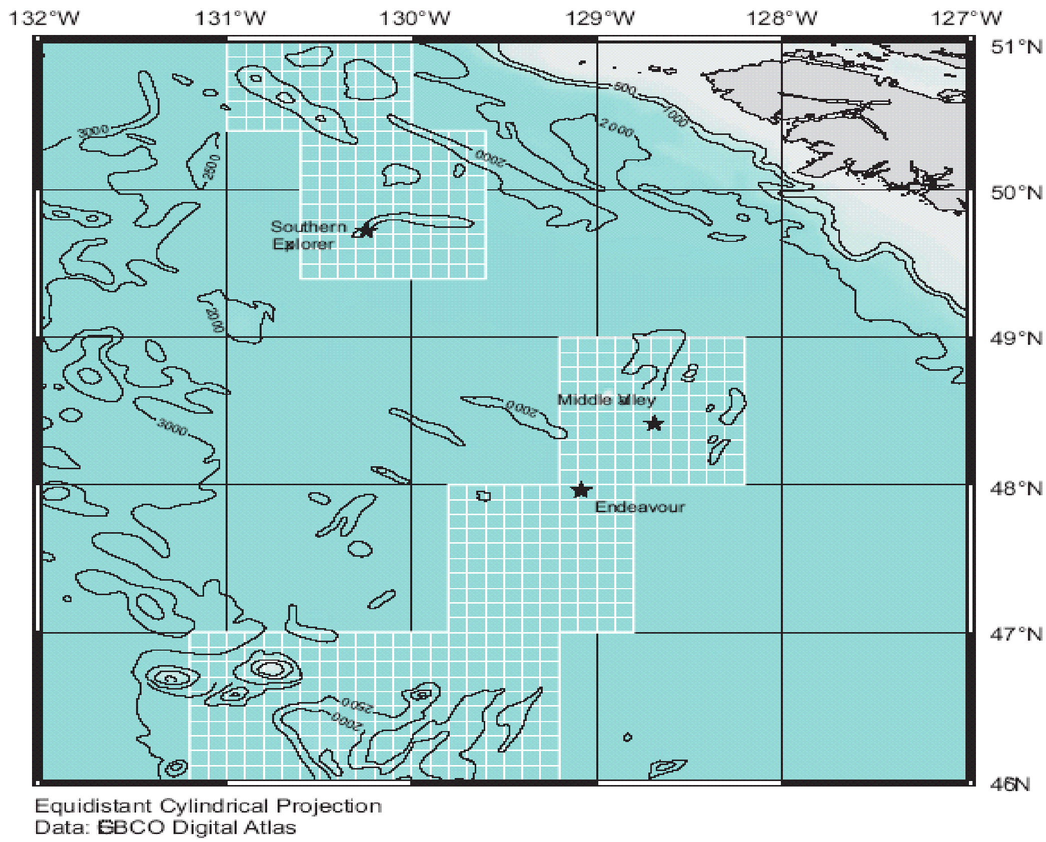


Figure A1. Example of a 5 degree by 5 degree area in the North-eastern Pacific (1,000-m contour interval), overlapping the Juan de Fuca Ridge and known occurrences of polymetallic sulphides at Southern Explorer Ridge, Middle Valley, and Endeavour Ridge.

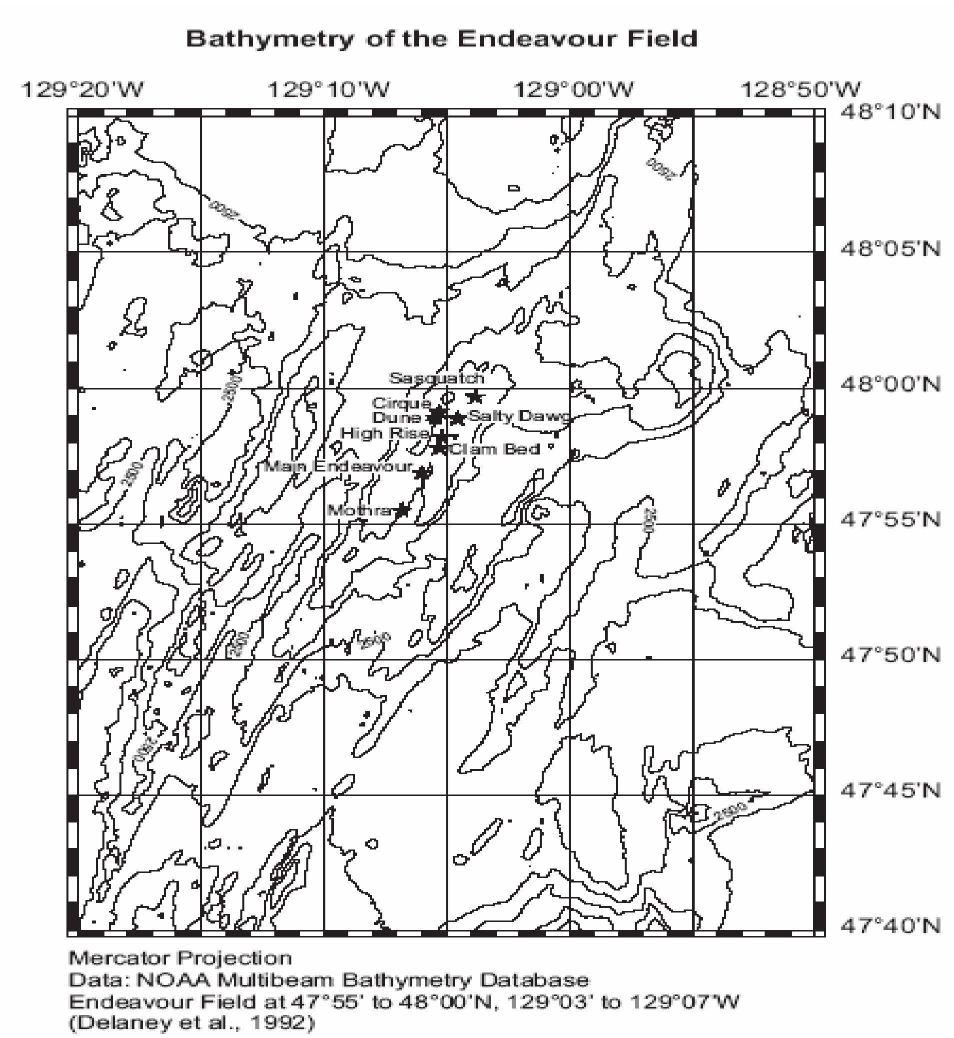


Figure A2. 30 min by 30 min map of the Endeavour Ridge (100-m contour interval) showing the locations of discrete sulphides occurrences, located about 2-3 km apart.

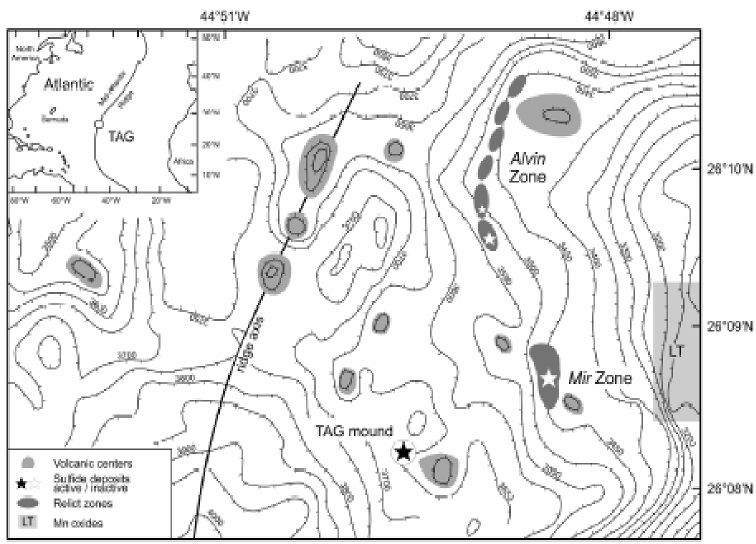


Figure A3. Distribution of sulphides occurrences in the TAG Hydrothermal Field, Mid-Atlantic Ridge. (Humphries et al., 1995). The three main massive sulphides mounds (TAG, MIR, Alvin) are located within an area of about 25 km^2.

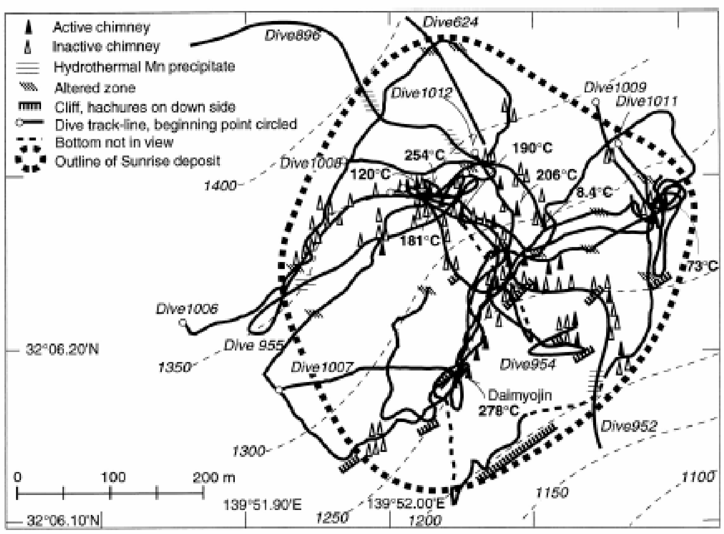


Figure A4. Map showing the submersible survey of the Sunrise occurrence, on the Myojin Knoll submarine volcano, Izu-Bonin arc (Iizasa et al., 1999). The depicted area of sulphides mineralization measures 400 m x 400 m. Based on a relief of 30 m and a bulk density of 1.9 gm/cm3, a total accumulation of 9 million tonnes of massive sulphides was calculated. However, surveys based on submersible observations or camera tows typically have a maximum field of view of not more than 10 m beyond the survey track. In the map shown, no more than 5 line-km of surveys cover the 400 m x 400 m outlined area, providing a visual coverage of not more than 30 per cent. Visually identifiable sulphides outcrops (i.e., active or inactive sulphides chimneys) are shown to cover only about 25 per cent of the area. Given the limitations of the visual surveys, the lack of any drilling information and the fact that the sulphides are not deposited on a flat seafloor, the calculated tonnage is uncertain.

CYPRUS MASSIC SULPHIDE DEPOSITS

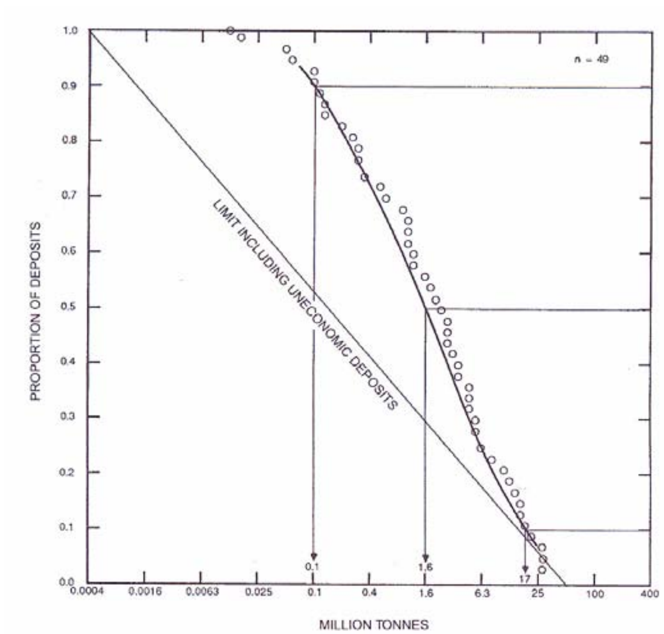


Figure A5. Tonnage model for 49 "Cyprus-type" massive sulphides deposits, showing the range of sizes of deposits. The median tonnage (50th percentile) is indicated at 1.6 million tonnes. The plotted data are from Singer and Mosier (1986), and include only those deposits of sufficient size to have been mined economically or for which reserves have been reported. The vast majority of sulphides occurrences are either too small or of too low grade to be mined, and large numbers of small deposits are not included in the published reserves. This includes more than 90 undeveloped prospects containing <100,000 tonnes each (Hannington et al., 1998, and references therein), and probably many more much smaller occurrences that were never considered to be prospects. When undeveloped prospects are included, the curves are shifted towards significantly lower tonnages, as indicated. In the case of the Cyprus-type deposits, the median size including undeveloped prospects is expected to be less than 500,000 tonnes.

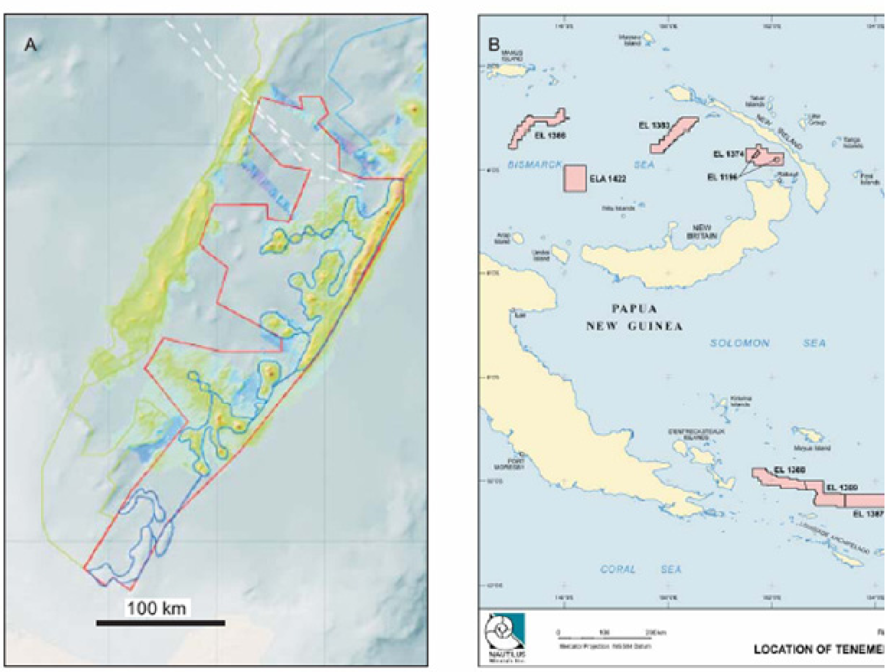
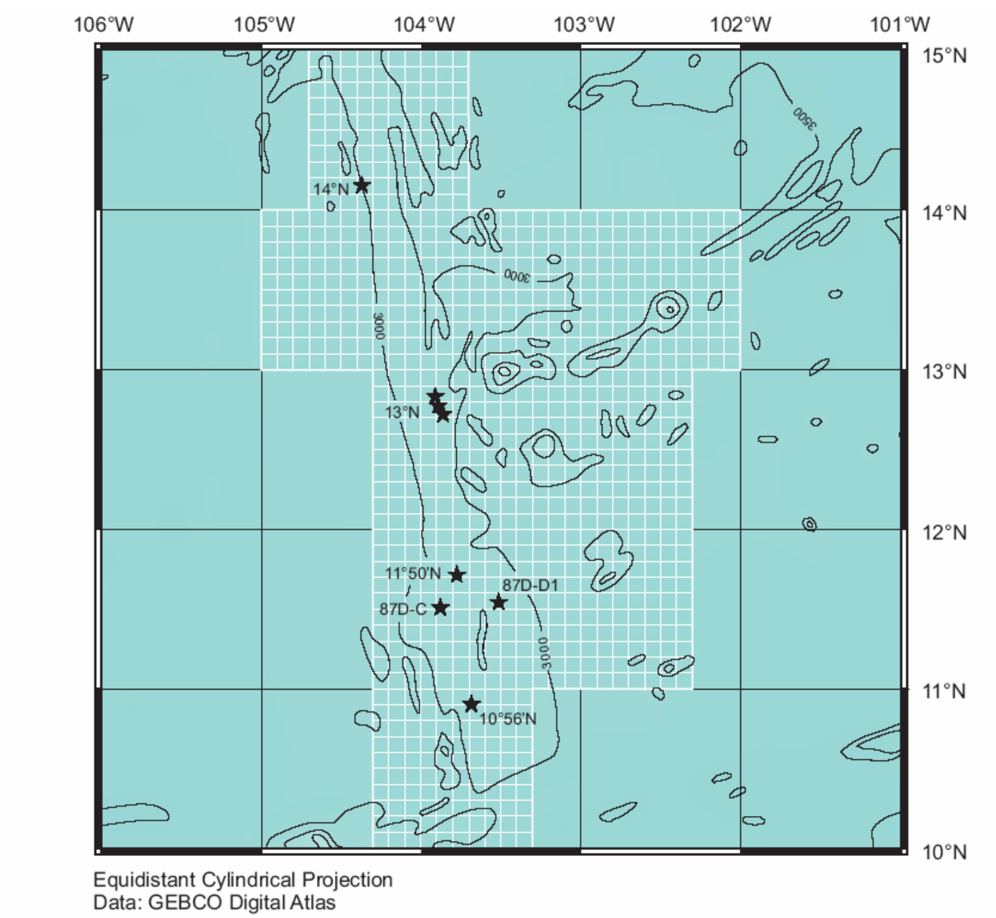


Figure A6. Examples of commercial exploration licences in Papua New Guinea and New Zealand. The original prospecting licences of Neptune Minerals in New Zealand (A) were 33,000 km^2 in 1999 and were reduced to a tenement of 7,790 km^2 (24 per cent) in 2003. The licences of Nautilus Minerals in Papua New Guinea (B) totalled 15,000 km^2 in 1996, and 2,500 km^2 (17 per cent) have now been identified that contain the two most prospective areas in the Eastern Manus Basin (www.nautilusminerals.com). In these examples, exploration licences based on 100 contiguous blocks would not have permitted all of the known sulphides occurrences to be included in a single tenement (see also appendix 3).

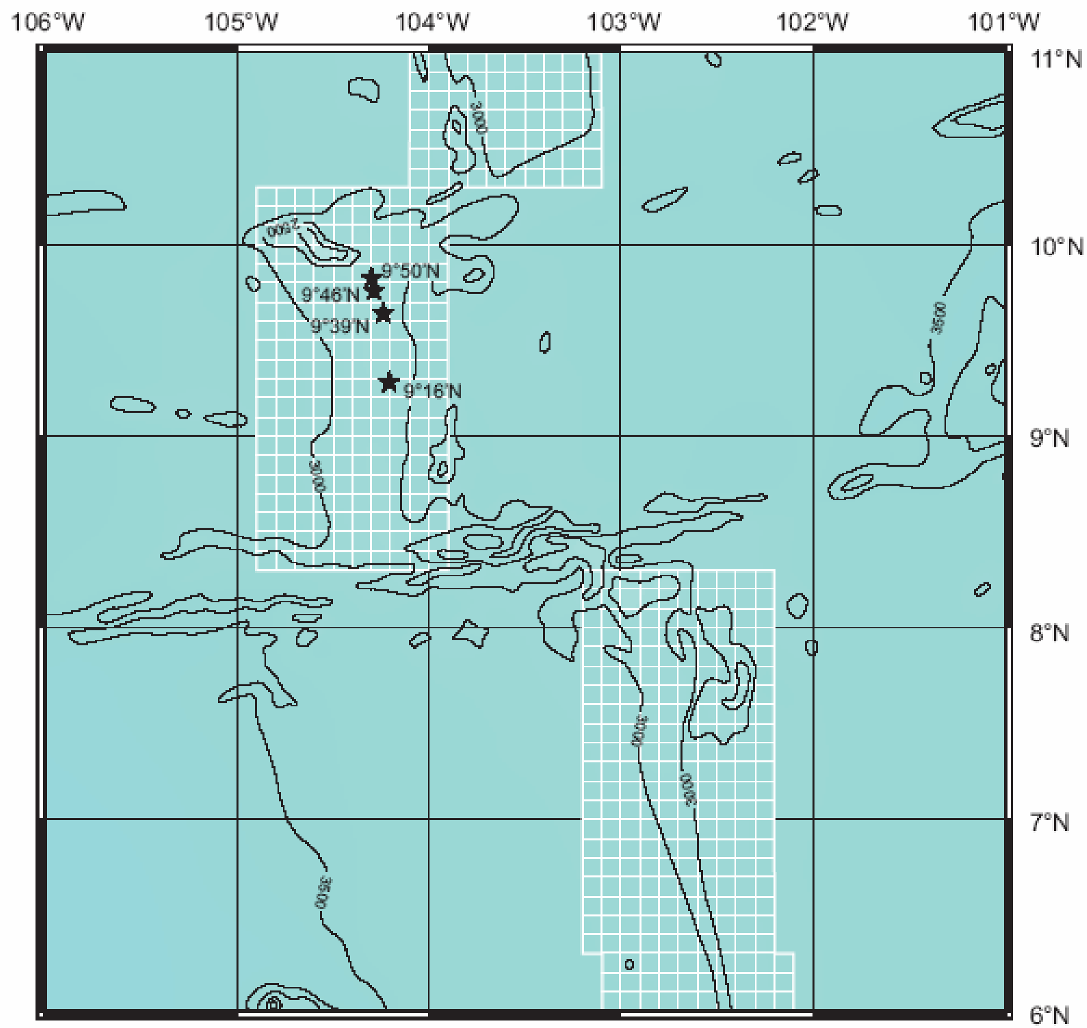
Appendix 4
Maps of 32 areas permissive for the occurrence of polymetallic sulphides

1. Areas that are considered permissive for polymetallic sulphides were selected in 32 map areas of 5 deg. by 5 deg. The prospecting area was arbitrarily defined as less than 5 degrees by 5 degrees and containing at least one known sulphide occurrence or other positive indication of mineralization. A 0.1 degree grid was overlain on each map in the areas considered to be permissive for polymetallic sulphides and where exploration might be carried out. This grid corresponds approximately to block sizes of 10 km x 10 km each (0.1 x 60 nm x 1.852 km = 11.11 km grid spacing). Decimal-degrees are used for ease of plotting sulphide locations. In each case, the placement of the grid is intended to cover all permissive areas, based on the broad geological attributes of each map area as discussed in the present paper. In the models presented herein, the size of the permissive areas correspond approximately to 20 times the size of the final allocation of blocks at the end of a 15-year exploration cycle (20 x 25 blocks).

Locations of the sulphide occurrences near 14°N, 13°N, 11°50'N, 10°56'N
and at the 87D-D1 and 87D-C Seamounts

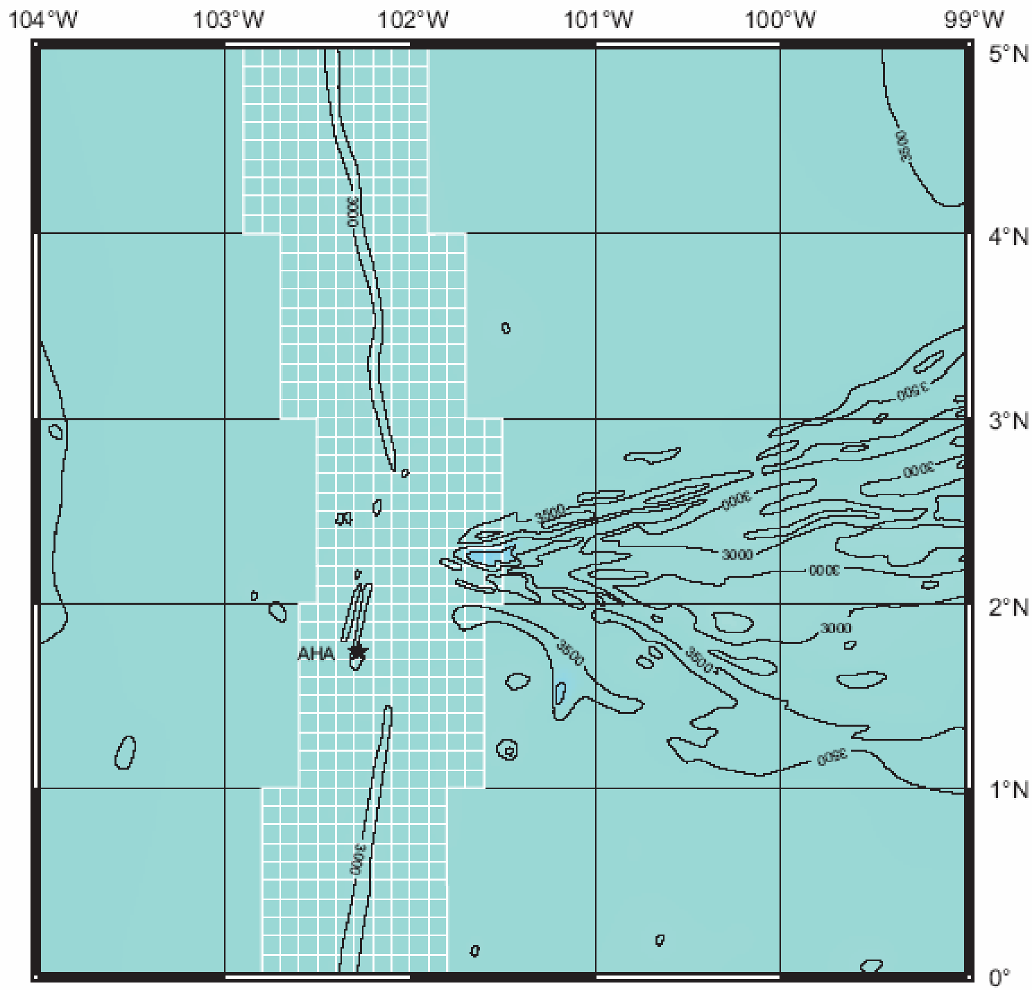


Locations of the sulphides occurrences near 9°50’N. 9°46’N
9°39°N, 9°16°N



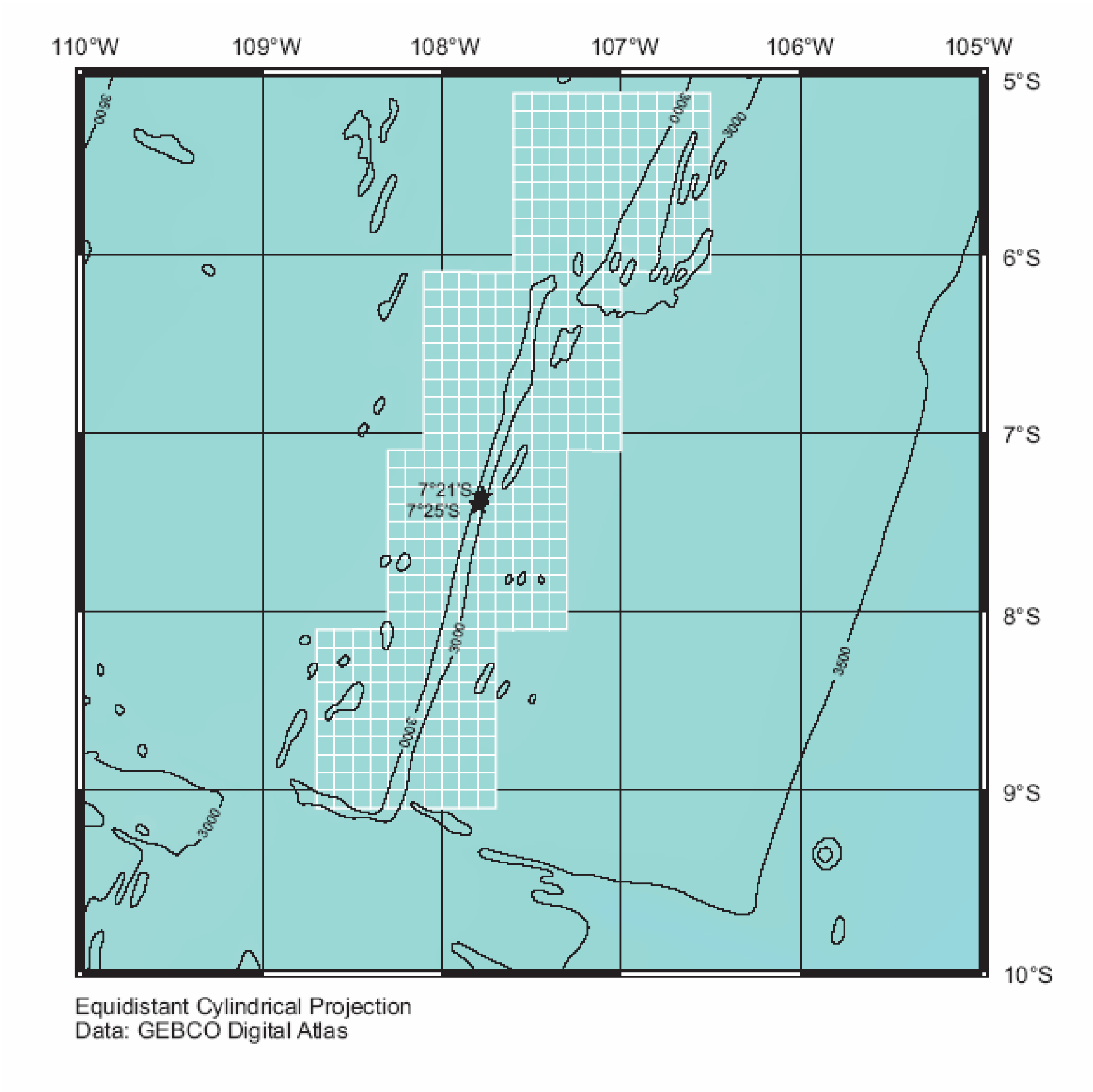
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Location of the AHA Vent Field

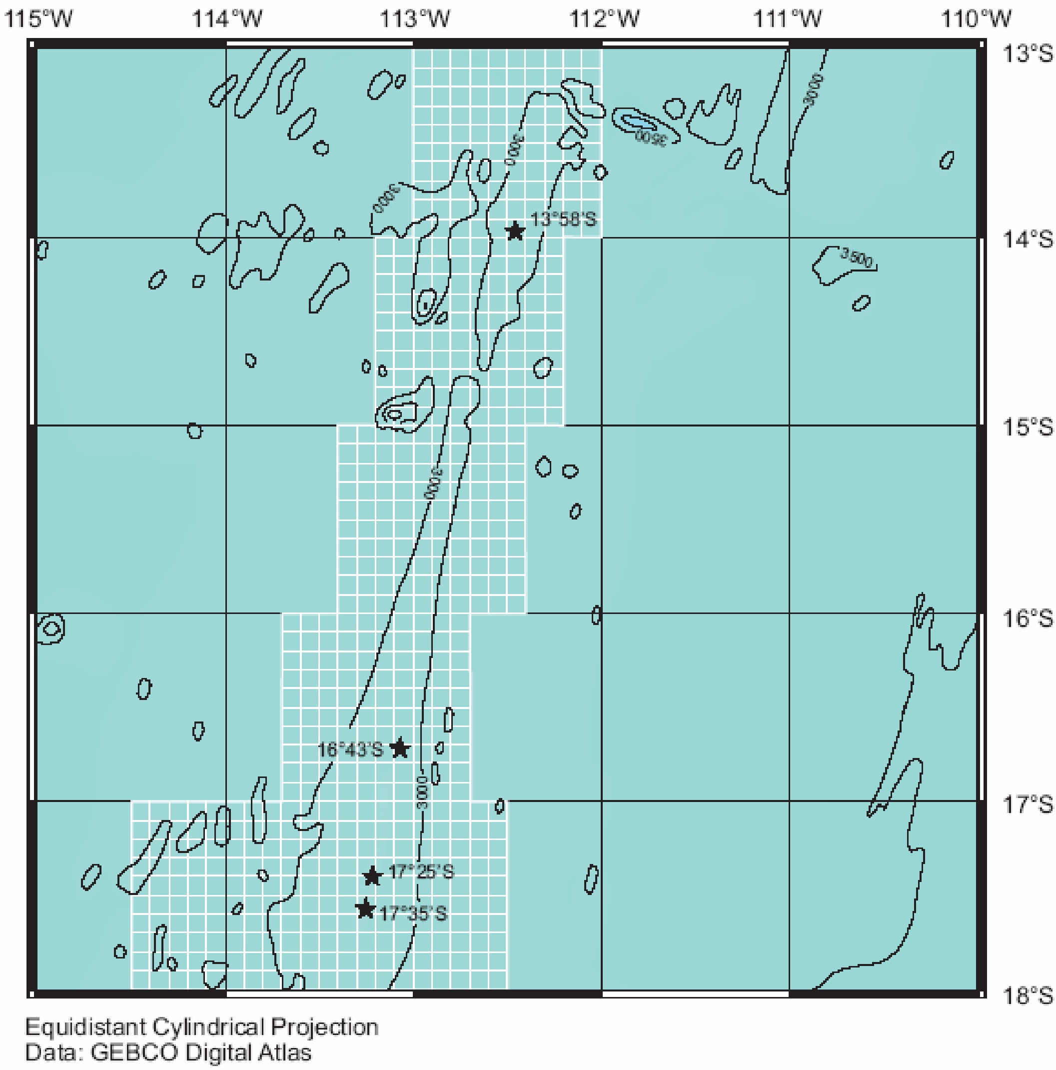


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

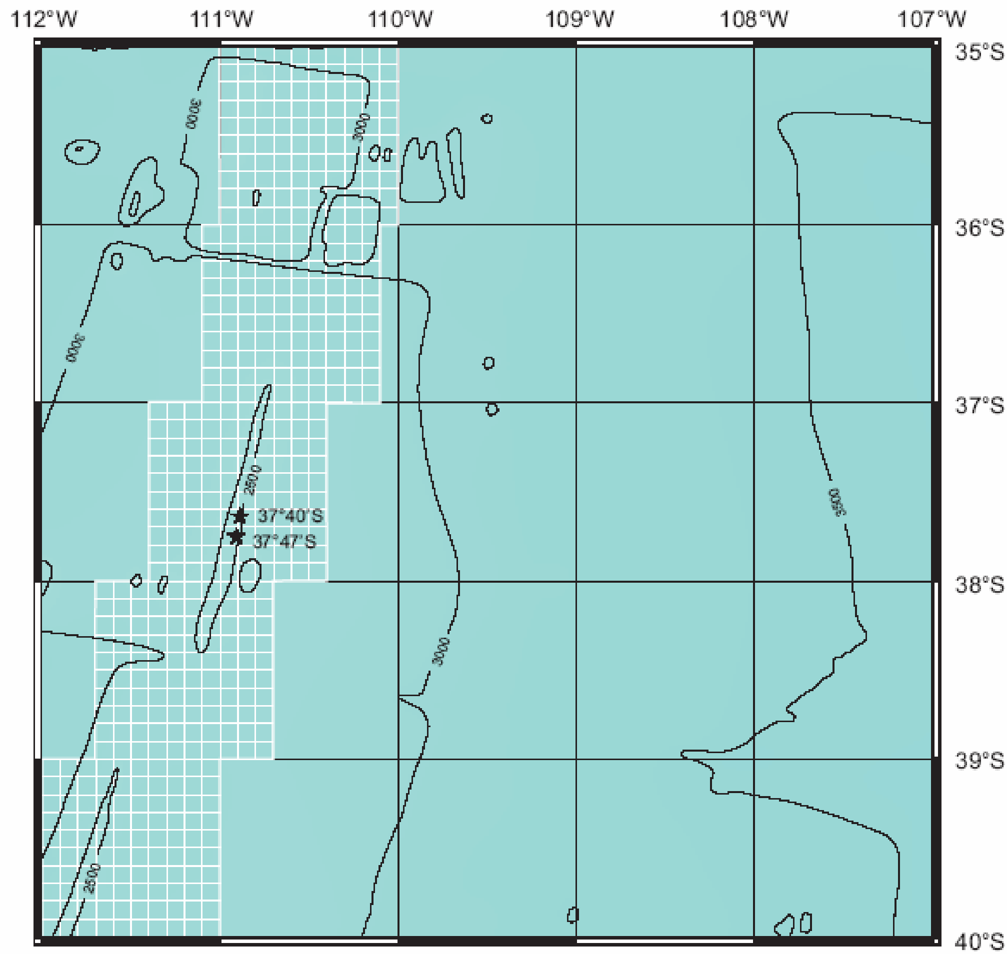
Location of the sulphides occurrences near 7°21'S and 7°25'S



Locations of the sulphides occurrences near 13°58'S, 17°25'S, and 7°35'S

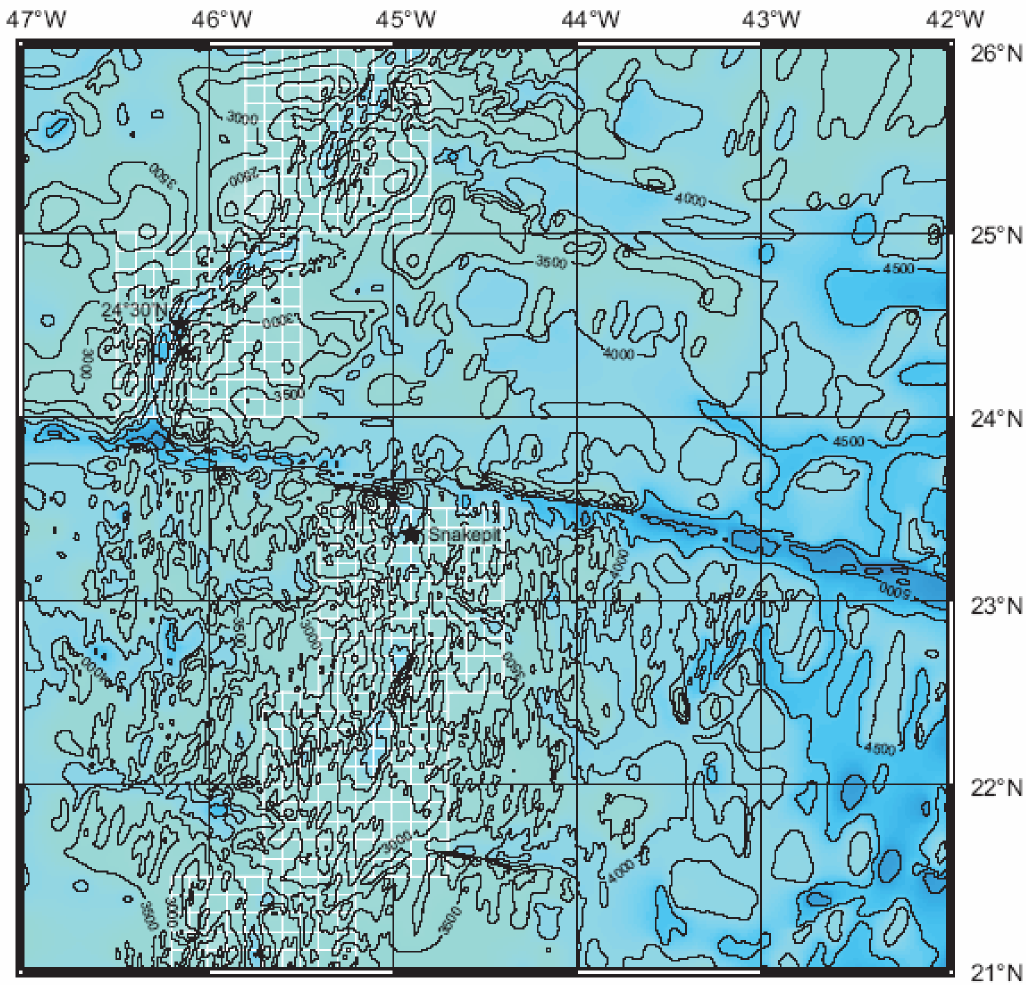


Locations of the sulphides occurrences near 37°40'S and 37°47'S



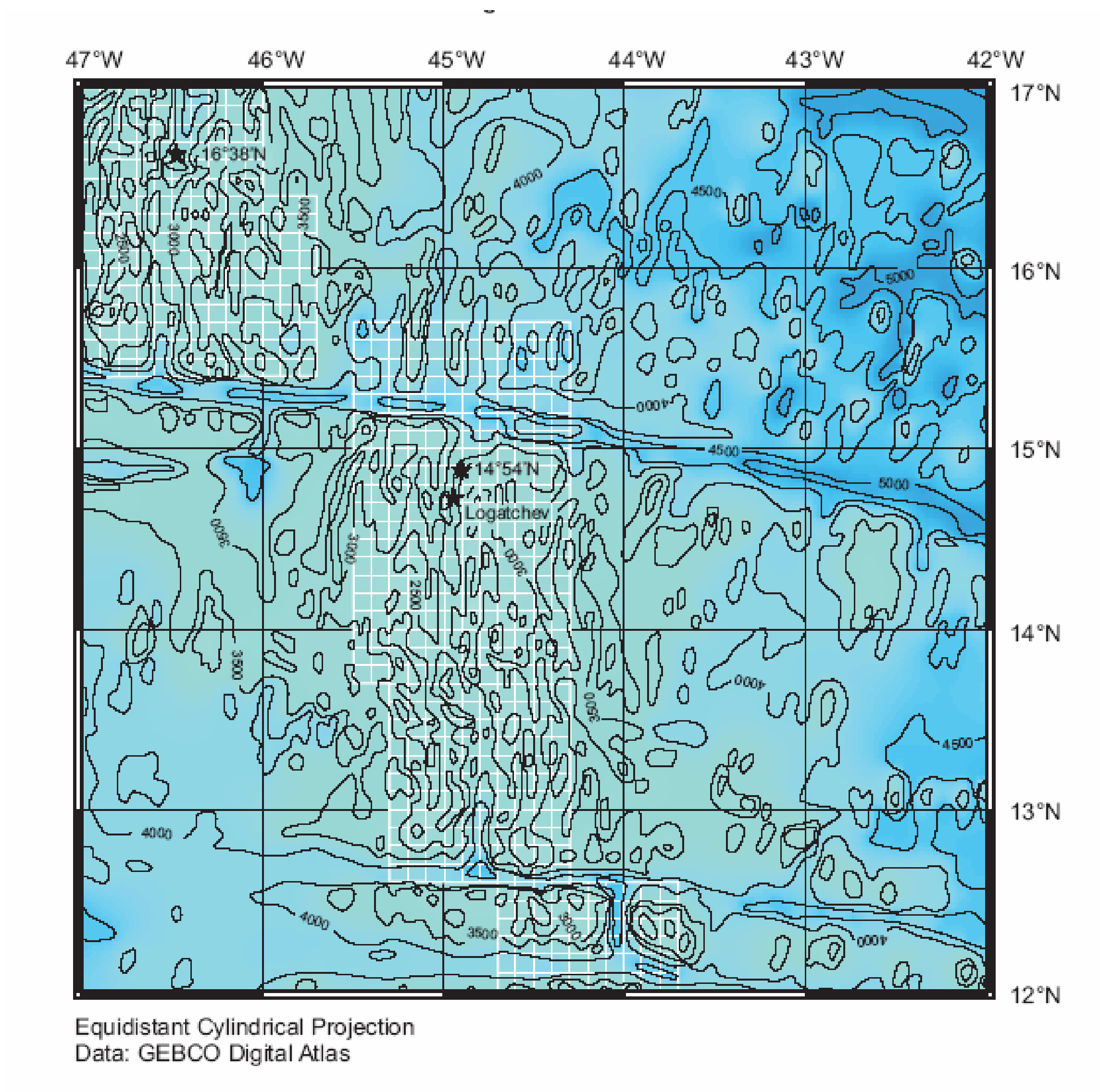
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Location of the 24°30'N and Snakepit sulphides occurrence

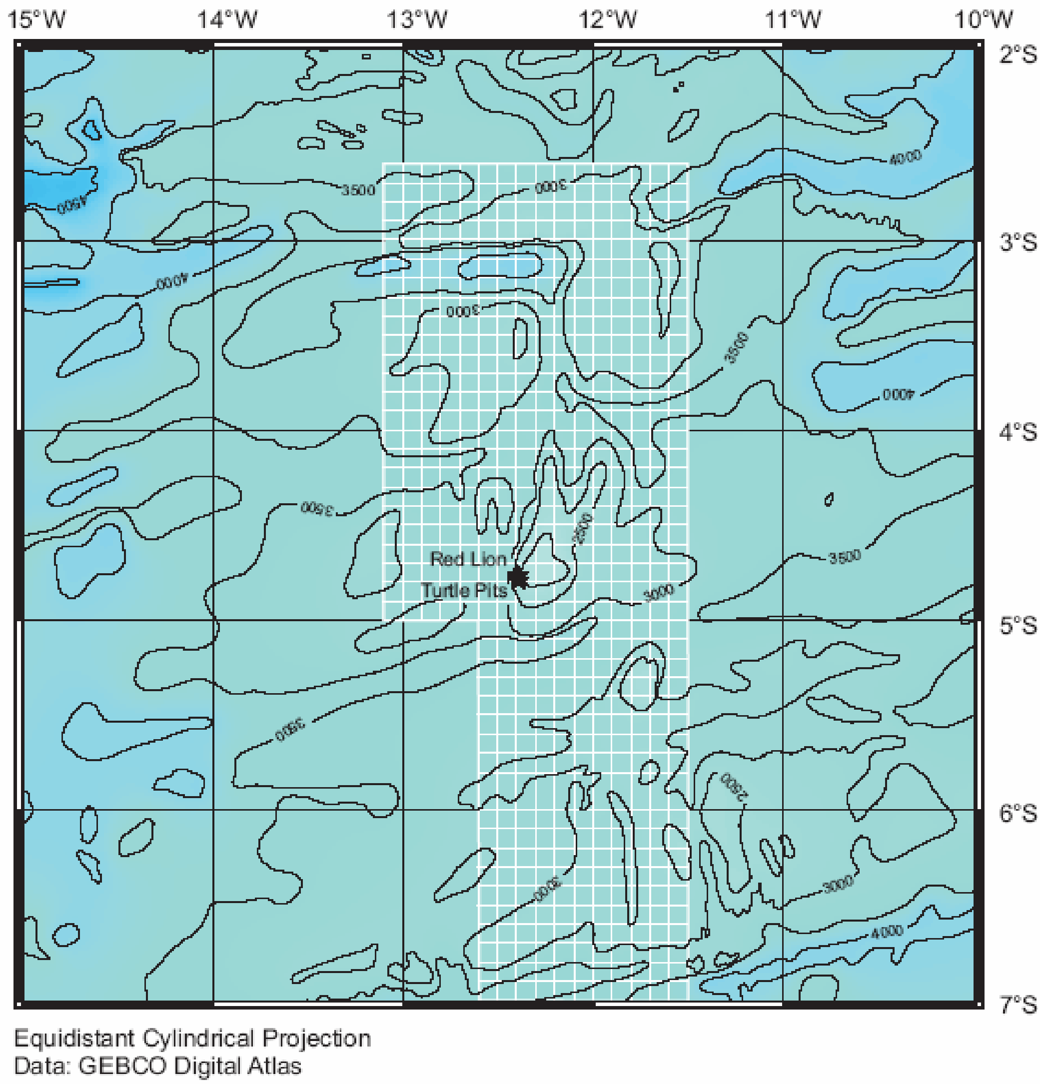


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

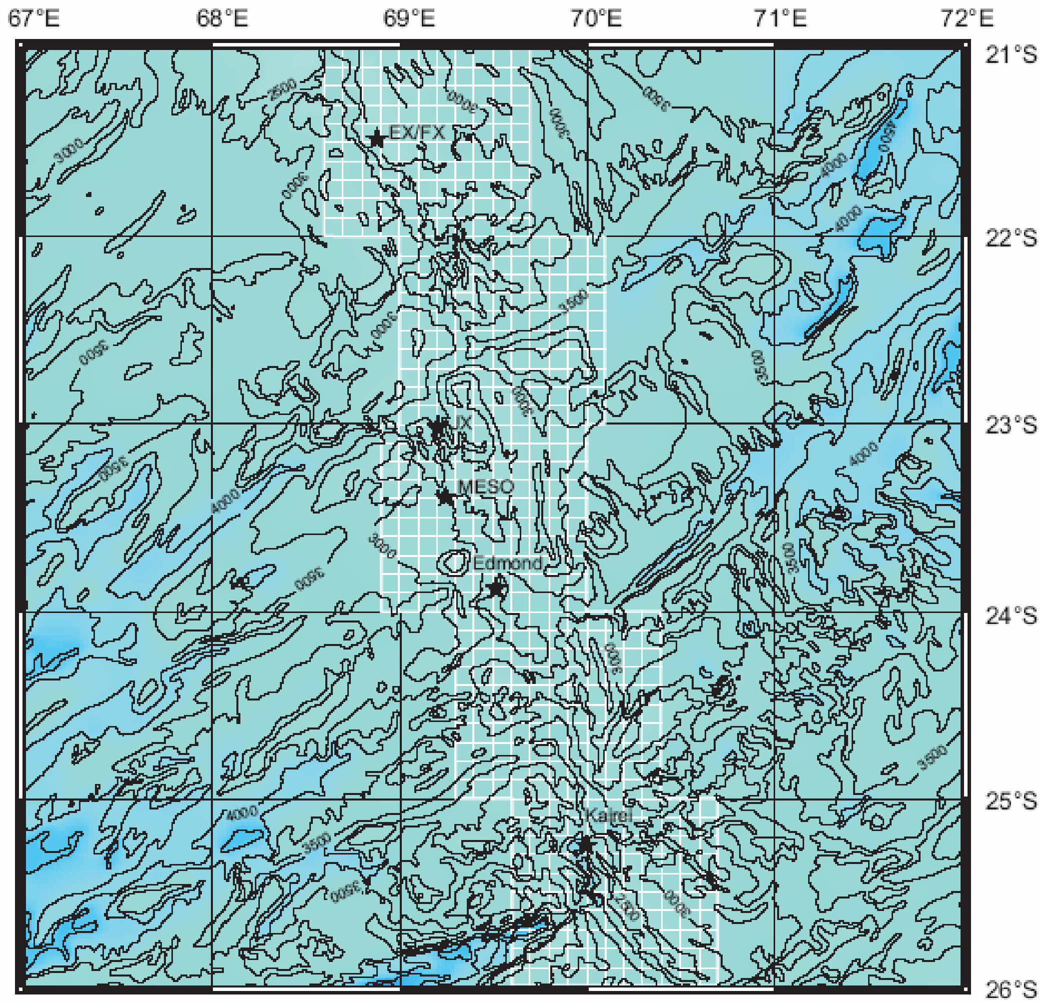
Location of the sulphides occurrences at 16°38'N, 14°54'N and the Logatchev Field



Locations of the Turtle Pits and Red Lion sulphides occurrences

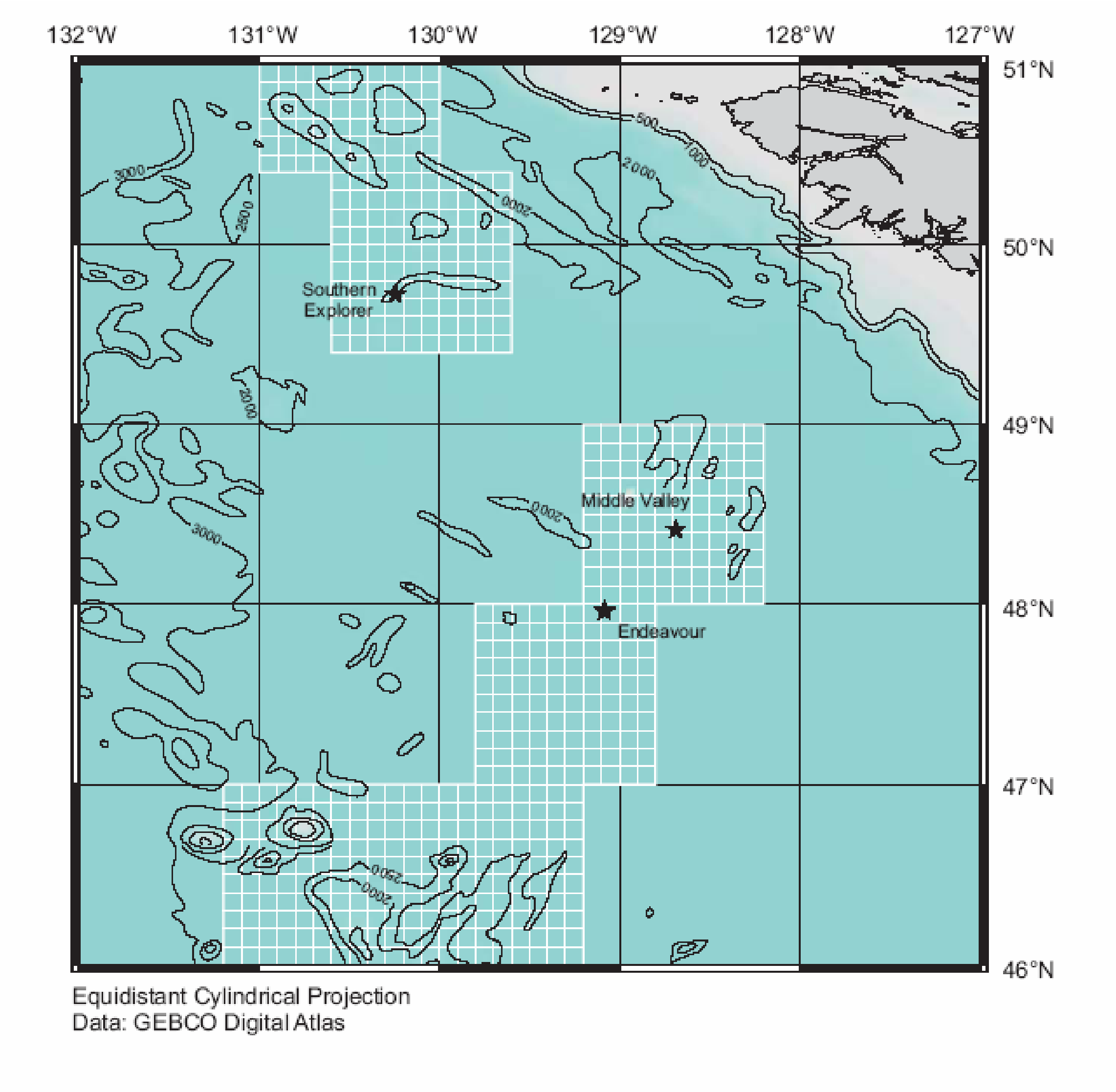


Location of the MESO Zone sulphides occurrence

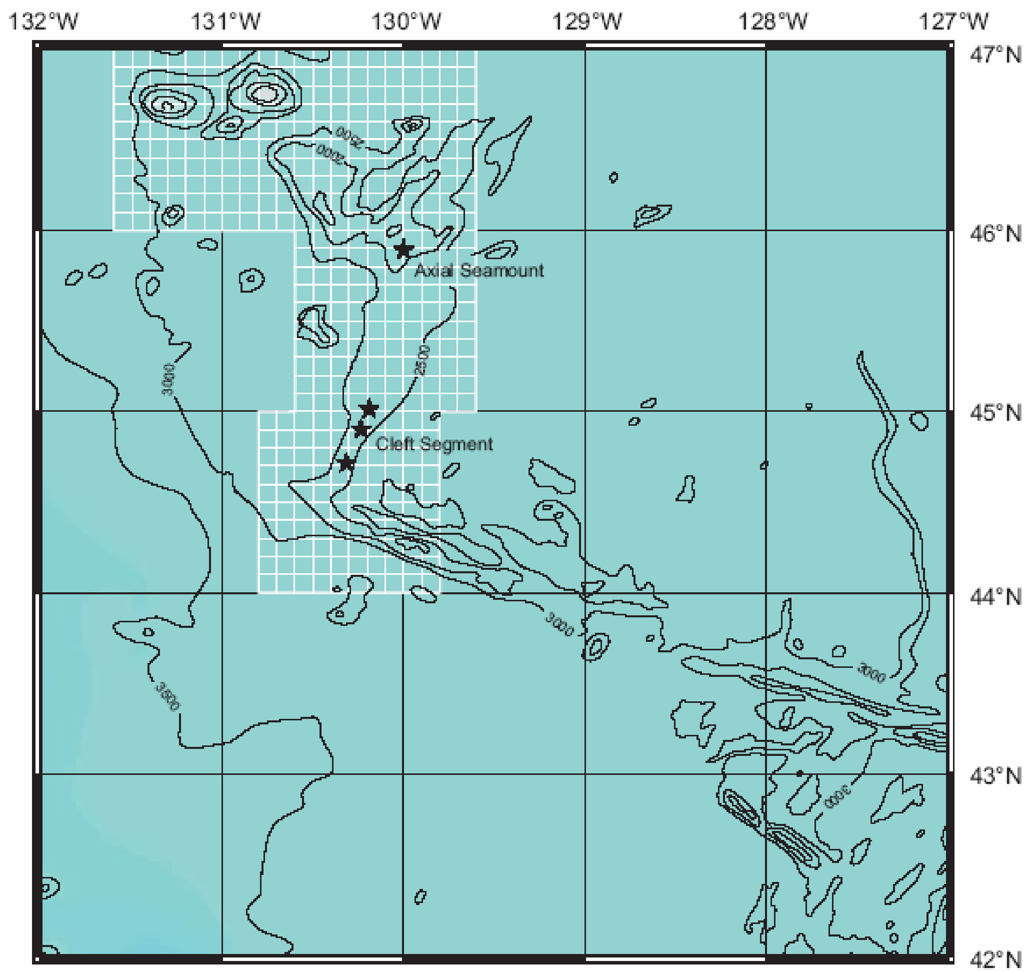


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Location of the Southern Explorer, Middle Valley and Endeavour sulphides occurrences

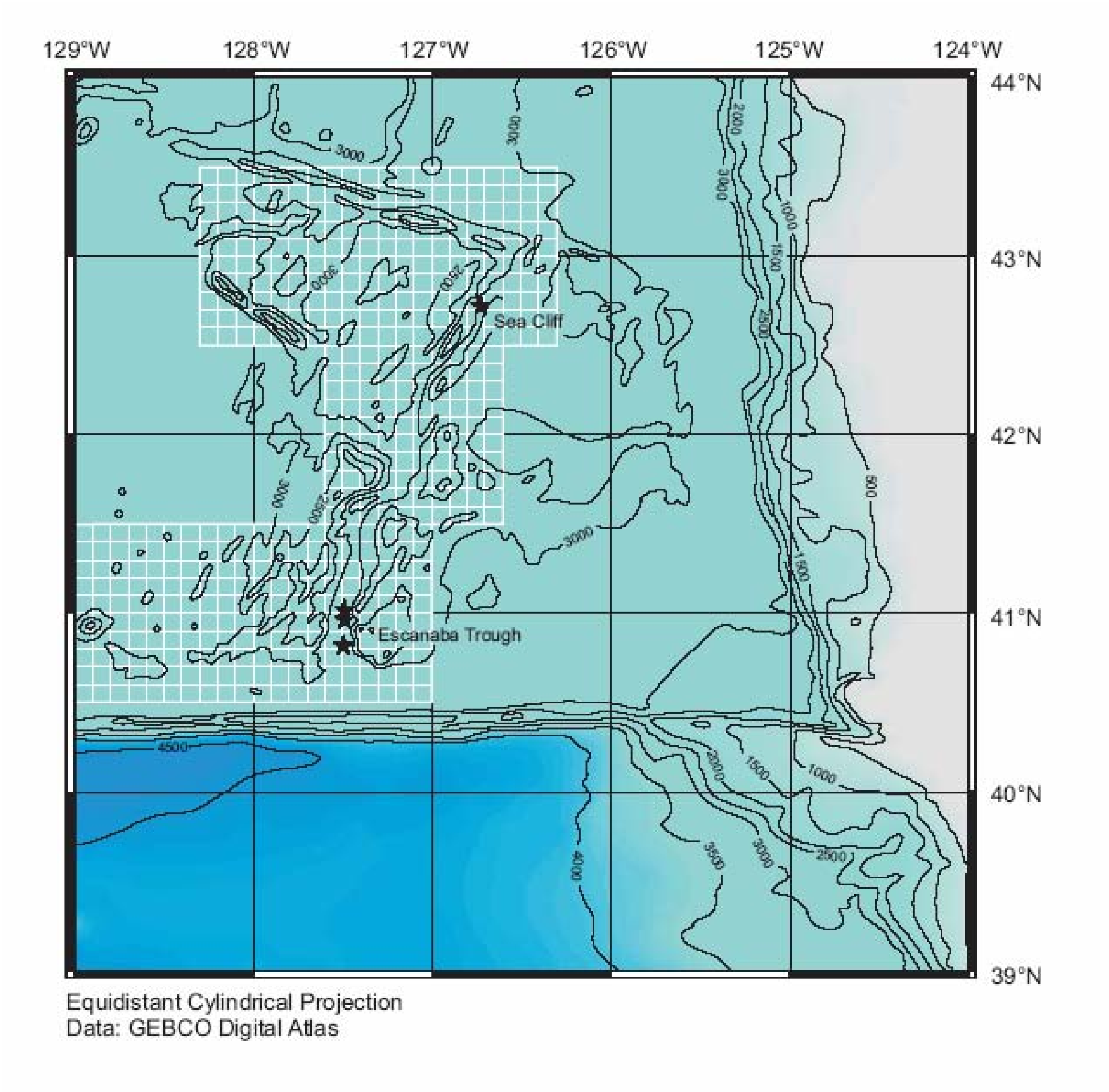


Locations of the Axial Seamount and Cleft Segment sulphides occurrences

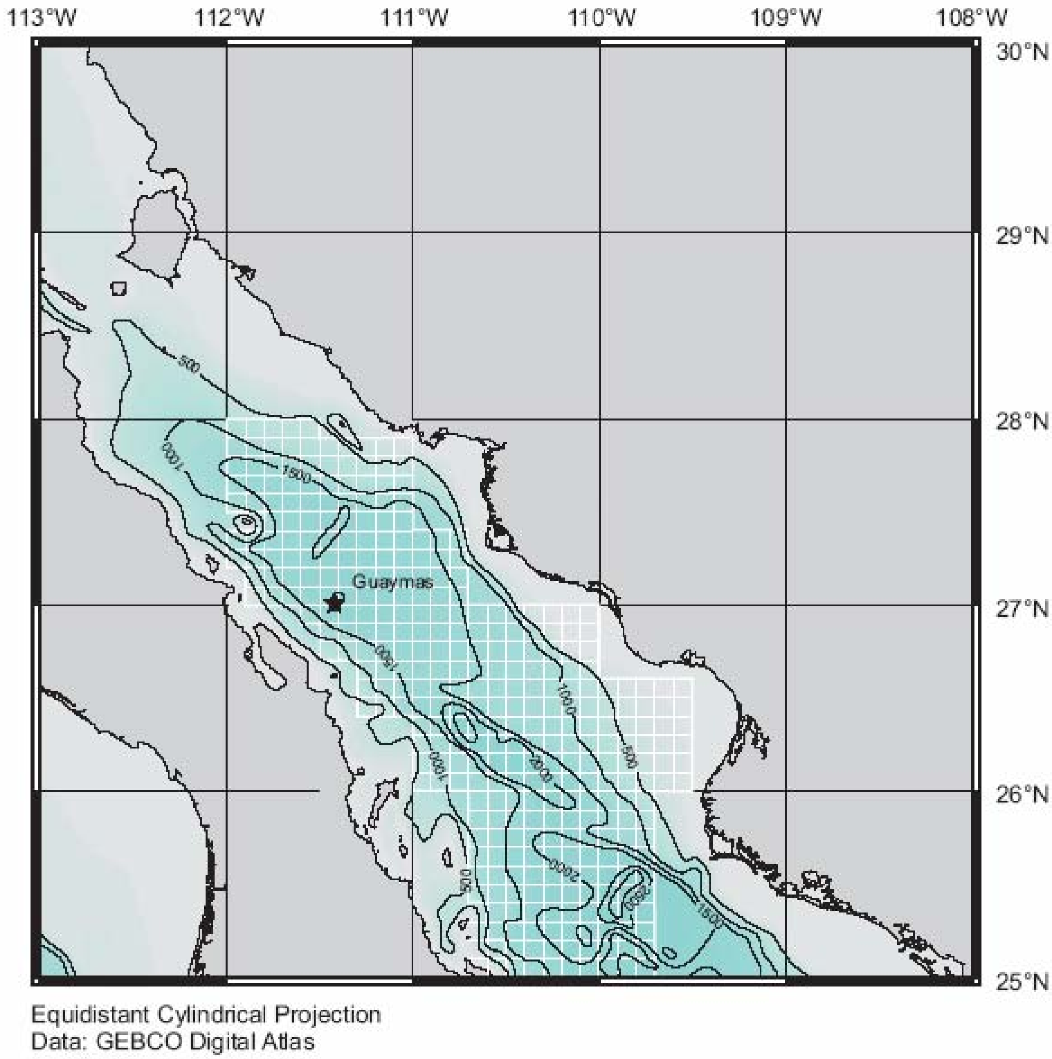


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

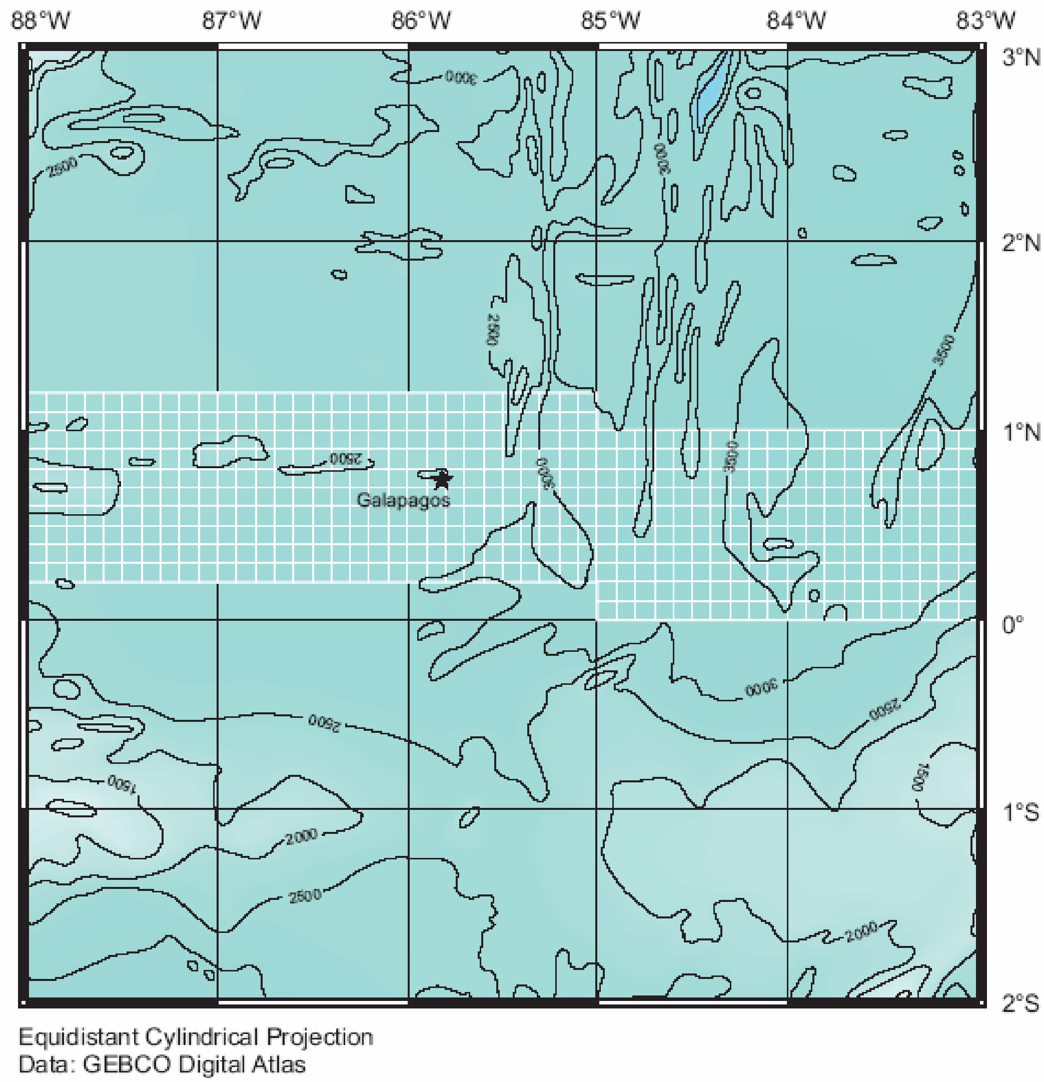
Locations of the Escanaba Trough and Sea Cliff sulphides occurrences



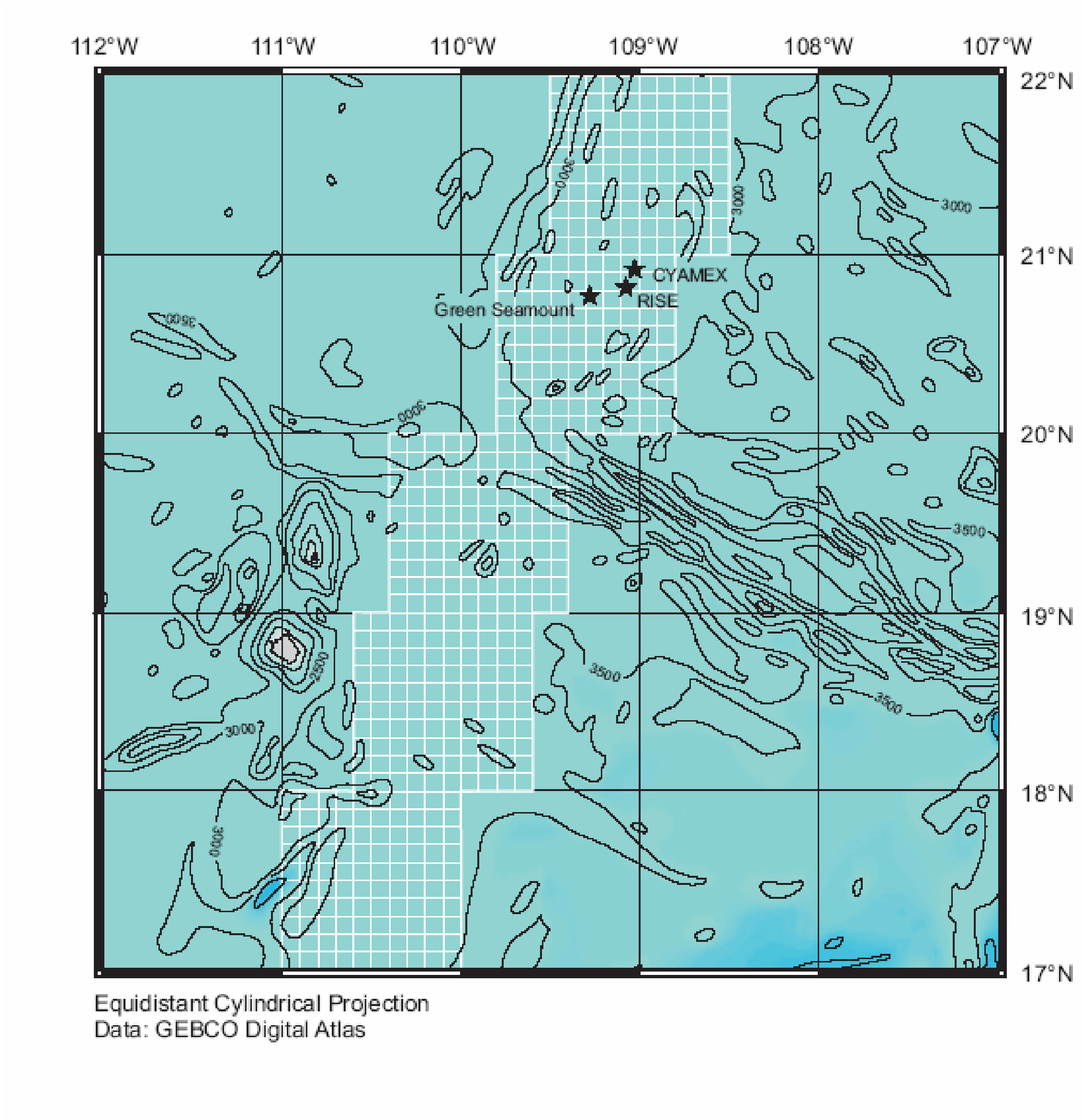
Location of the Guaymas Basin sulphides occurrences



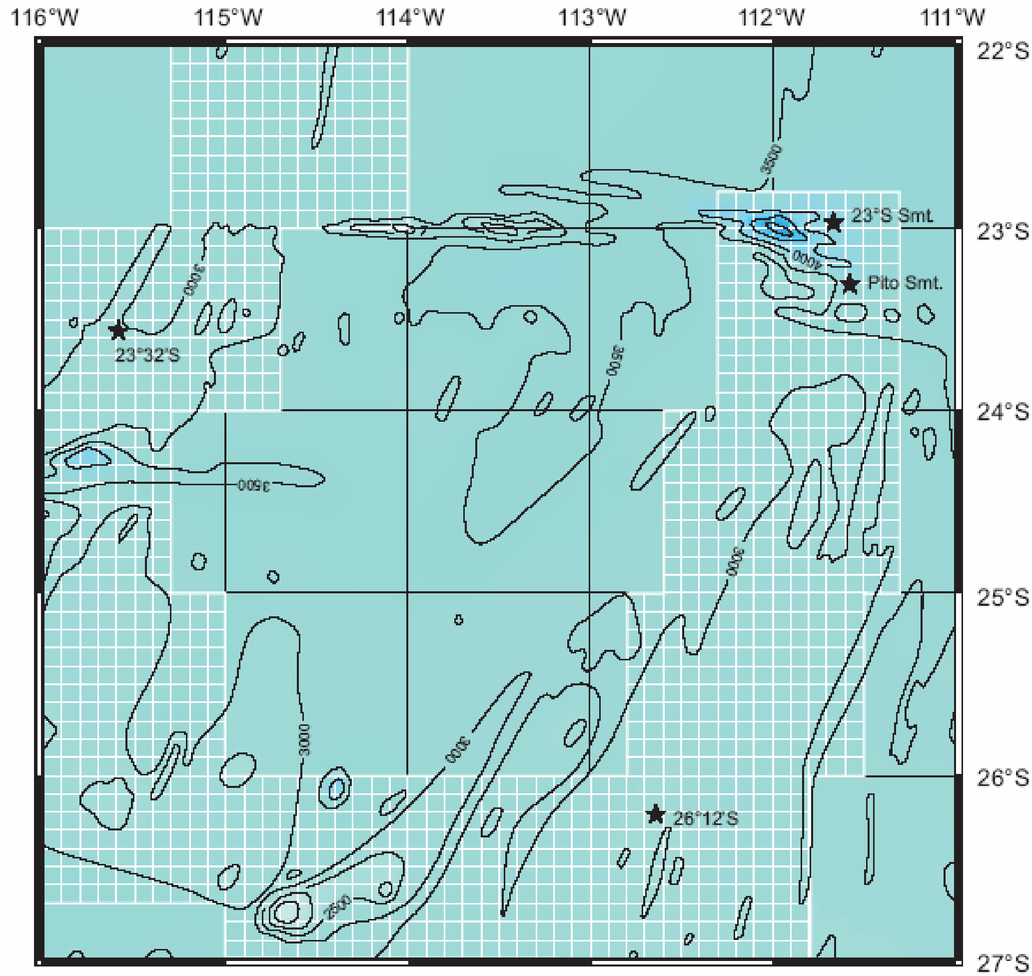
Location of the Galapaos Rift sulphides occurrence



Locations of the CYAMEX and RISE Fields and the sulphides occurrence at Green Seamount

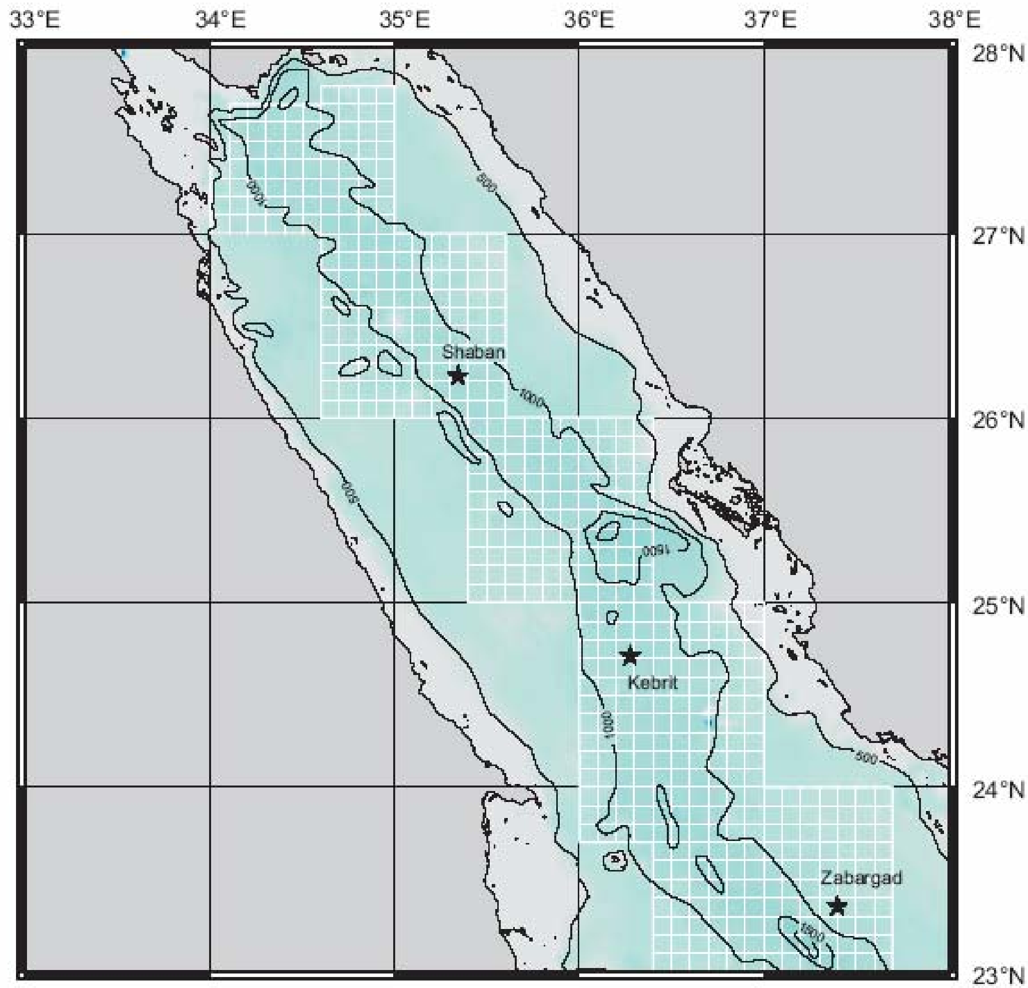


Locations of the sulphides occurrences at the 23°S and Pito Seamounts as well as at 23°32'S and 26°12'S



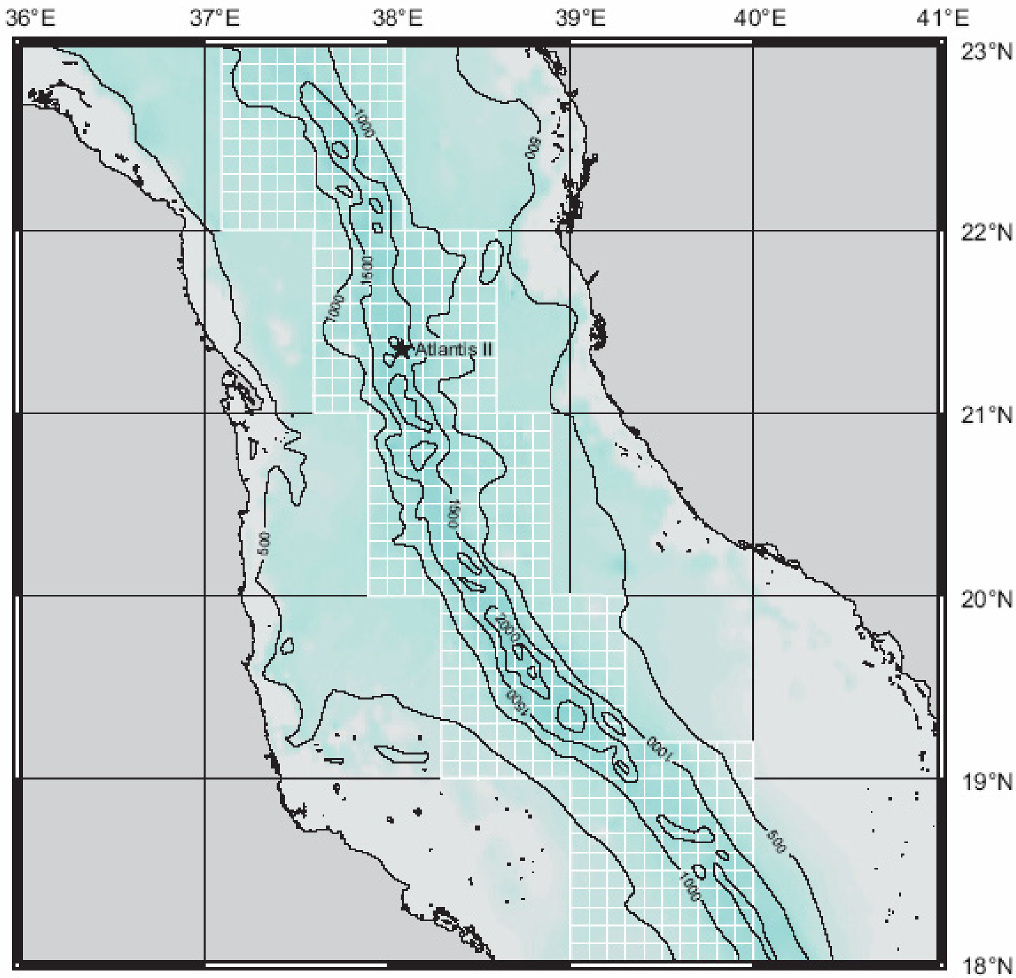
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Locations of the sulphides occurrences in the Shaban, Kebrit, and Zabargad Deeps



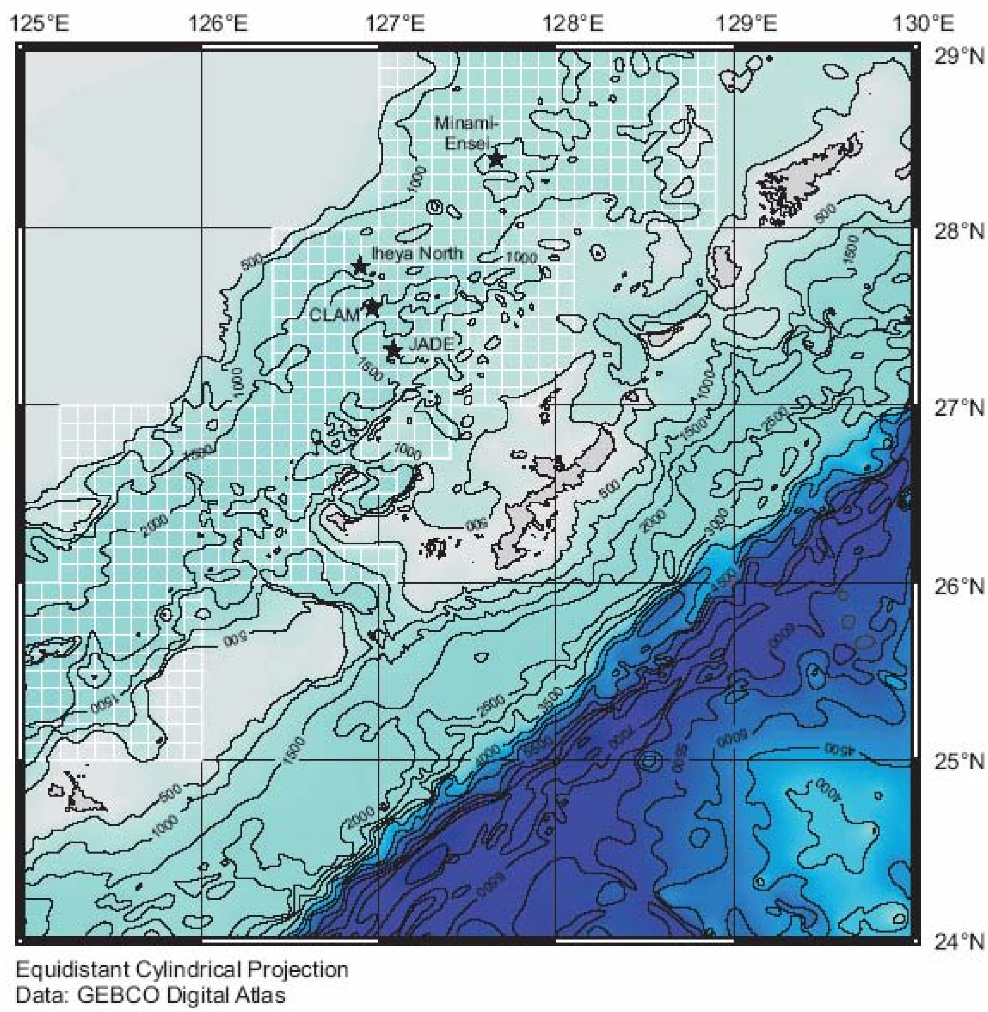
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Location of the sulphides occurrence in the Atlantis II Deep

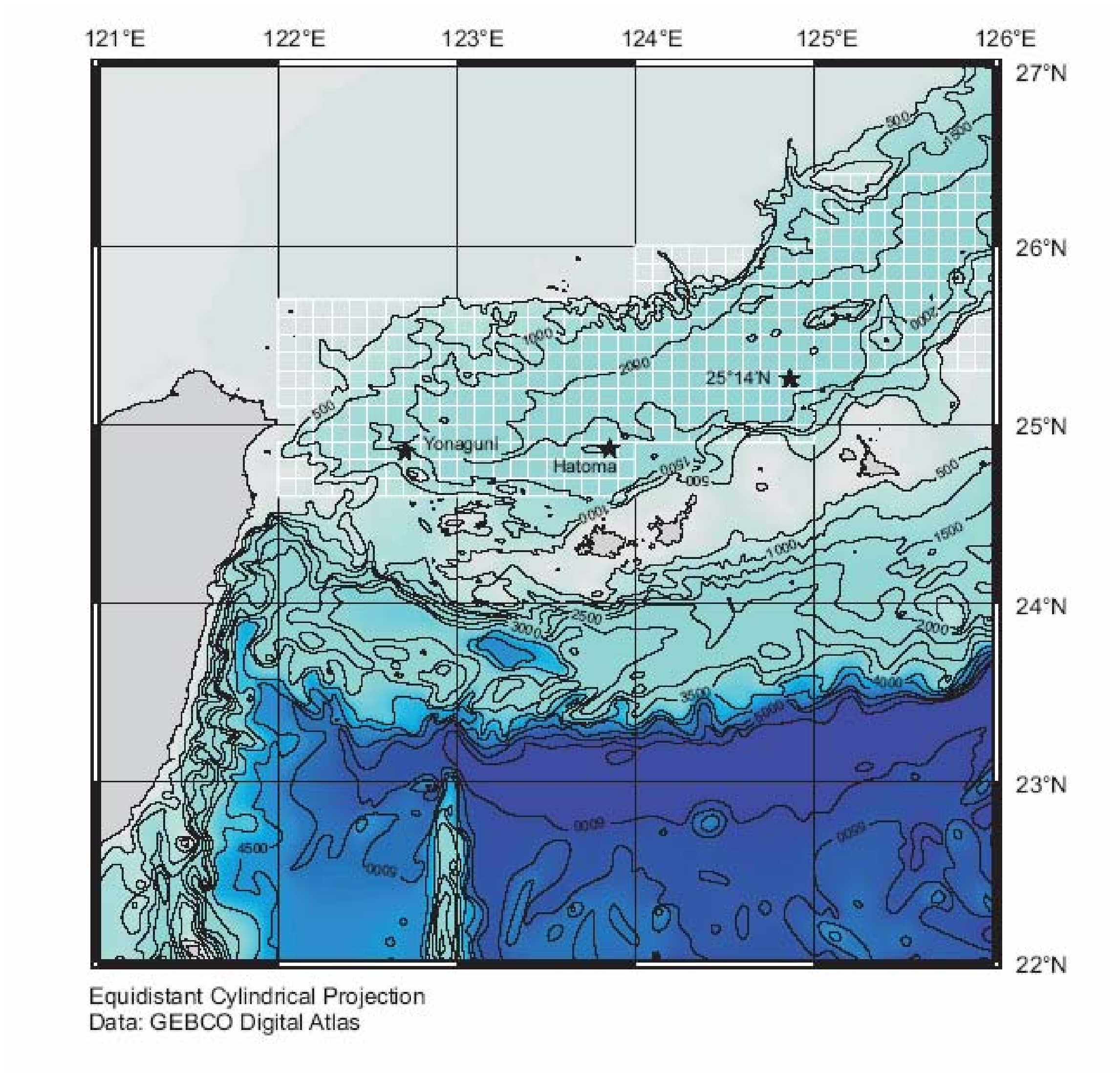


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

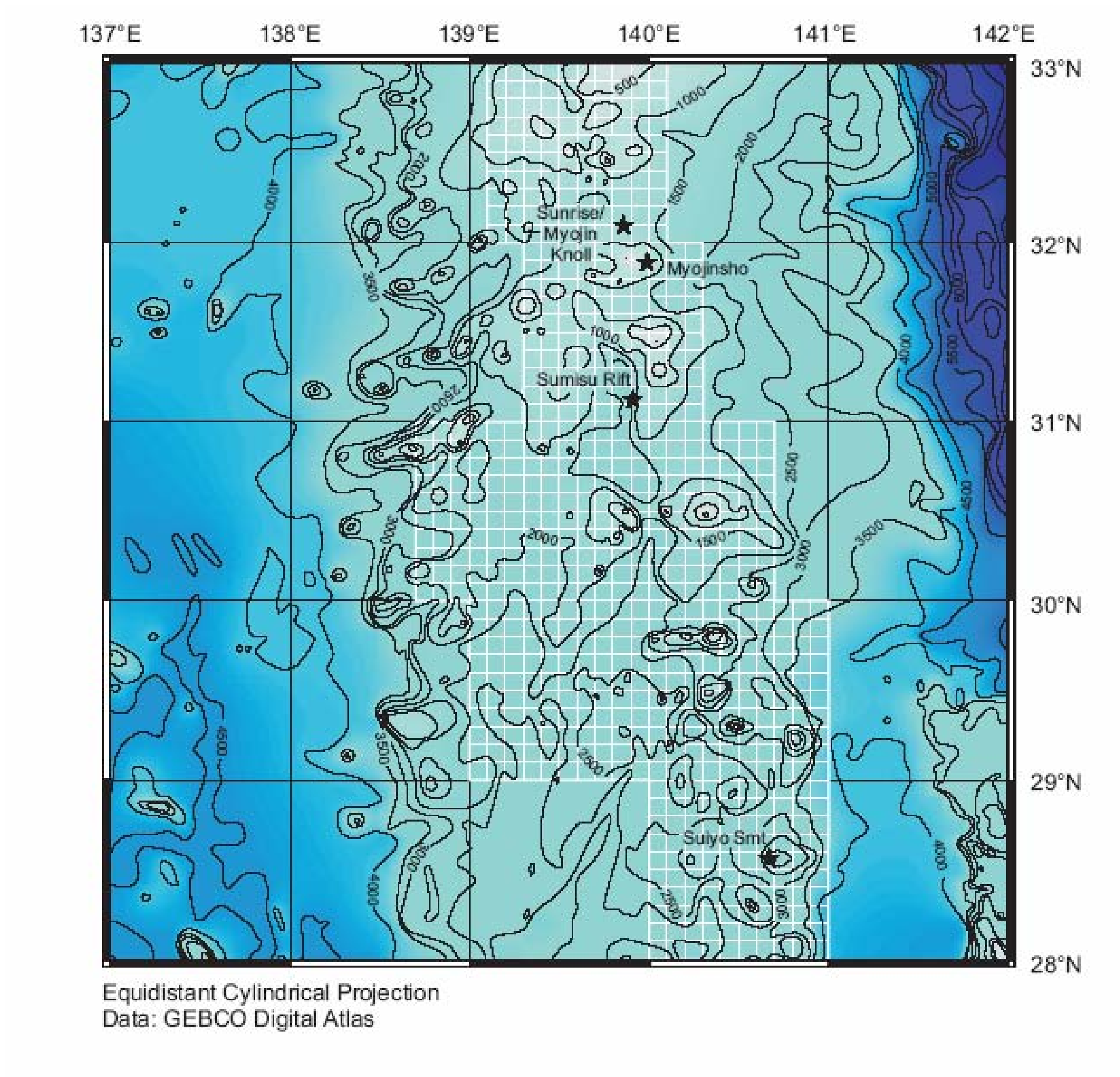
Locations of the sulphides occurrences at the JADE and CLAM Sites as well as at the Minami-Ensei and Iheya North Knolls



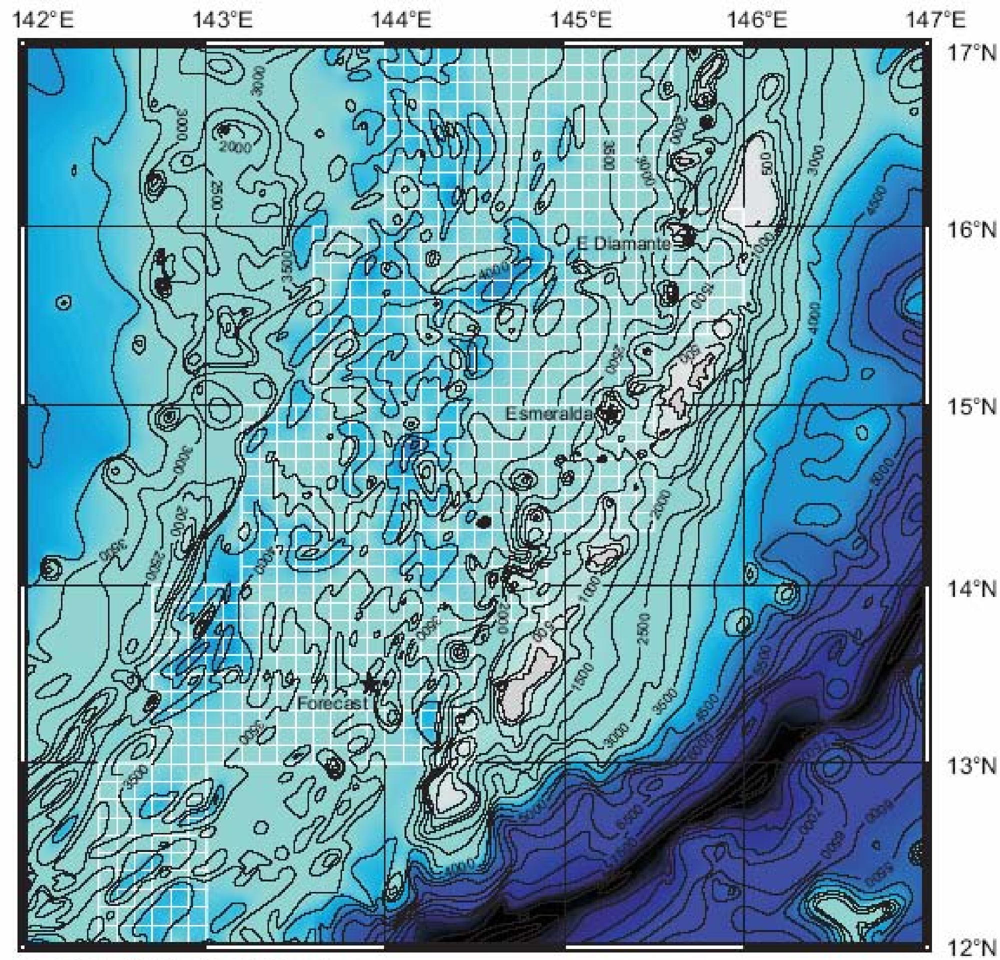
Locations of the sulphides occurrences at Yonaguni Knoll, Hatoma Knoll and at 25°14'N



Locations of the sulphides occurrences at Myojin Knoll, Myojinsho Knoll and at Suiyo Seamount

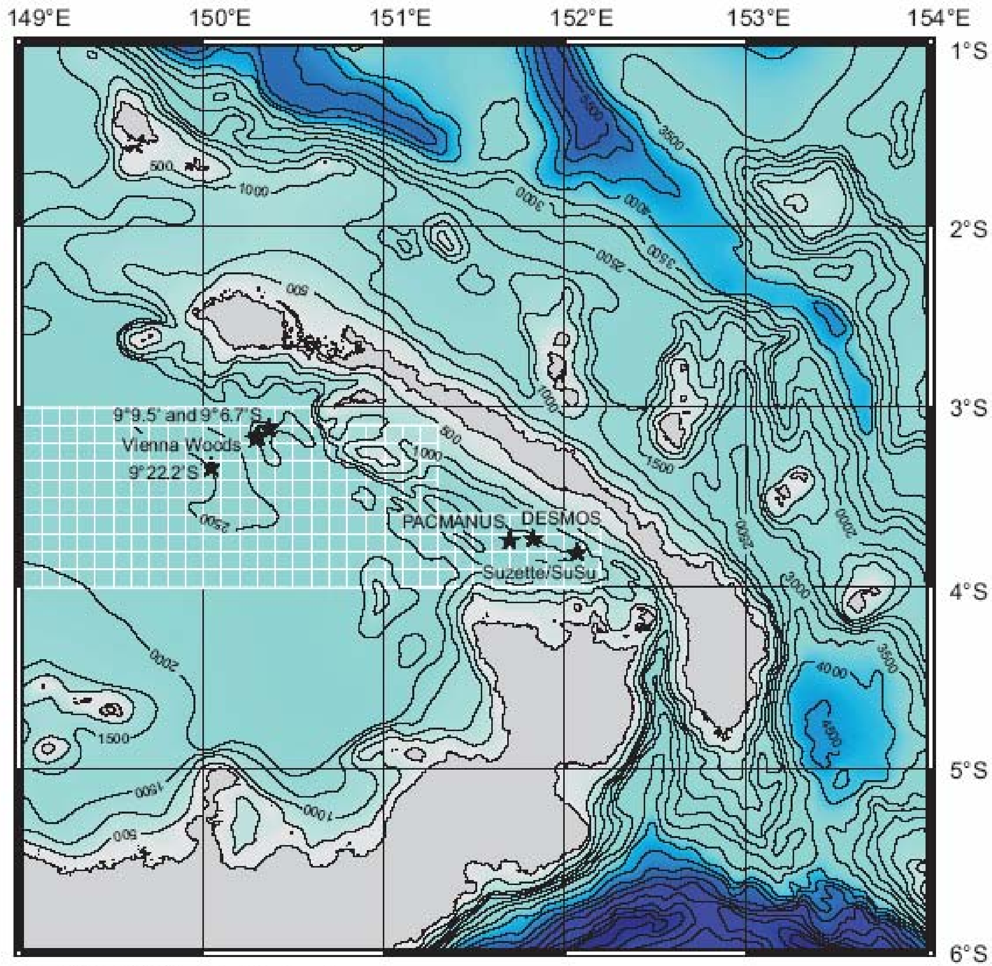


Locations of the sulphides occurrences at East Diamante, Esmerelda Bank and the Forecast Vent Field



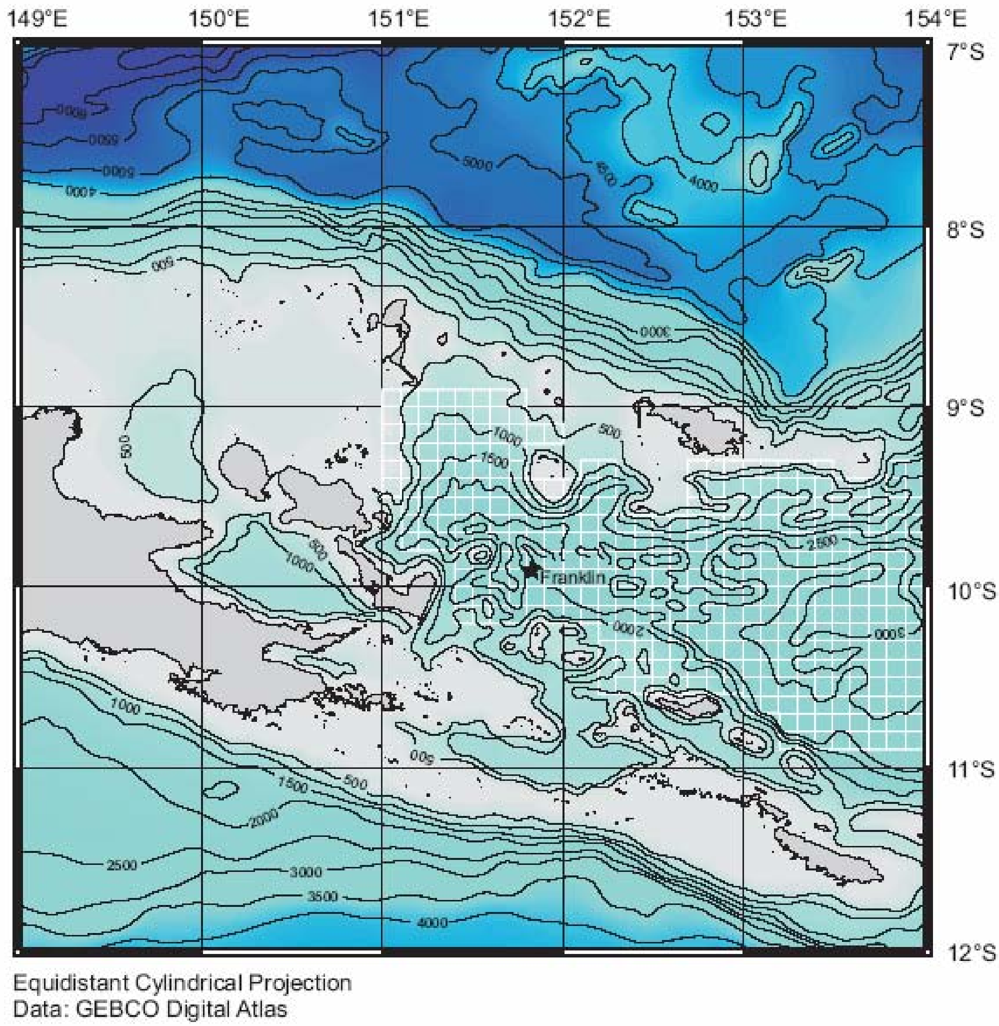
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

Locations of the sulphides occurrences at PACMANUS, DESMOS, Suzettte/SuSu, Vienna Woods and the fields near 9^{o}9.5'S, 9^{o}6.7S and 9^{o}22.22'S

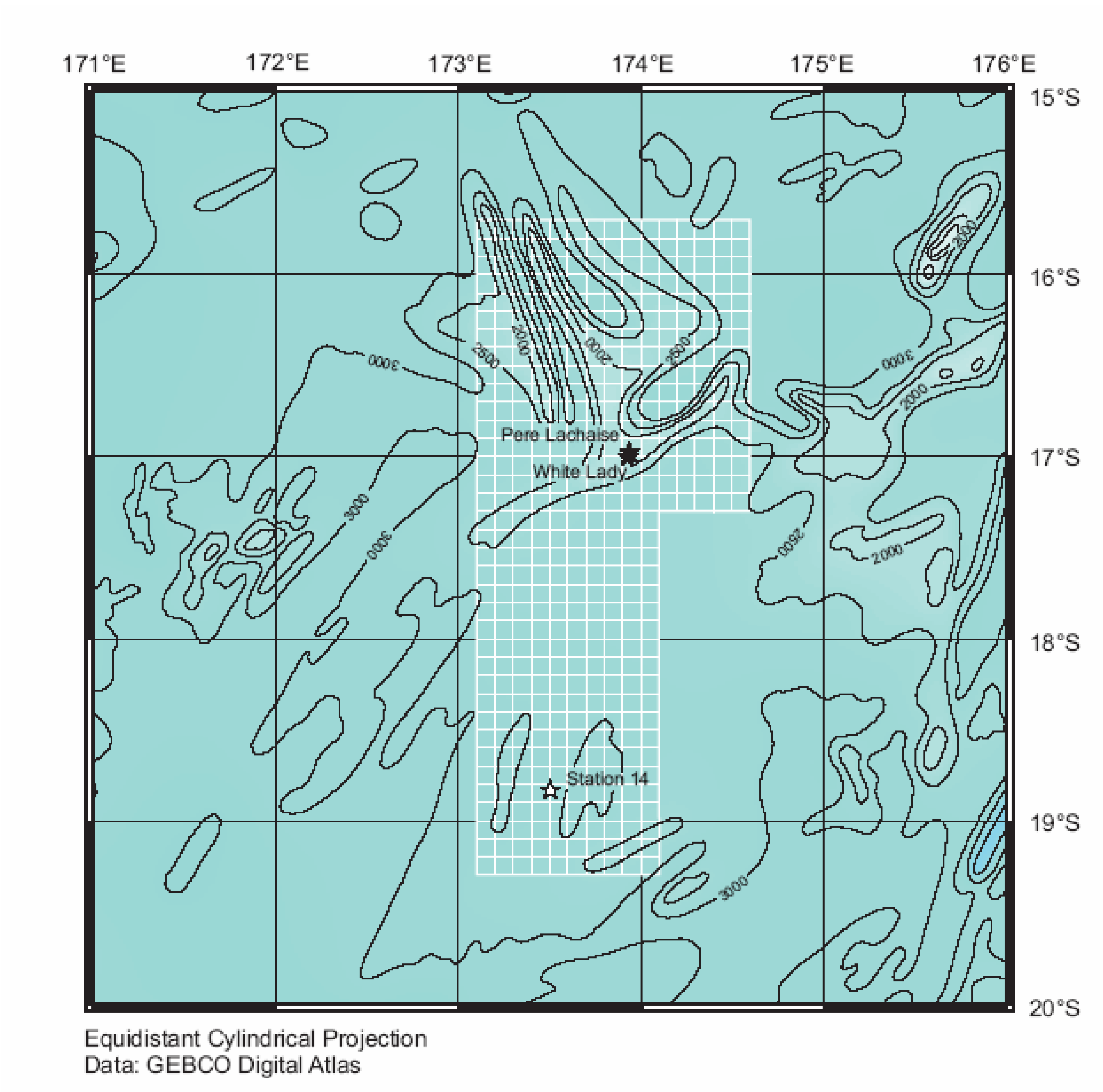


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

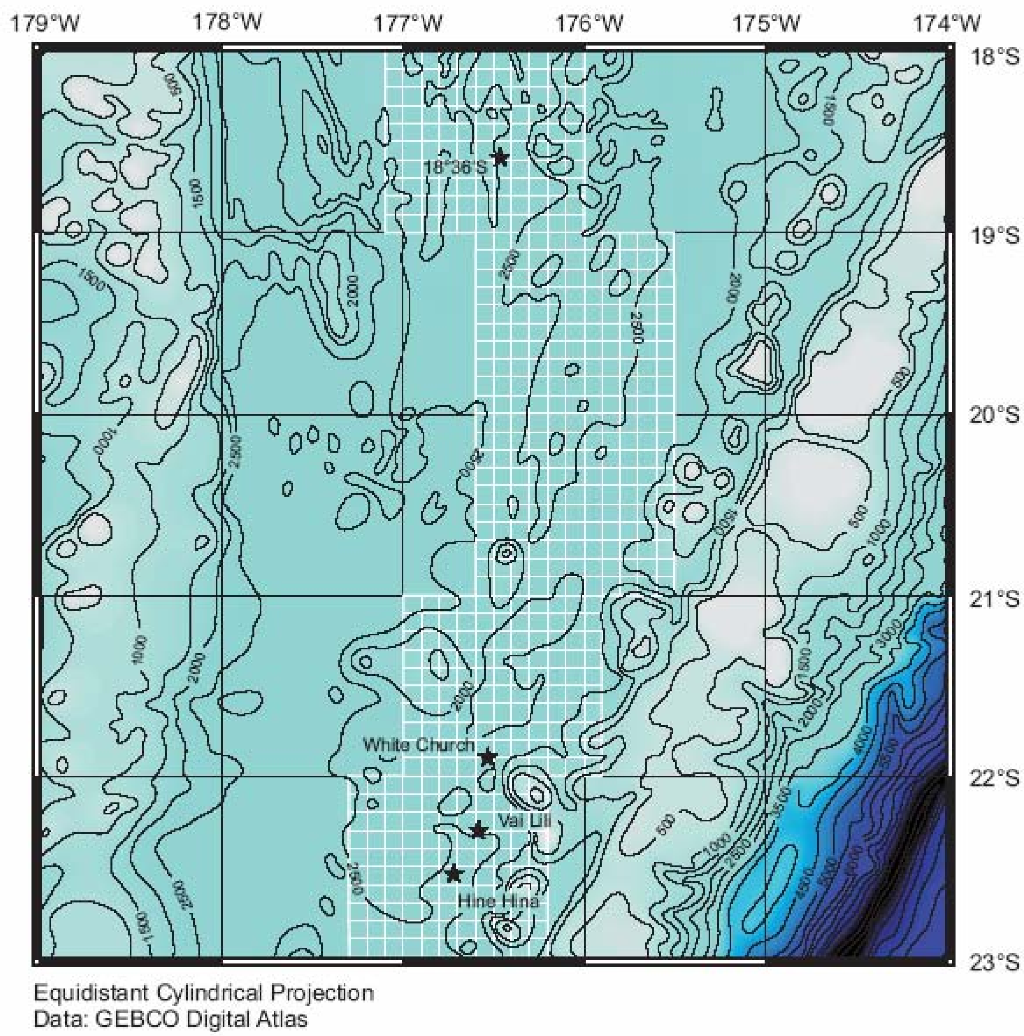
Locations of the sulphides occurrence at Franklin Seamount



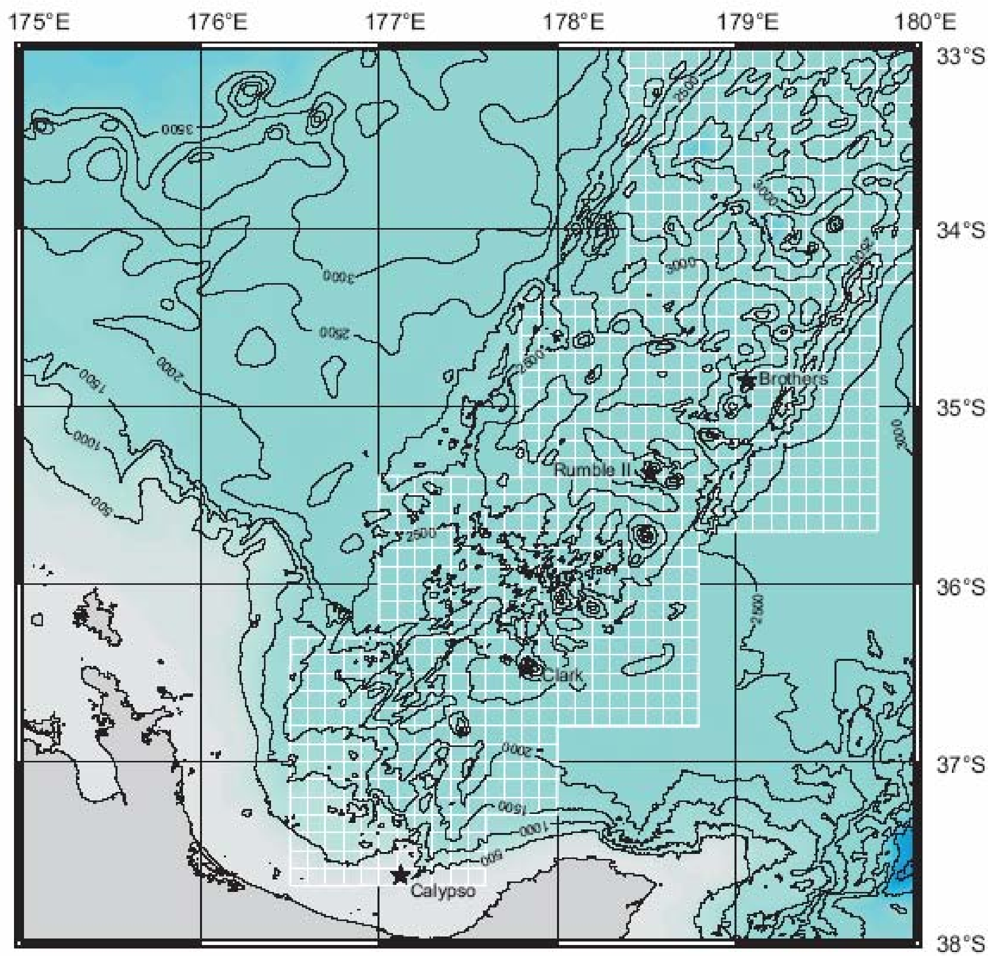
Locations of the Pere Lachaise and White Lady sulphides occurrences



Locations of the sulphides occurrences at 18.36'S, White Church, Vai Lili and Hine Hina



Locations of the sulphides occurrences at Brothers Seamount, Rumble II Seamount, Clark Seamount and at the Calypso Vents



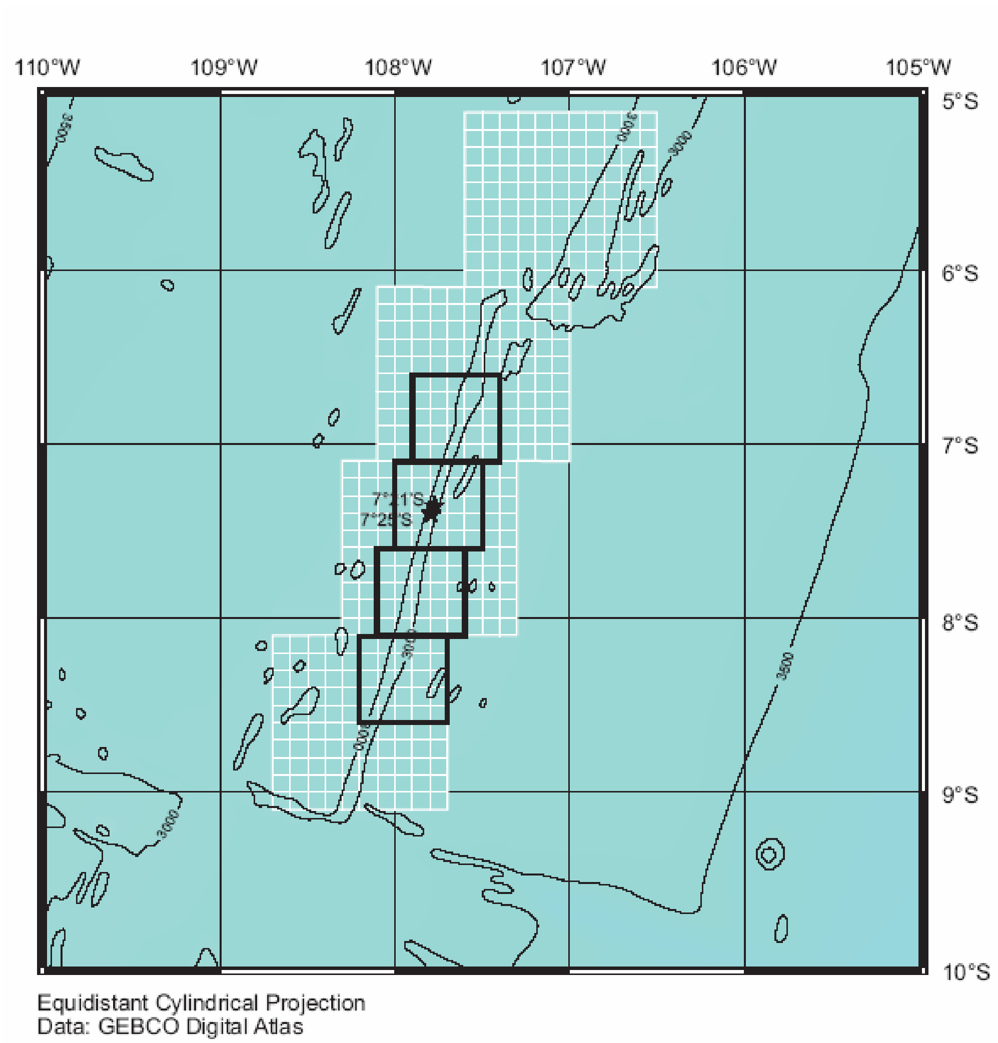
Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

<u>Appendix 4</u>

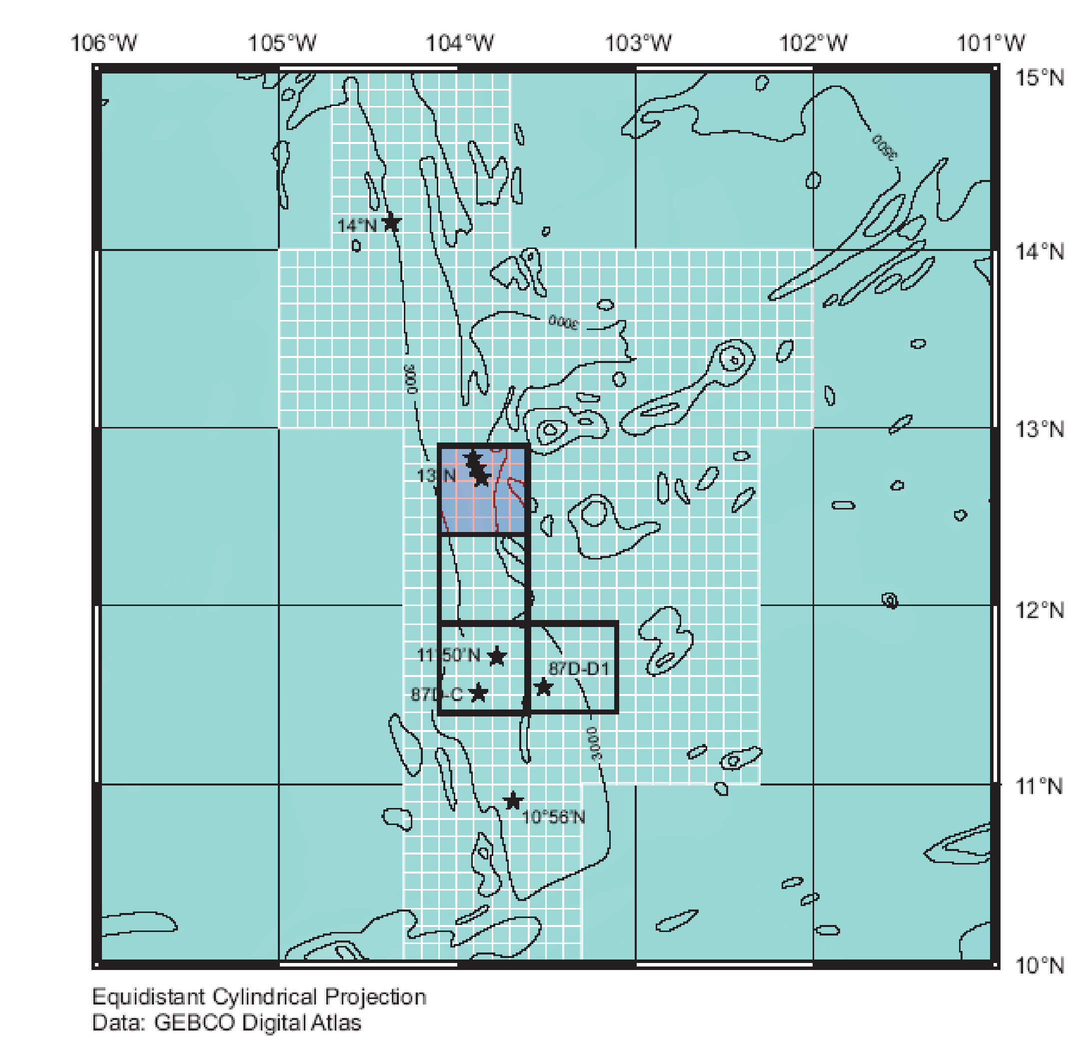
Maps of 12 model exploration areas

Model exploration areas using 5 deg. by 5 deg. maps and 1,000-m contour intervals were measured for 12 case studies in the Area. Models are presented that illustrate how these areas might be reduced to the minimum number of exploration lease blocks according to the schedule of relinquishment proposed in the draft regulations (50 per cent of the allocated area after year 5, 75 per cent after year 10, and a maximum of 25 blocks after year 15).

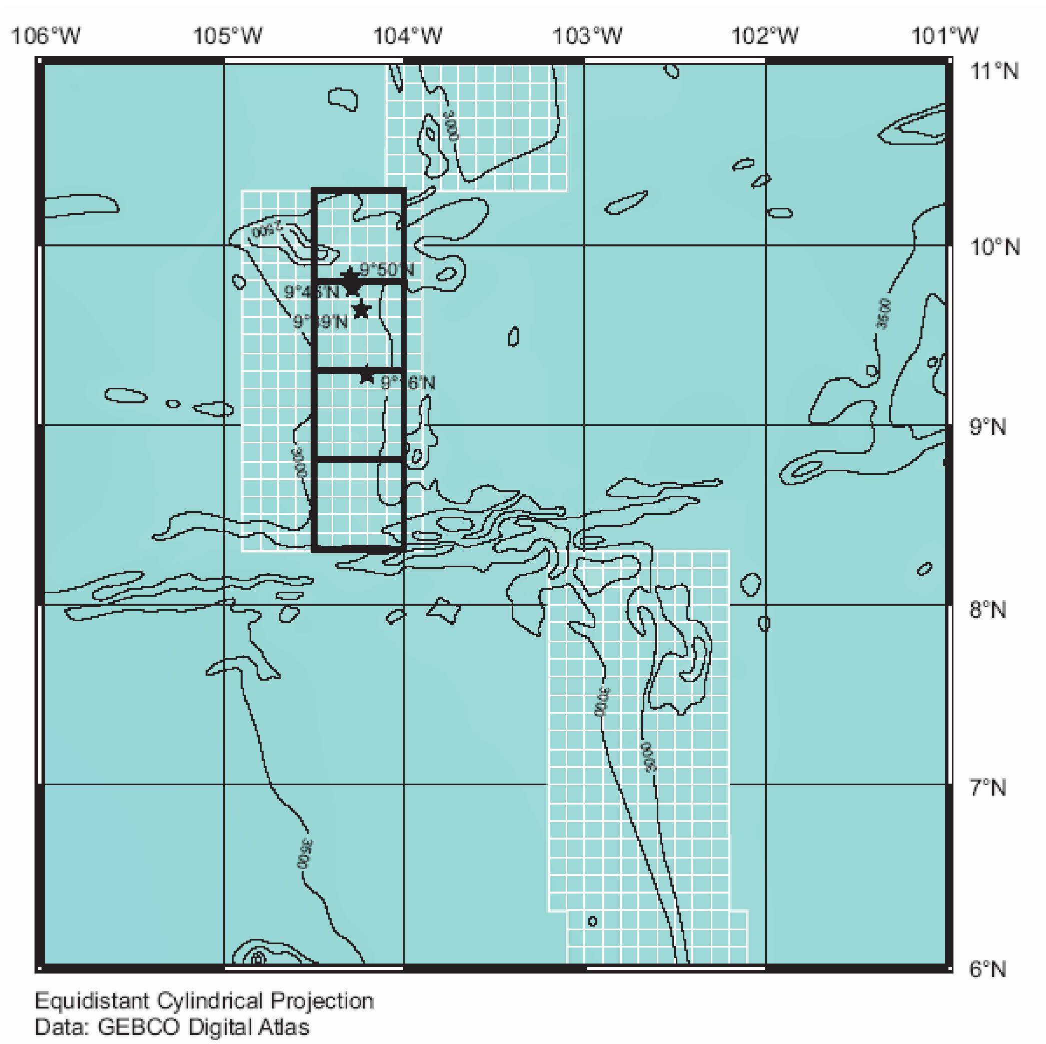
Locations of the sulphides occurrences near 7°21'S and 7°25'S



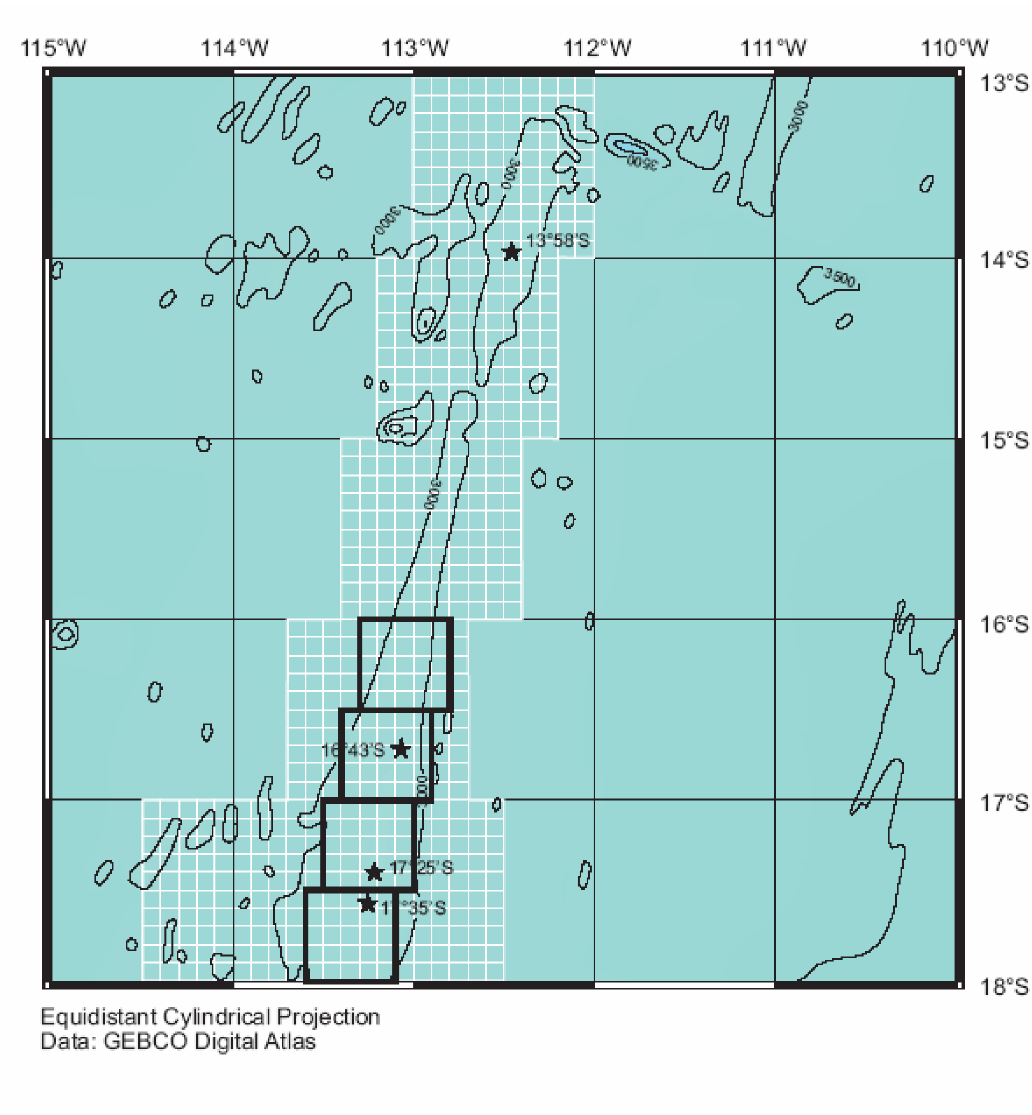
Locations of the sulphides occurrences near 14°N, 13°N, 11°50'N, 10°56'N
and at the 87D-D1 and 87D-C Seamounts



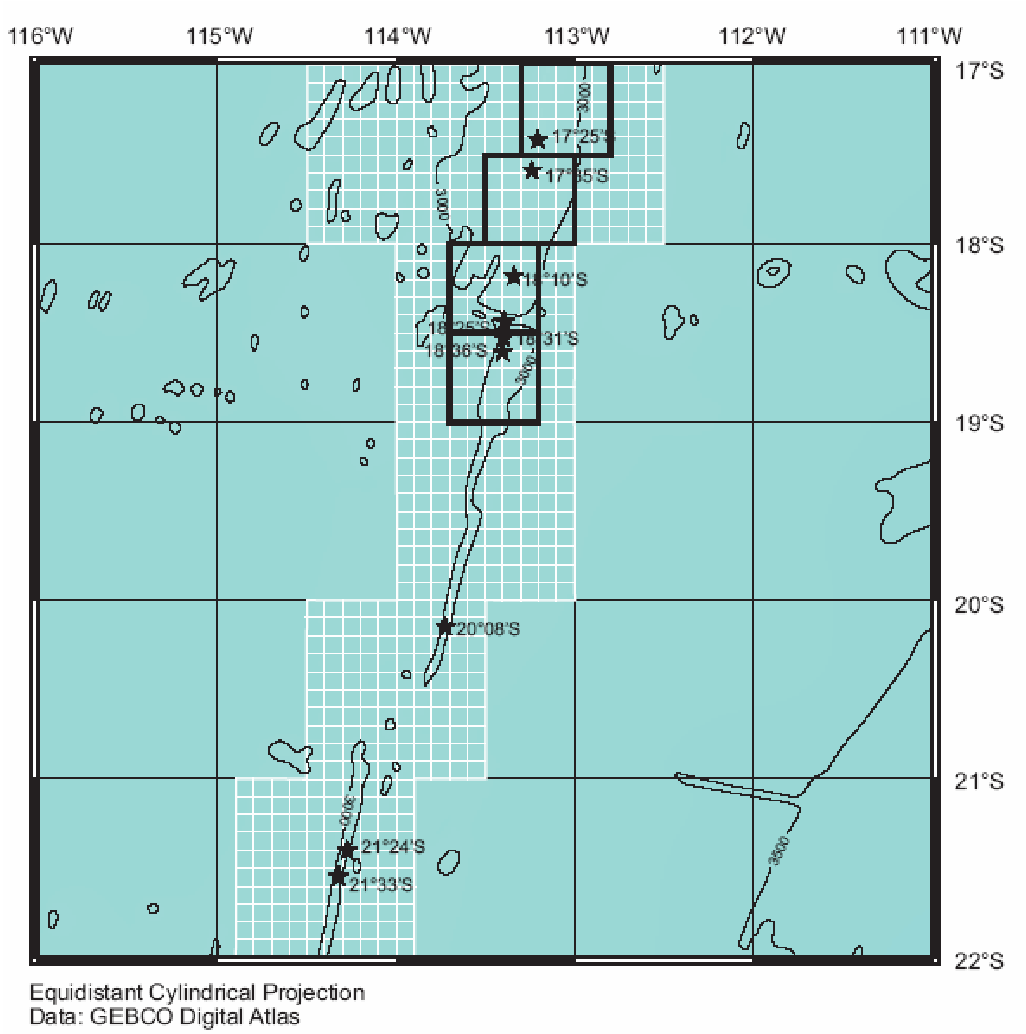
Locations of the sulphides occurrencesnear 9°50'N, 9°46'N, 9°39°N and 9°16°N



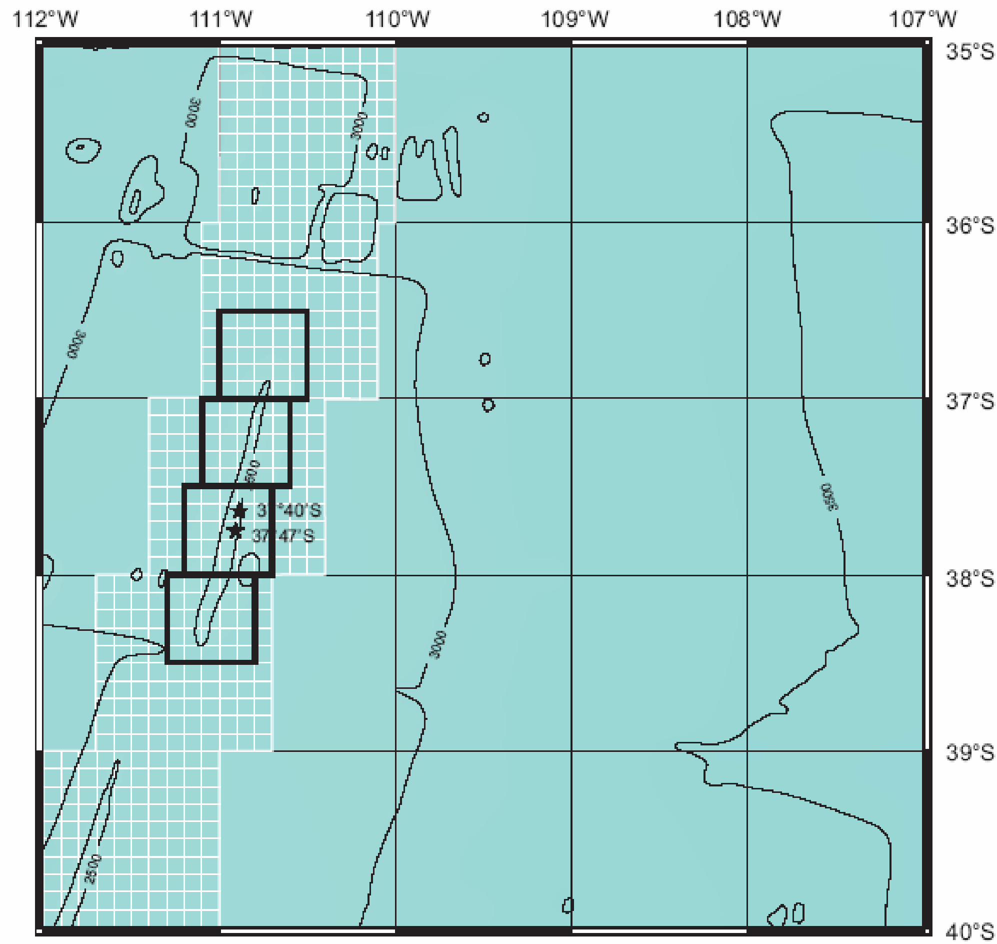
Locations of the sulphides occurrences near 13°58'S, 17°25'S and 7°35'S



Locations of the sulphides occurrences near 17°25'S, 17°35'S, 18°10'S, 18°25'S, 18°31'S, 18°36'S, 20°08'S, 21°24'S and 21°33'S

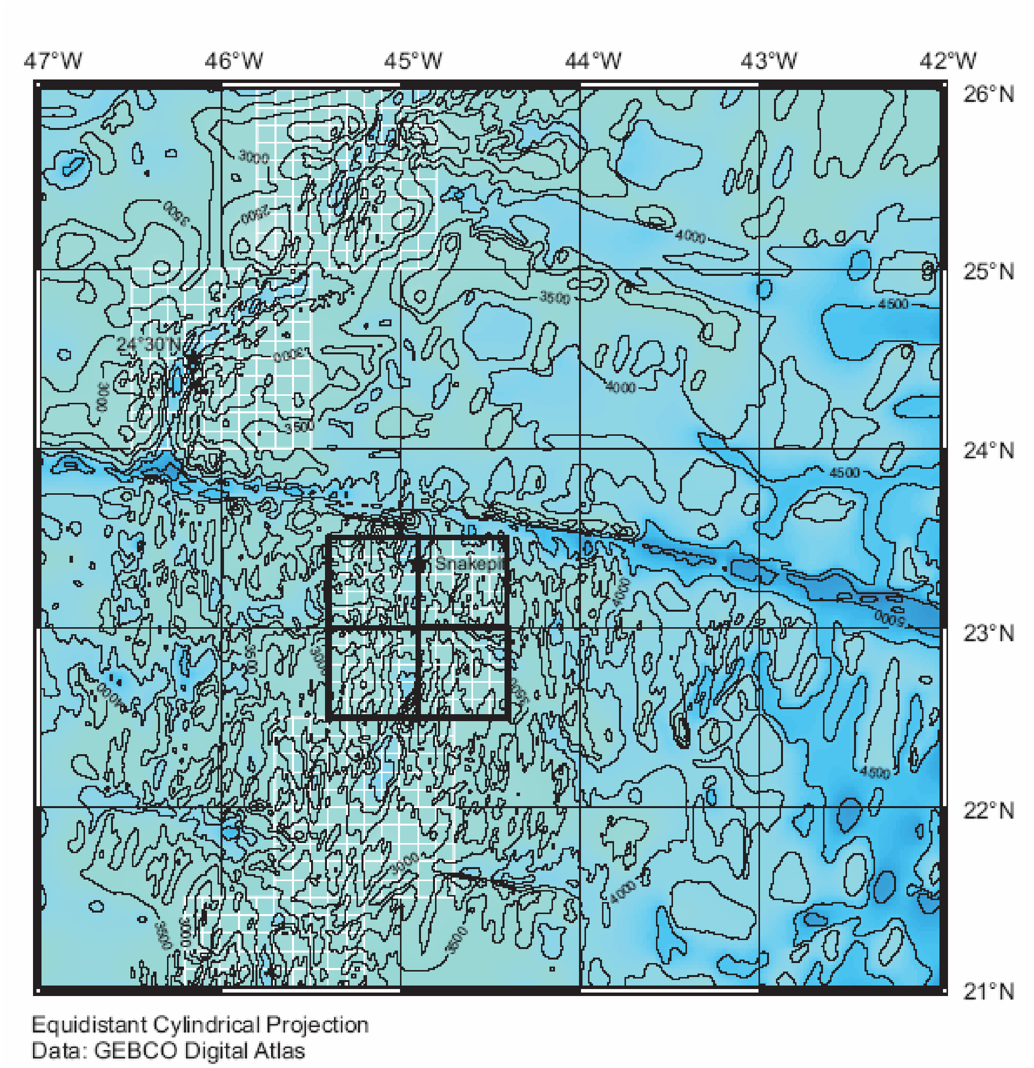


Locations of the sulphides occurrences near 37°40'S and 37°47'S

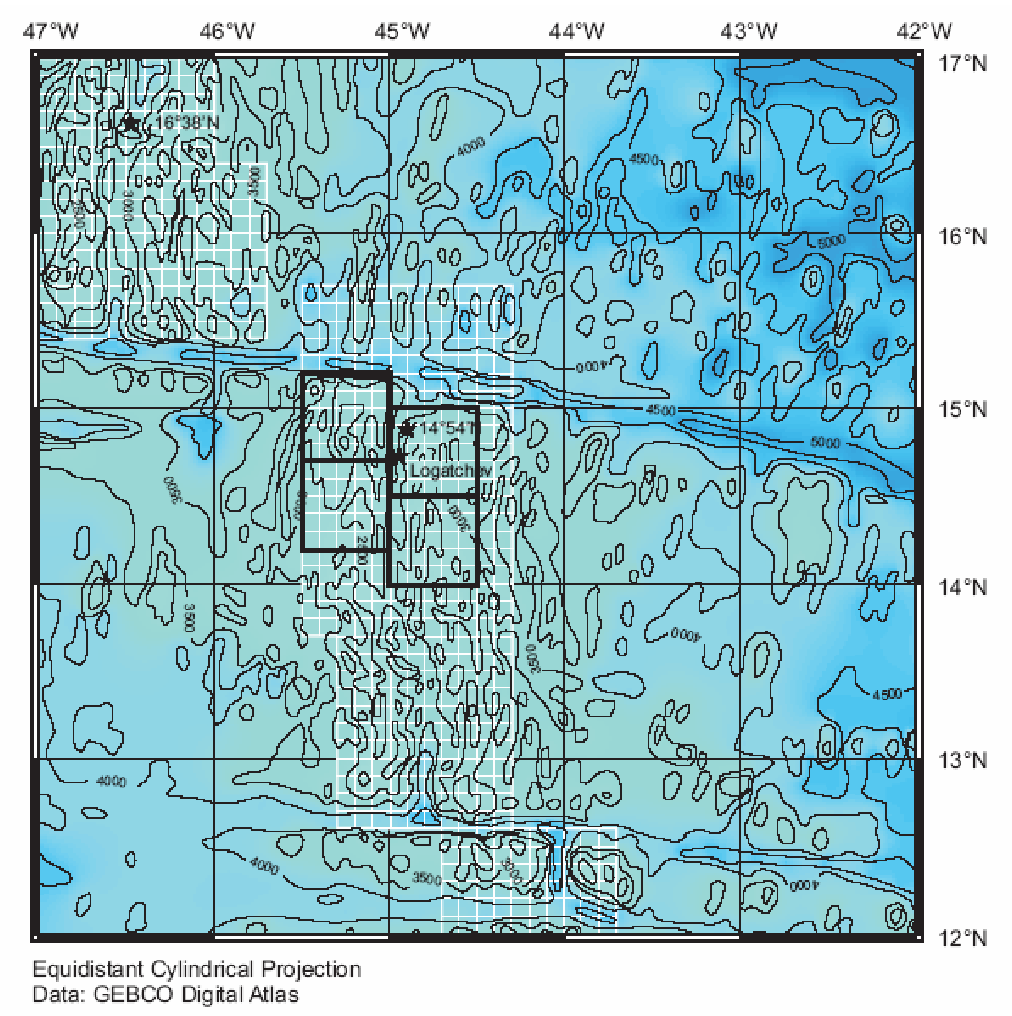


Equidistant Cylindrical Projection
Data: GEBCO Digital Atlas

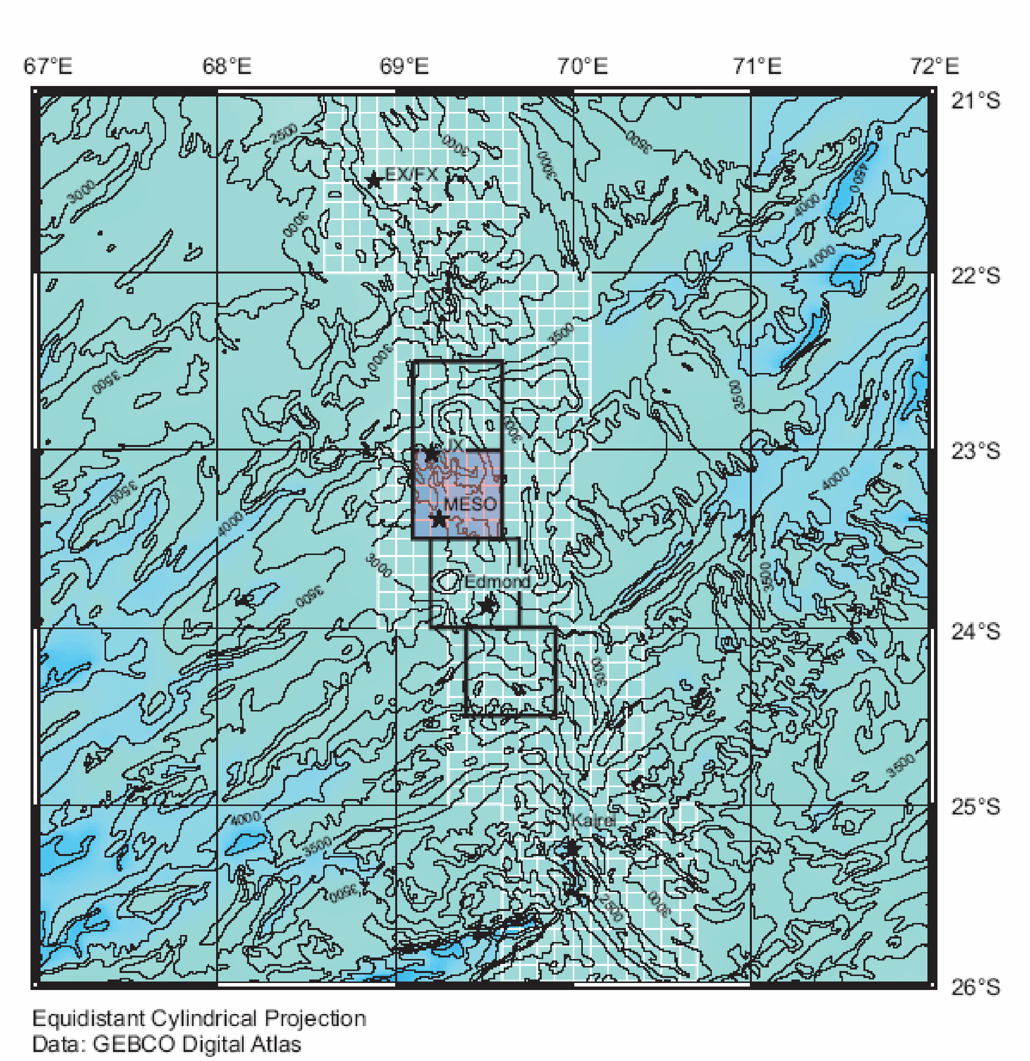
Location of the 24°30'N and Snakepit sulphides occurrences



Location of the sulphides occurrences at 16°38'N, 14°54'N and the Logatchev Field



Location of the MESO Zone sulphides occurence

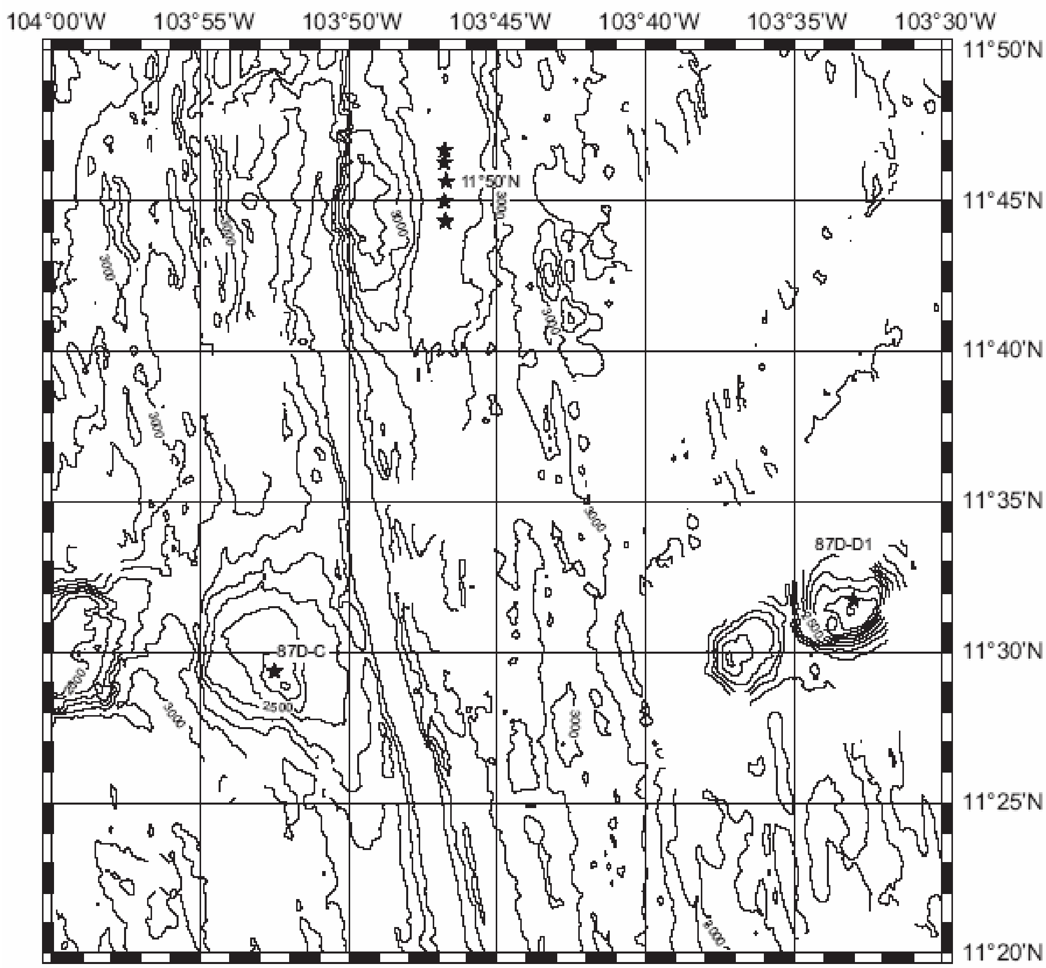


<u>Appendix 5</u>

Detailed maps of selected areas at 100-m contour intervals

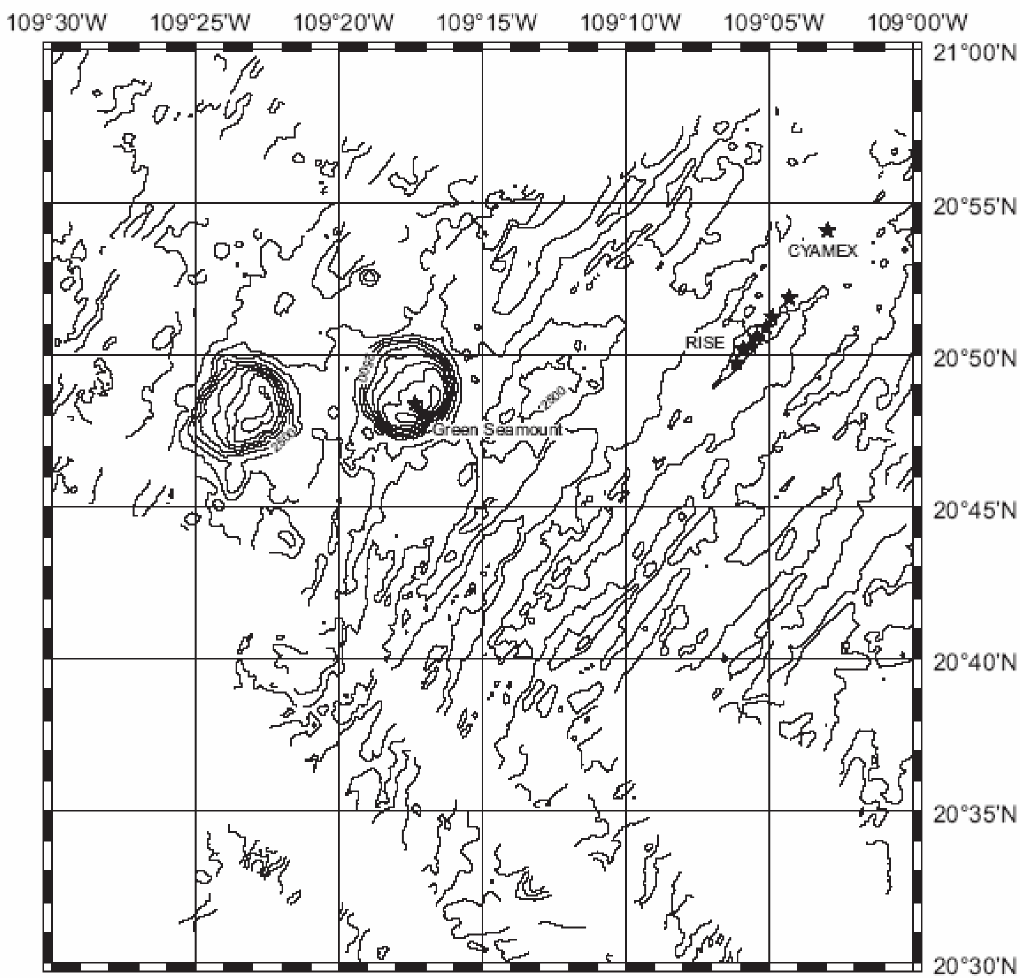
A series of 30 min x 30 min maps (100-m contour interval) illustrate the selection of permissive areas in cases where more detailed bathymetric information may be available. The data shown here are from the United States of America National Geophysical Data Center inventory of multibeam bathymetry (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html). These maps can be used to significantly reduce the initial size of a permissive area, but the data are not available for all parts of oceans.

Bathymetry of sulphides occurrences near 11°50’N and at the 87D-D1 and 87D-C Seamounts



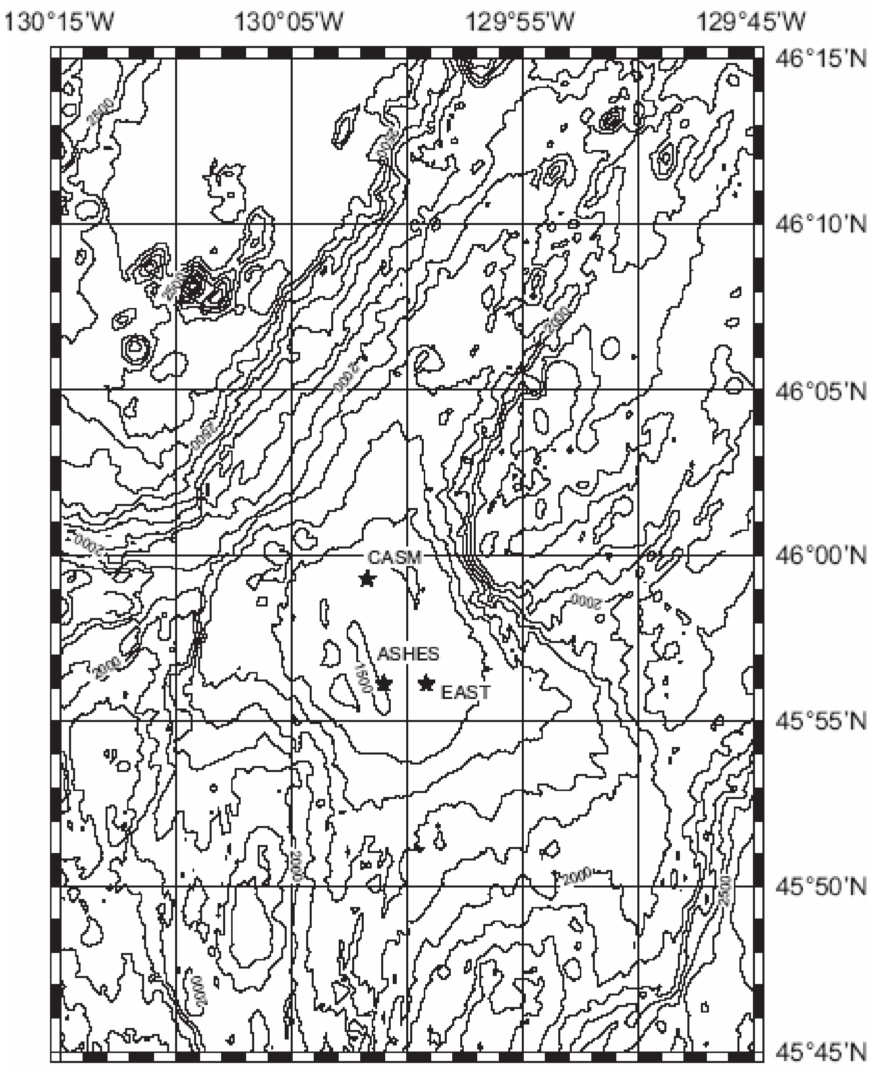
Mercator Projection
Data: NOAA Multibeam Bathymetry Database
87D-D1 Seamount at 11°31.8'N, 103°33.0'W (Kuriyama et al., 1994)
87D-C Seamount at 11°29.5'N, 103°52.5'W (Kuriyama et al., 1994)
11°50'N Site between 11°44.5' to 11°47'N, 103°47'W (Ballard et al., 1988)

Bathymetry of the CYAMEX and RISE Fields and the sulphides occurrences at Green Seamount



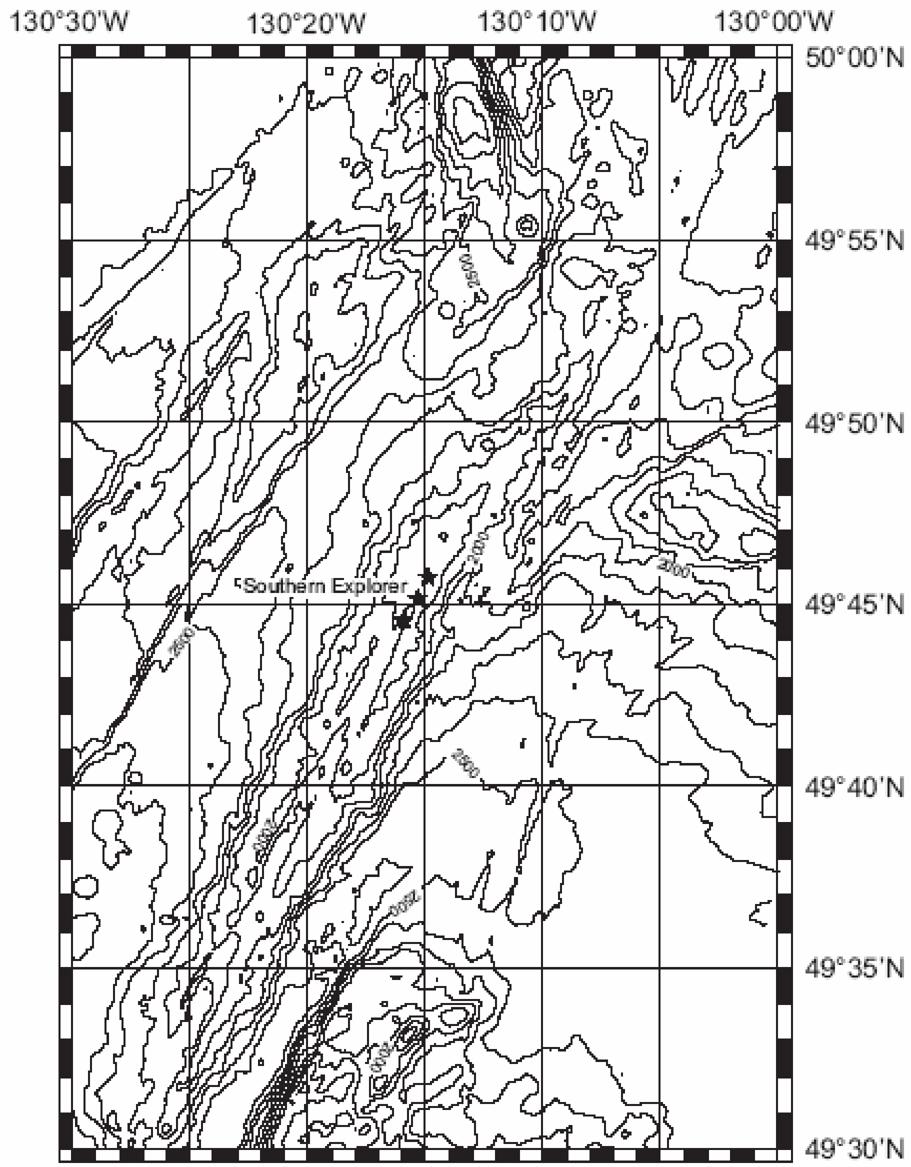
Mercator Projection
Data: NOAA Multibeam Bathymetry Database
Green Seamount at 20°48'N, 109°17'W (Alt, 1988)
CYAMEX Field at 20°54'N, 109°03'W (Hekinian et al., 1980)
RISE Field at 20°49.5' to 20°52'N, 109°04.5' to 109°06'W (Spiess et al., 1980)

Bathymetry of sulphides occurrences at Axial Seamount



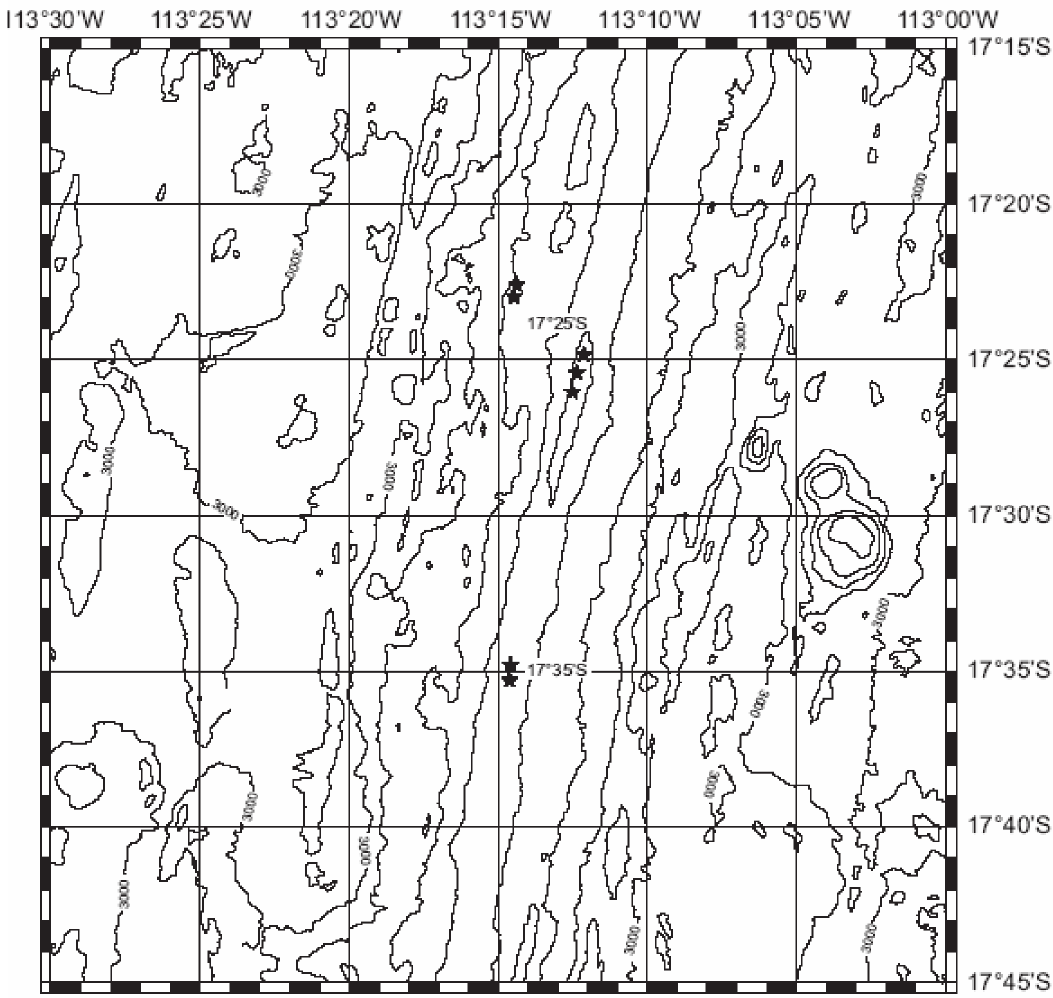
Mercator Projection
Data: NOAA Multibeam Bathymetry Database
CASM Field at 54°59.4'N, 130°01.8'W (Embley et al., 1991)
ASHES Field at 45°56.0'N, 130°00.9'W (Embley et al., 1991)
EAST Field at 45°56'N, 129°59.0'W (Embley et al., 1991)

Bathymetry of the Southern Explorer Field



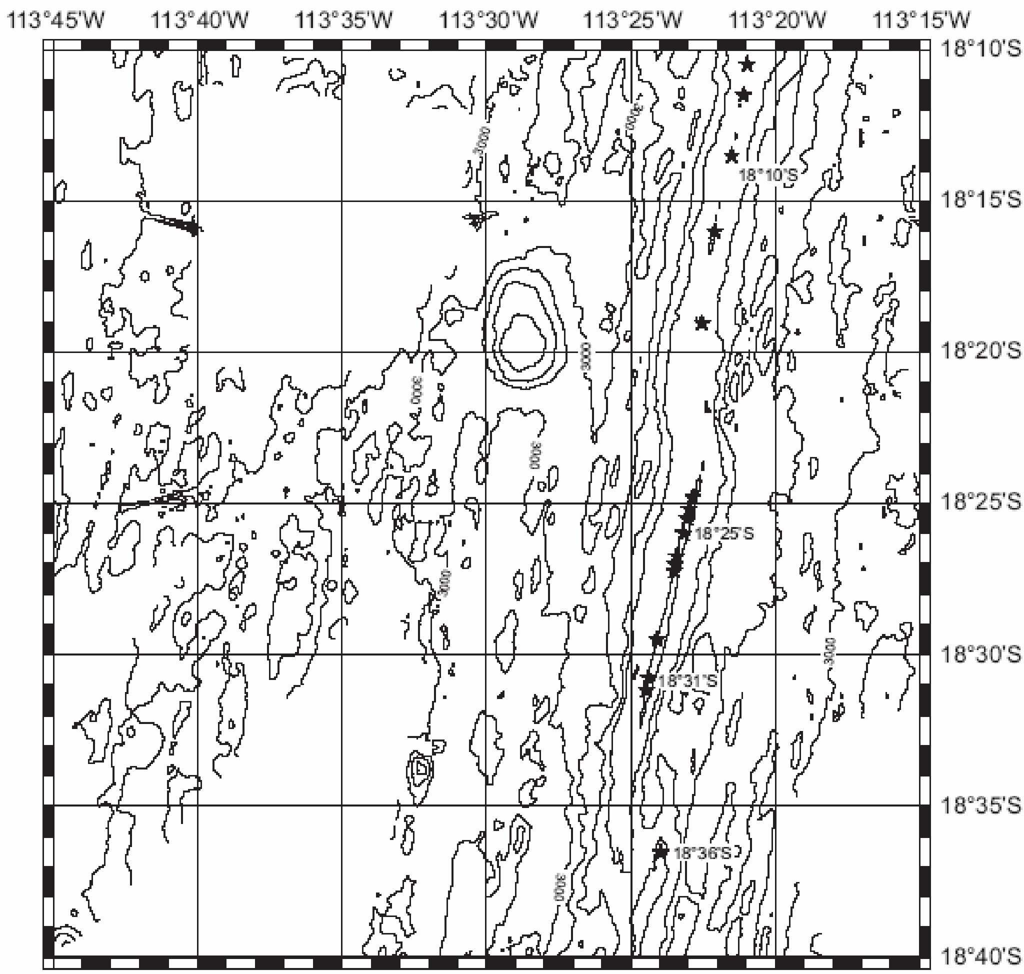
Mercator Projection
Data: NOAA Multibeam Bathymetry Database
Southern Explorer Field at 49°44' to 49°46'N, 130°14' to 130°16'W
(Tunicliffe et al., 1986; Scott et al., 1990)

Bathymetry of the sulphides occurrences at 17°25'S and 17°35'S



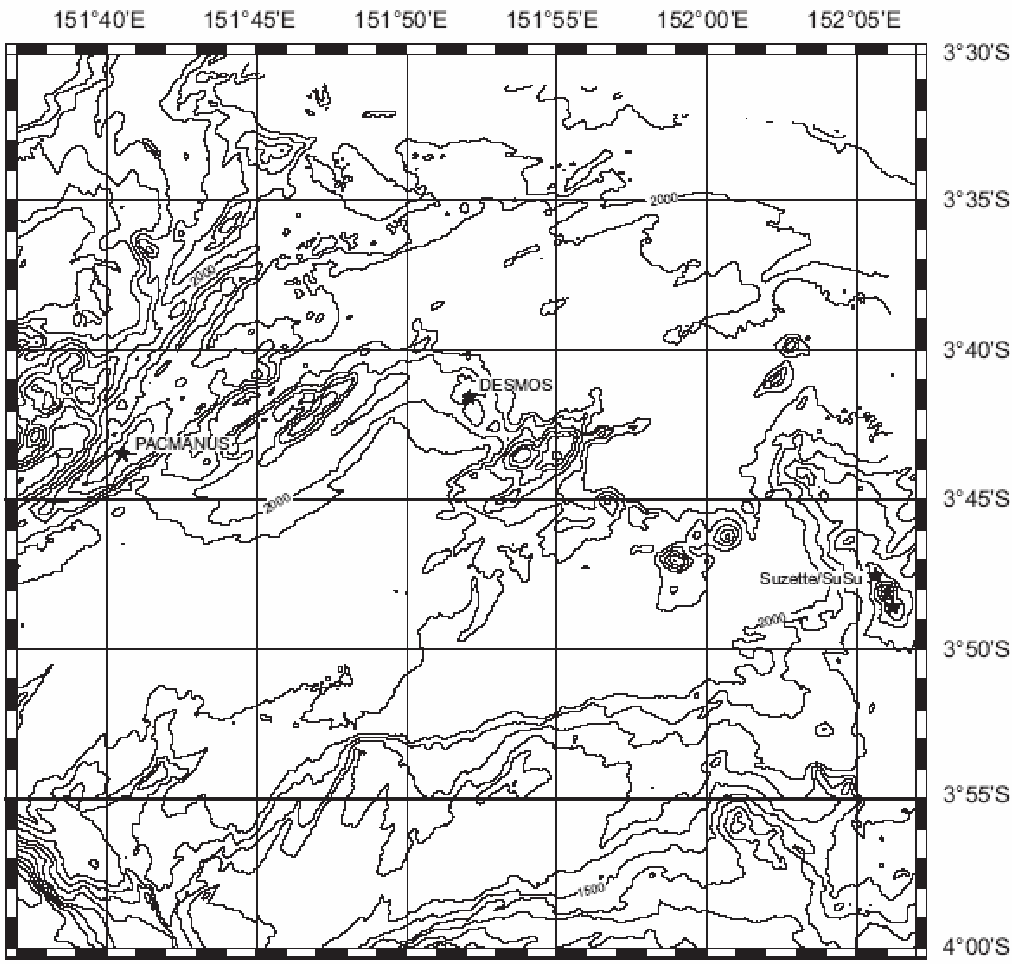
Mercator Projection
Data: NOAA Multibeam Bathymetry Database
17°25'S Zone at 17°22.5' to 17°26'S, 113°12.1' to 113°14.5'W (Renard et al., 1985; Auzende et al., 1994; Jollivet et al., 2004)
17°35'S Zone at 17°34.9' to 17°35.5'S, 113°14.7 to 113°14.8'W (Jollivet et al., 2004)

Bathymetry of the sulphides occurrences near 18°10'S, 18°25'S, 18°31'S and 18°36'S



Mercator Projection
Data: NOAA Multibeam Bathymetry Database
18°10'S Zone at 18°10.5' to 18°11.5' S, 113°21'W, at 18°13.5'S, 113°21.5'W, at 18°16'S, 113°22'W, and at 18°19'S, 113°22.5'W (Auzende et al., 1994)
18°25'S Zone at 18°24.8' to 18°27.6'S, 113°23.5' to 113°24.0'W (Marchig et al., 1988; Auzende et al., 1994)
18°31'S Zone at 18°29.5' to 18°31.3'S, 113°24.5' to 113°25'W (Renard et al., 1985; Bäcker et al., 1985; Marchig et al., 1988; Auzende et al., 1994)
18°36'S Zone at 18°36.5'S, 113°24.0'W (Jollivet et al., 2004)

Bathymetry of the sulphides occurrences at PACMANUS, DESMOS and Suzette/SuSu Knolls



Mercator Projection
Data: Multibeam Bathymetry from Auzende et al. (2002)
PACMANUS Field at 3°43.5'S, 151°40.3'E (Binns et al., 2002)
DESMOS at 3°41.5'S, 151°52'E (Gena et al., 2001)
Suzette/SuSu at 3°47' to 3°49'S, 152°05.5' to 152°06.5'E (Binns et al., 2004)

Summary of the presentation

Dr. Mark Hannington and Dr. Thomas Monecke of the University of Ottawa assisted the Secretariat in the preparation document ISBA/12/C/3 - Part II on "*Global exploration models for polymetallic sulphides deposits in the Area – Possible criteria for lease block selection under the Draft Regulations on prospecting and exploration for polymetallic sulphides*", in partial response to the request made by the Council at the eleventh session of the Authority. Unfortunately neither Dr. Hannington nor Dr. Monecke could be present at the workshop. Dr. James Hein agreed to make the presentation and to respond to those questions that he could during the discussions. The summary of his presentation as well as the discussions following his presentation are presented below.

Dr. Hein explained that in the absence of the two authors, he did not have the benefit of a powerpoint presentation so he had extracted figures from their paper for the presentation. Dr. Hein said that he did not have Dr. Hannington's training in this field but would do the best that he could to be faithful to his train of thought.

Dr. Hein said that the paper consisted of an effort to see how the draft Regulations of the International Seabed Authority would apply in the real world of sulphides deposits. He said that the authors of the paper took all of the known deposits or occurrences of sulphides in the global ocean and applied them a grid system. He said that the authors used a grid system based on latitude either in degrees, latitude or some sub-unit of degrees latitude, which was an easy grid system to use on the earth. He indicated that a problem with that system was that the size of an area bound by longitudes and latitudes changed with latitude because kilometers representing that degree changed depending on where one was located.

With regard to the occurrence of polymetallic sulphides deposits in the oceans, Dr. Hein named three sources. The first source was oceanic spreading centres where molten rock comes up to the seafloor. The second source was oceanic hotspots, and the third source was in volcanic arcs where oceanic crusts are subducted either below other oceanic crusts or continental crusts, creating volcanic activity.

In relation to oceanic spreading centers, Dr. Hein said that and seafloor spreading occurs at mid-ocean ridges, where new oceanic crust is formed through volcanic activity and then gradually moves away from the ridge. He said that this was where a lot of sulphides deposits occur.

He said that another place where hydrothermal deposits are found was at oceanic hot spots, with a perfect example being the island of Hawaii. Dr. Hein said that hot spots were fixed places within the mantle or oceanic lithosphere, where rocks melted to generate magma. He said that the whole Hawaiian chain forms as the Pacific Ocean moves NW over a hot spot deep within the earth, creating new islands as the plate moves over that hot spot. He also said that the island of Hawaii was presently over that hot spot so the island of Hawaii is volcanically active today, whereas if you go the next island over to the north it is not volcanically active.

Dr. Hein described the third source of hydrothermal activity as volcanic arcs. He said that a volcanic arc was a chain of volcanic islands or mountains formed by plate tectonics as an oceanic tectonic plate subducts under another tectonic plate and produces magma. He informed participants that there were two types of volcanic arcs: oceanic arcs (commonly called island arcs, a type of archipelago) and continental arcs. He said that in the former, oceanic crust subducts beneath other oceanic crust on an adjacent plate, while in the latter case the oceanic crust subducts beneath continental crust. With regard to island volcanic arcs, he said that these were places like the Marianna's, the Izu Bonin Arc, and the Aleutian Islands. Dr. Hein said that volcanic arcs have only recently been the focus of studies of hydrothermal activities and there have been some exciting results. Dr. Hein said that behind the arc there was another kind of seafloor spreading that occurs on a much smaller scale that produces hydrothermal activity and very important hydrothermal mineral deposits. Dr. Hein also said that there was spreading in oceanic settings and spreading in back arc settings. These were basically the sort of environments in the ocean basins where hydrothermal activity occur and polymetallic sulphides are formed. He noted that in the hot spots, although hydrothermal deposits were formed, one generally does find polymetallic sulphides, at least not in any significant quantity.

With regard to document ISBA/12/C/3 - Part II - "Global exploration models for polymetallic sulphides deposits in the Area – Possible criteria for lease block selection under the Draft Regulations on prospecting and exploration for polymetallic sulphides", Dr. Hein said that Dr. Hannington had put together a global distribution of known hydrothermal deposits. He said that there were about three known hydrothermal deposits: those that were out in the ocean basins as seamount deposits, which are not polymetallic sulphides, but are hydrothermal manganese deposits that occur along the 55,000km oceanic spreading centers. Another type of hydrothermal deposit that was not included in ISBA/12/C/3 - Part II were those found in fracture zones where there are small hydrothermal systems, and deposits associated with volcanic arcs.

Dr. Hein provided some examples of sulphides deposits at spreading centers. He emphasised the fact that spreading centers spread at different rates. He informed participants that the spreading ridges in the Atlantic Ocean were slow, and that those in the Artic Ocean were even slower. Dr. Hein defined a very fast spreading ridge as one that spread at a rate of 4cm-6cm per year. He said that variations in the spreading rate have a profound influence over the type of hydrothermal deposit created. He said that at fast spreading ridges many smaller deposits were formed, but that they were buried much quicker, because they were moving away from the central axis. He then described magma-dominated systems found in the Atlantic Ocean where the spreading rate was slower. He said that in tectonic-dominated systems there was less magma involved, resulting in the formation of larger but fewer sulphides deposits.

Dr. Hein identified the following points that he said came from ISBA/12/C/3 - Part II:

- There are more than 300 hydrothermal sites in the world's oceans;
- 40 per cent of them are in The Area, or in marine areas beyond the limits of national jurisdiction;
- 65 per cent are found at mid-ocean ridges; 22 per cent are found in back-arc basins;12 per cent are found in volcanic arcs, and 1 per cent are found at mid-plate volcanoes;
- 100 of the hydrothermal sites have polymetallic sulphides;
- 55,000 kilometres of oceanic spreading centres; 22,000 kilometres of volcanic arc and back-arc spreading. In total that is a lot of territory for the occurrence of hydrothermal activity;
- There are only two known deposits that are greater than 1 million tons, one of them is in the Atlantic Ocean, the other one is in the NE Pacific Ocean in the Juan de Fuca Gorda Ridge region. Dr Hein said that the latter deposit is now

included in a national reserve. Based on geologic characteristics, Dr Hein said that there may be five other deposits of this size.

- Individual occurrences cover no more than 1km diameter;

- The median tonnage in most 100 square kilometres blocks will not be greater than 50,000 tons. That is not based on data collected in the ocean basins; it is based on data from the geologic record. Dr Hein said that if it is expected that Cyprus and Kuroko-type deposits would be representative of what might be found in the ocean basins, such a tonnage is reasonable.

He said that the average spacing of vent sites along the ridge was about 98 kilometres . He said that this average varied according to whether the spreading was fast or slow. He said that the spacing was about 167 kilometres for slow-spreading ridges and 46 kilometres for fast-spreading ridges. He also said that based on heat flux mass balance considerations there should be about 1 vent field for every 50-100 kilometres of ridge crest.

Dr. Hein described individual vent fields as being quite small. He said that they were tens to hundreds of metres in diameter and were separated from adjacent vent fields by hundreds to thousands of metres. He described the Endeavour segment of the Juan de Fuca Ridge as one example. He told participants that this was a spreading center in the NE Pacific Ocean. He said that Endeavour segment consisted of about 30 different sulphides complexes distributed among eight vent fields along a 10-kilometre segment of axial valley.

Dr. Hein informed participants that the TAG hydrothermal deposit was probably the best known of all polymetallic sulphides deposits in the ocean basins. He said that the deposit had been drilled seventeen times by the Ocean Drilling Programme. Dr. Hein said that the deposit measures about 200 metres x 60 metres and contained about 2.7 million tons of 2 per cent copper. The stock work also contained 1 per cent copper.

In relation to the terminology used in the document, Dr. Hein said that a prospecting area was defined by 5 degrees by 5 degrees latitude[1]. He described this as arbitrary and said that it was based on the resolution of maps that currently available for most of the ridge system. He suggested that the area was arrived at using maps of 1,000m bathymetric contours and 5 degrees by 5 degrees, which was about 308,000 square kilometres. Dr. Hein suggested that Dr. Hannington was able to fit within those 5-degree by 5-degree maps, all of the known sulphides deposits within 32 of those grids. He said that the 32 maps included in the report show the deposits in each grid.

Dr. Hein said that the report considers as permissive area a portion of the ridge where there were indications that polymetallic sulphides deposits should be present.[2] He emphasised

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[1] *Prospecting area* – A preliminary area that may contain seabed polymetallic sulphides or an area permissive for the occurrence of sulphides, a portion of which may be allocated for exploration as defined in the draft regulations. In the 32 examples discussed in the paper, a prospecting area is arbitrarily defined as an area of less than 5 degrees by 5 degrees and containing at least one known sulphides occurrence or other positive indication of mineralization. In reality, a prospecting area may be identified solely on the basis of permissive geology, in the absence of any indication of mineralization.

[2] *Permissive area* – A portion of a prospecting area having a number of geological attributes that are considered to be essential for the formation of polymetallic sulphides. In defining the limits of a permissive area, two key indicators that are commonly used are evidence for tectonic activity and seafloor volcanism. Typically, these are required to drive hydrothermal circulation and to focus hydrothermal fluids to the seafloor where metals may be deposited. A permissive

the point that an actual polymetallic sulphides deposit(s) need not be present, although most of the permissive areas do contain occurrences or deposits of polymetallic sulphides. He said that the definition includes other hydrothermal indicators, or appropriate geologic conditions for the occurrence of hydrothermal deposits. Dr. Hein pointed out that the indicated size of the permissive area in the report was 500 blocks or 50,000 square kilometres.

Dr. Hein said that the report recommends an appropriate exploration area size of 100 square kilometres blocks, which is about 10,000 square kilometres.[3] Dr. Hein said that based on the report, a single lease block is 100 square kilometres, he did not want to talk about the final lease for exploitation, but from the report he thought the recommended size of an exploitation area was about 2,500 square kilometres.

Dr. Hein reminded participants that in the paper he had assisted the Authority with, relating to a model for crusts, "Exploration and Mine Site Model Applied to Block Selection for Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides" ISBA/12/C/3 -Part I, he had one sentence saying that his model was not an economic evaluation for crusts. He noted that in this model for polymetallic sulphides, Dr. Hannington said something similar. Dr. Hein said that Dr. Hannington did not recommend a site, deposit or anything else for mining.

Referring to the 32 maps contained in Dr. Hannington's model for sulphides, Dr. Hein said that 12 of the 5-degree by 5-degree grids fall within the Area, and that the others did not. He said that the permissive areas as defined for the Area or those areas where it is possible to find hydrothermal deposits within each of the 308,000 square kilometres areas numbered twelve. With a map, Dr. Hein pointed out the East Pacific Rise, the mid Atlantic Ridge and the Central Indian Ridge. He said that on a global average they contained 55,000 square kilometres of permissive area for each of those 5-degree by 5-degree grids. Referring to the contents of ISBA/12/C/3 Part II, Dr Hein said that based on the global distribution of ferromanganese crusts, particularly on how many occurrences of sulphides there were in each permissive area, Dr. Hannington had come up with some recommendations. Dr Hein noted that while the recommendations did not include a scheme, they state, *inter alia*, that a contiguous block system will not work, at least if you want to get to the majority of the polymetallic sulphides deposits. These little squares are all 5 degree squares.

In relation to the exploration models, Dr. Hein said that two models were evaluated by Dr. Hannington. According to Dr. Hein, in exploration Model 1 all blocks in the exploration area were contiguous, and that there was an average of 2.5 occurrences in each 10,000 square kilometres exploration area. He pointed out that this encompasses 73 per cent of the known sulphides occurrences in exploration areas and only 53 per cent in the permissive areas. Dr. Hein said that in exploration Model 2, the blocks were contiguous within non-contiguous clusters. He picked four clusters within each exploration area, noting that clusters need not be contiguous, but that the blocks within each of the four clusters were contiguous. He pointed out that this was a modification of the draft Regulations. He further pointed out that the really important point of the exercise was that it captures 97 per cent of the known sulphides occurrences within each 5

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area may include occurrences of polymetallic sulphides or other positive indications of mineralization, but this is not a requirement.

[3] b) *Exploration area* – A "license" or tenement within a prospecting area and comprising multiple contiguous or non-contiguous blocks reserved for advanced exploration. This is typically an area of not more than 1 degree of longitude by 1 degree of latitude and containing at least one known sulphides occurrence or other positive indication of mineralization. In the models presented herein, the size of an exploration area corresponds to 100 blocks of 10 km x 10 km each, as specified in the draft regulations.

degrees by 5 degrees geographic block and concluded that this was a good effort. He said that he was of the opinion that the appropriate conclusion was to use non-contiguous blocks in one form or another.

To shed further light on the matter, Dr. Hein provided the following example. With a map, he showed Model 1 in the Central Pacific Ridge inclusive of the grid system. Within the grid, he pointed to the cells or the small squares that he said were each 100 square kilometres. Pointing to a 5 degrees by 5 degrees block, he said that this area, with a size of 308,000 square kilometres, was the prospecting area. Within the prospecting area he indicated the grid along the spreading axis, describing this as the permissive area, or an area within which a prospector could identify polymetallic sulphides occurrences/deposits for exploration. Within the permissive area, he suggested four blocks each of 2,500 square kilometres that amounted to a total area of 10,000 square kilometres, or the size of an exploration area. He said that the best that could be achieved using this system of contiguous blocks within the 5 degrees by 5 degrees grid was to capture three of the five sulphides deposits/occurrences in the area during initial exploration. He said that some of the area would be relinquished in accordance with the draft Regulations, and with the contractor settling on the final 2,500 square kilometres block. The best that the system yields in the 5-degree by 5-degree grid was to capture two of the five known deposits in that area. He reiterated his view that the system did not work very well with contiguous blocks for most of the global ridge system.

With regard to Model 2, Dr. Hein said that with exactly the same area and non-contiguous clusters of blocks, one could put all five known deposits in four boxes during exploration and find out which of them was going to be the beneficial deposit. He said that the non-contiguous grid system seemed appropriate. He noted that a polymetallic sulphides deposit in any one of the boxes was very small, less than 1 km in diameter. He described the deposits as very tiny spots in the overall area that would be leased. He further noted that this issue was not addressed in ISBA/12/C/3 Part II. He made the observation that a lot of territory was being leased where there really was not going to be anything recoverable. He also observed that within the 5 degrees by 5 degrees square grid any one of the groups of sulphides deposits when mined would amount to one year of a large operation (20-year mine life). He suggested that there were lots of issues that needed to be addressed, and that what the paper did was to apply the draft Regulations to what was presently known about sulphides deposits.

Dr. Hein said that another important aspect was water depth. He said that most polymetallic sulphides occur at water depths of 2,000 metres -3,000 metres, but that the draft Regulations refer to 2,500 metres. He said, in the Area there were deeper deposits at oceanic spreading centres, some as deep as 4,000 metres, and that a limitation like 2,500 metres water depth wasn't very useful.

Dr. Hein provided other examples using the system as applied to the Juan de Fuca Gorda Explorer ridge system in the North Pacific, the TAG, Mir and Alvin mounds in the North Atlantic Ocean and the Izu Bonin arc. With regard to the Juan de Fuca Gorda Explorer ridge system, he said that there had been ODP drilling and a lot of exploration. He said that all these deposits were small, and told participants that the TAG, Mir and Alvin deposits were distributed within about 25 square kilometres. He noted that the base unit of 100 square kilometres was much more than some of the largest polymetallic sulphides deposits that are known.

Dr. Hein concluded his presentation stating once more that the permissive areas were quite large. He said that the reason for selecting permissive areas of that size was because of the base maps that were available for most of the ocean basins. He noted that these base maps have a certain resolution, and were constructed from maps with 1,000-metre contour interval. He said that under the circumstances one had to generalise what the permissive area would be because no detailed maps were available. He said that if one had a 30 minute map, instead of a 5 degree map the permissive area could be much smaller. In this regard he noted that even though the resolution was only increased by an order of magnitude, the permissive area was decreased by 50 per cent. In closing, Dr. Hein said that the current situation provides an incentive for the creation of better maps of potential sulphides bearing areas so that a more adequate job could be accomplished to identify exploration areas.

Summary of the discussions

The discussions following Dr. Hein's presentation of Dr. Mark Hannington and Dr. Thomas Monecke's paper on "Global exploration models for polymetallic sulphides deposits in the Area – Possible criteria for lease block selection under the Draft Regulations on prospecting and exploration for polymetallic sulphides", focused on the 5-degree by 5-degree blocks, the permissive areas, the contiguous versus the cluster model and the costs associated with exploring the size of the area proposed in the draft Regulations.

With regard to the 5-degree by 5-degree blocks, a participant suggested that the choice was arbitrary. Another suggested that it should be modified to reflect the actual configuration of deposits, and yet others wanted to find out if the blocks impacted on both the contiguous and cluster models.

In response, Dr. Hein said that the 5-degree by 5-degree blocks, while arbitrary, encompass known deposits or occurrences of polymetallic sulphides. Stating that Dr. Hannington is an expert on the global distribution of polymetallic sulphides in the oceans, he assumed that Dr. Hannington must have selected the block size for a reason. On his part, he said that he thought one of the reasons was the quality of available base maps. He said that maps of the ridge systems were currently available at this resolution. He also said that for US$1.0 billion, the entire ocean basin could be mapped at a much higher resolution.

Dr. Hein said that in keeping with the draft Regulations, an exploration area is 10,000 sq km, comprising 100 blocks of 10 kilometres x 10 kilometres each. He said that Dr. Hannington could have selected the 5 degrees by 5 degrees prospecting area of size 2,500 square kilometres or 25 of the 10 x10 kilometre blocks. Four of these 5-degree by 5-degree areas would be the exploration area.

Some participants described the 5-degree by 5-degree areas as imposing a confinement on the system. It was argued that since the actual deposits are smaller than the potential block size following exploration, the proposed mine site would consist of deposits with irregular shapes and sizes and thus require the contractor to carve out similar figures from his exploration area. To this query, Dr. Hein suggested that it could still be done with the grid system. He said that with a base grid of 20 square kilometres, a deposit could be defined fairly well. It was also argued that since there was no reason to maintain the 5-degree by 5-degree areas, this concept could be dropped and renegotiated as a detail.

In relation to the impact of contiguous clusters of blocks or non-contiguous clusters of blocks, Dr. Hein was asked if applying the regulations as they stand and requiring contiguous clusters of blocks would result in losses of prospective areas.[4] He was also asked if the use of the non-contiguous clusters of blocks would ameliorate the situation.

Dr. Hein responded in the affirmative to both questions and said that other than in some rare circumstances, the non-contiguous clusters model would result in a pick-up of 97 per cent of the known polymetallic sulphides deposit in an exploration area.

A representative of Nautilus Minerals Inc, a company with tenements for offshore exploration and exploitation of polymetallic sulphides in Papua New Guinea, pointed out that the company's total tenement package in that country was 17,500 square kilometres. He said that the company's work commitment during exploration for the total tenement was in the range of US$ 6 to 10 million. He said that this represented the sum of money that the company felt was required to confidently relinquish areas. He commented that it would cost a lot, based on the size of areas being proposed, to enable any contractor with the Authority to explore their areas to the level of detail required for relinquishment. In this regard he said that based on discussions at the workshop, what he understood the objective of exploration to be was an inactive hydrothermal system. He said that these types of systems do not have high temperature plumes associated with them. He said that the inactive systems would be harder to find and required a lot more work to define. He said that for one of the prospects that the company drilled, the bathymetric data that it had to obtain was down to a resolution of 1metre. He suggested that for the size of areas being discussed, this process would take a very long time.

Another participant noted that from active hydrothermal areas the presence of sulphides mounds may be detected. The participant further observed that there were many more non-active mounds to be found beyond these areas. He added that if the sediment cover on these mounds were very thick they would not be mining targets and that the old inactive mounds were more attractive because of their sizes. This participant bemoaned the unavailability of the required data and information. In response to the observations, Dr. Hein said that 20 per cent of the dataset on the sulphides occurrences were dead systems. He said that it just so happened that the dead systems were occurring in fairly close proximity to the active systems. He also said that there were probably other dead systems that were farther away that have not been found and would be more difficult to find. He noted that there were a few sediment-covered ridges, and that thicker sediment could act as a reservoir for hosting a substantial polymetallic sulphides deposit. He identified as a problem, the fact that the technology to mine such deposits had not yet been established.

A participant agreed with the idea that the size of the permissive areas was arbitrary. This participant also said that the permissive areas should be configured to encourage exploration in areas for which data are scarce. Dr. Hein responded that a permissive area was not arbitrary and that it was based on geologic criteria and the distribution of known deposits. He said that if there was no known deposit in a permissive area, then it was based on geologic criteria indicating that hydrothermal activity is associated with the area. A suggestion was made that one of the activities that the Legal and Technical Commission should encourage through

[4] *Permissive area* – A portion of a prospecting area having a number of geological attributes that are considered to be essential for the formation of polymetallic sulphides. In defining the limits of a permissive area, two key indicators that are commonly used are evidence for tectonic activity and seafloor volcanism. Typically, these are required to drive hydrothermal circulation and to focus hydrothermal fluids to the seafloor where metals may be deposited. A permissive area may include occurrences of polymetallic sulphides or other positive indications of mineralization, but this is not a requirement.

these rules and systems, was the exploration of areas that did not contain sites that are already known.

The Secretary-General of the Authority, provided participants with a synopsis of the exploration system that the International Seabed Authority was trying to establish. He informed participants that his point of reference was that of an organisation trying to administer the international seabed area (the Area), to give reasonable opportunity for research, and for the identification of mineable areas. The Secretary-General said that in order to be able to do that the Authority has to allocate areas to interested parties and to have a system for allocation. He noted that discussions were taking place on the grid system for allocation of areas and on the number of blocks within the grid that are to be made available for exploration. He said that the shape of the grid could be varied for cobalt-rich ferromanganese crusts as well as for polymetallic sulphides. He said that in the case of sulphides deposits, since they occur along or around the ridges, a system was required to identify possible areas and how much to allocate for exploration purposes. He described the problem with the initial draft Regulations as the introduction of the requirement for selected areas to be contiguous and the need to find contiguous mineable areas. He said that the introduction of the grid system was to provide flexibility to that system and this had been introduced in the more recent set of regulations. He said that from the Authority's point of view as the administrator of the Area, an applicant is offered a broad area based on the grid system. The applicant selects an area demarcated by coordinates.

Mr. Nandan said that within the exploration area, the applicant then identifies certain areas which are mineable areas or potential mineable areas. Following its research on this exploration area, the applicant then relinquishes those parts that it is not interested in. The relinquished area reverts to the Area enabling potential applicants to conduct prospecting or exploration for the minerals that it contains. Mr. Nandan said that the Authority has to ensure that the applicant obtain a reasonable sized area for exploration. The Authority also has to ensure that the applicant can retain a reasonable part of the exploration area that can support a 20-year mining project.

Mr. Nandan continued that the Council has obtained proposals on a good scheme to achieve this objective, and that it has to come to a conclusion as to what would be a reasonable and fair scheme from the point of view of the applicant as well as from the point of view of the Authority. He also said that the Authority does not want to give away large areas and create monopolies. He reiterated that the Authority has to be fair to the applicant and give the applicant a reasonably sized area to explore, where in the end, a part of the exploration area could be retained by the applicant for its mining activities.

A participant made the observation that in order to achieve the objective of reasonable and fair, a definition of reasonable and fair is required. This participant said that different people have different views on what constitutes reasonable and fair. The same participant noted that some people could argue that by allowing a company to cherry-pick the entire known world oceans sulphides system was not reasonable and fair, while others people would argue that it was, since the operation is shrouded in a lot of risks. The participant said that the first thing to do was to define what is reasonable and what is fair. This participant pointed out that there were systems used around the world which involved auctioning ground where companies put money up, depending on how prospective they think the ground is, based on work that the government has done. He added that in other countries it is first come, first served.

The Secretary-General ended discussions on the presentation adding that it is not only about being reasonable and fair, but about how common sense is applied to the situation. He said that the Authority was trying to be objective through the grid system and the issue was whether the proposed grid system is sufficient for exploration purposes, whether the four blocks that remain at the end are a reasonable size and as was rightly said, to avoid cherry-picking. The Secretary-General concluded by informing participants that one of the responsibilities of the Authority is to ensure that there is no wastage of the resources from the common heritage, and to make sure that people take some good with the bad, and that there is good use of the resources that are found.

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Chapter 11: A Cost Comparison of Implementing Environmental Regulations for Land-Based Mining and Polymetallic Sulphides Mining

David Heydon, CEO Nautilus Minerals Inc. Presented by Michael Johnston, Vice-President, Corporate Development, Nautilus Mineral Inc.

Summary of the presentation

Mr. Heydon, who had provided a PowerPoint presentation on a cost comparison of implementing environmental regulations for land-based mining and polymetallic sulphides mining, could not be present for the workshop. His presentation was made by Mr. Michael Johnston, Vice-President for Corporate Development of Nautilus Minerals Inc.

Mr. Johnston apologised for the absence of Mr. Heydon and prefaced his presentation with a remark that his talk would focus on processes for implementing the environmental regulations in the draft Regulations for polymetallic sulphides. He stated that the talk was based on his personal experience in exploration, both on land and in the ocean, and that he was going to make some suggestions for incorporation in the draft Regulations. In his presentation, Mr. Johnston first outlined land-based practices for environmental protection during mining and then turned his attention to sea-bed prospecting and how these practices relate in terms of evaluating the impact of required activities. Mr. Johnston said that over the last 10 years a shift in most government and regulatory policies had been observed; ranging from a highly prescriptive regime toward a more pragmatic approach with accepted levels of self regulation within the framework of a work programme to be agreed to in advance. He said compliance with the work programme is often controlled by an observer. He added that this system works well for both explorers and regulators and that it could be adapted to activities in the Area.

Mr. Johnston informed participants that land based exploration programmes were usually graded according to the expected impact of planned activities on the environment prior to the start of work.

Mr. Johnston said that the expected impact of the activity and the steps required to mitigate impacts to the environment are agreed to with the government in the initial work programme. He noted that in the case of Nautilus's off-shore activities in Papua New Guinea, the procedures were similar. Mr. Johnston said that the costs for implementing these procedures in the early phases of exploration on land were minimal, in the range of US$5,000 to US$20,000. He suggested that the Authority needed to have a similar approach in the Area and noted that environmental impacts at sea were generally expected to be lower than on land, since ships do not leave tracks like vehicles, which are major environmental disturbances in land-based prospecting and exploration programmes.

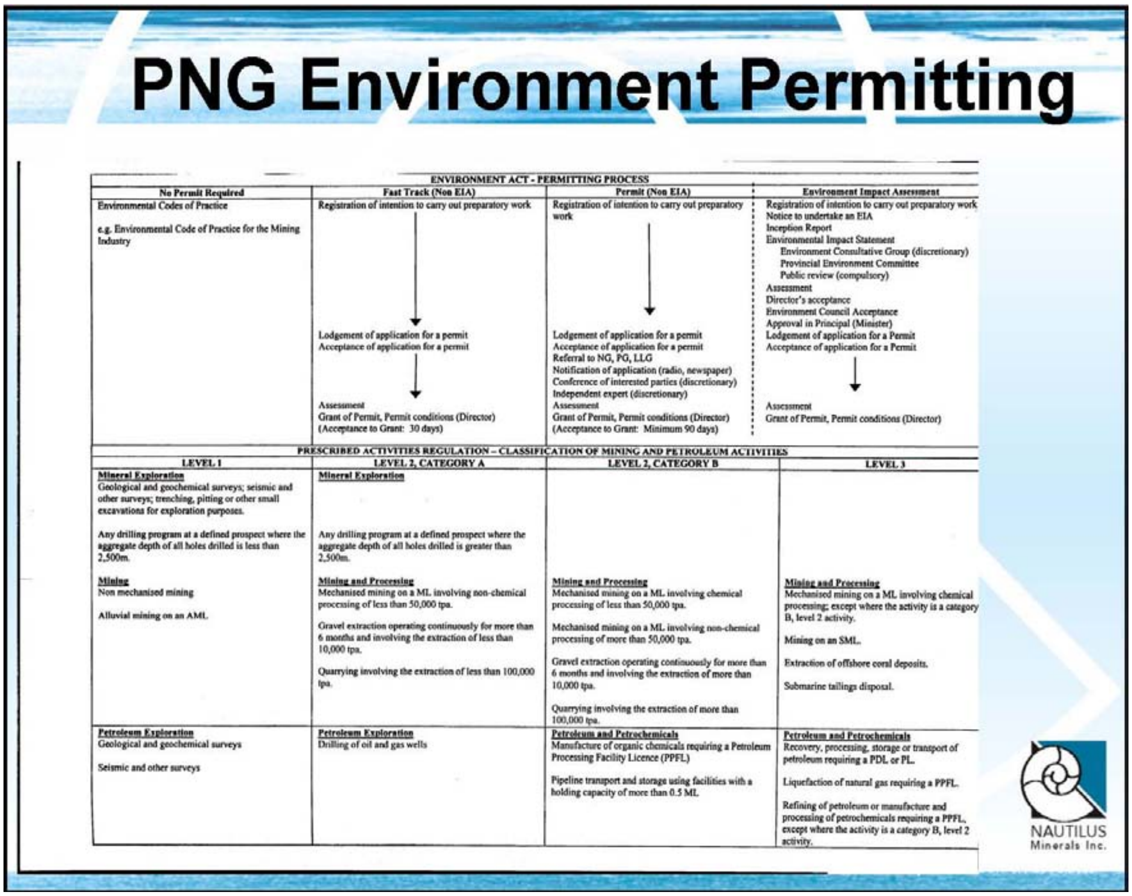
Mr. Johnston said that the main cost in both a land-based exploration programme and for a deep sea exploration project was in preparing an EIS (Environmental Impact Statement) or an equivalent impact study in the Area. He noted that the cost and the efforts for an EIS varied enormously due to varying land use conflicts, the type of mine and its impacts, the processing options and other factors. He also said that common costs range from US$ 3-$10 million or more. Mr. Johnston said that generally it takes about 12 to 18 months to prepare the study for a land-based mine and an additional 6 months for government review. He said that an EIS for land-based activities needed to be thoroughly carried out and usually must cover all seasons of the year in order to avoid criticism from various stakeholders. According to Mr. Johnston a company would only put effort into preparing an EIS if there is an indication of a profitable venture. Before an EIS gets accepted. Mr Johnston said it is reviewed by government experts and eventually modified until a reasonable balance is reached.

With regard to seabed exploration in areas within the Authority's jurisdiction, he suggested implementing a similar collaborative approach, where an appropriate work programme would be agreed upon as the basis to complete an EIS which should be as transparent as possible, and for which the Authority would solicit input throughout the process, and involve any relevant groups as early as possible before submission of the final document.

Using a slide, Mr. Johnston presented the provisions of the Papua New Guinea (PNG) Mining Act with respect to environmental permitting which he said were similar to approaches taken by other countries like Australia and Canada.

He said that the basic principle of the approach was that activities are graded for impact during the mining cycle, with appropriate responses required of a contractor. He said that in the exploration phase associated activities are graded, and the regulator accepts in advance the levels of impact from known activities, and ensures that these levels are not exceeded.

Mr Johnston noted that during this stage of low impact activities, supervision from the regulatory body is minimal. Mr. Johnston further noted that it would not be possible for the Authority to fully supervise all activities throughout the Area. In this regard, he said that among the low-impact activities on land that are generally permitted in advance with little or no supervision are geophysical surveys, mapping (video tows) and general sampling. Mr. Johnston informed participants that usually the contractor is only required to show photos of the effects and compare them with the agreed activities. He said that higher-impact activities such as drilling are graded as well and monitoring measures are put in place. Mr. Johnston said that regional scale drilling generally does not require sophisticated regulatory approval procedures; the company normally only has to submit a work programme including the number and locations of drilling holes as well as access paths. He said that in the case of high impact activities such as bulk sampling and trial mining, commonly a limited form of an EIS is required prior to work commencing. Mr Johnston said that normally, at this stage, detailed environmental work has already started and it is not a big impediment for the company anymore to seek additional approvals and to have a more supervised level of work programme.



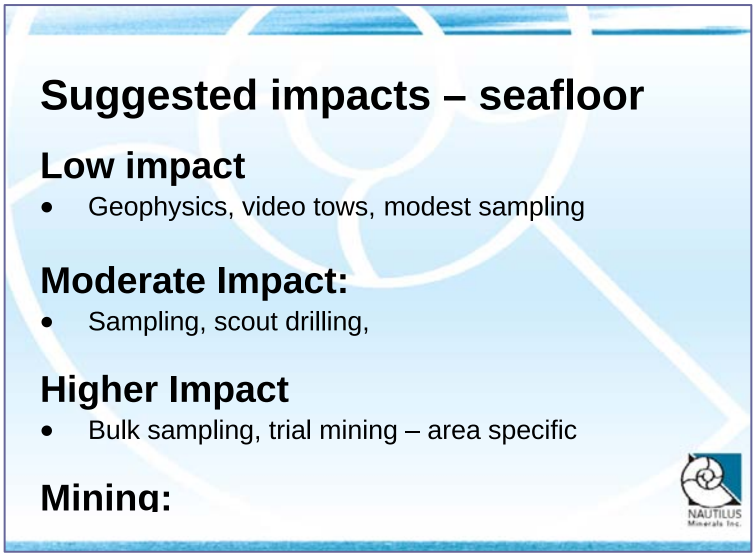
ENVIRONMENT ACT - PERMITTING PROCESS			
No Permit Required	**Fast Track (Non EIA)**	**Permit (Non EIA)**	**Environment Impact Assessment**
Environmental Codes of Practice e.g. Environmental Code of Practice for the Mining Industry	Registration of intention to carry out preparatory work ↓ Lodgement of application for a permit Acceptance of application for a permit ↓ Assessment Grant of Permit, Permit conditions (Director) (Acceptance to Grant: 30 days)	Registration of intention to carry out preparatory work ↓ Lodgement of application for a permit Acceptance of application for a permit Referral to NG, PG, LLG Notification of application (radio, newspaper) Conference of interested parties (discretionary) Independent expert (discretionary) Assessment Grant of Permit, Permit conditions (Director) (Acceptance to Grant: Minimum 90 days)	Registration of intention to carry out preparatory work Notice to undertake an EIA Inception Report Environmental Impact Statement Environment Consultative Group (discretionary) Provincial Environment Committee Public review (compulsory) Assessment Director's acceptance Environment Council Acceptance Approval in Principal (Minister) Lodgement of application for a Permit Acceptance of application for a Permit ↓ Assessment Grant of Permit, Permit conditions (Director)

PRESCRIBED ACTIVITIES REGULATION – CLASSIFICATION OF MINING AND PETROLEUM ACTIVITIES			
LEVEL 1	**LEVEL 2, CATEGORY A**	**LEVEL 2, CATEGORY B**	**LEVEL 3**
Mineral Exploration Geological and geochemical surveys; seismic and other surveys; trenching, pitting or other small excavations for exploration purposes. Any drilling program at a defined prospect where the aggregate depth of all holes drilled is less than 2,500m. **Mining** Non mechanised mining Alluvial mining on an AML.	**Mineral Exploration** Any drilling program at a defined prospect where the aggregate depth of all holes drilled is greater than 2,500m. **Mining and Processing** Mechanised mining on a ML involving non-chemical processing of less than 50,000 tpa. Gravel extraction operating continuously for more than 6 months and involving the extraction of less than 10,000 tpa. Quarrying involving the extraction of less than 100,000 tpa.	**Mining and Processing** Mechanised mining on a ML involving chemical processing of less than 50,000 tpa. Mechanised mining on a ML involving non-chemical processing of more than 50,000 tpa. Gravel extraction operating continuously for more than 6 months and involving the extraction of more than 10,000 tpa. Quarrying involving the extraction of more than 100,000 tpa.	**Mining and Processing** Mechanised mining on a ML involving chemical processing; except where the activity is a category B, level 2 activity. Mining on an SML. Extraction of offshore coral deposits. Submarine tailings disposal.
Petroleum Exploration Geological and geochemical surveys Seismic and other surveys	**Petroleum Exploration** Drilling of oil and gas wells	**Petroleum and Petrochemicals** Manufacture of organic chemicals requiring a Petroleum Processing Facility Licence (PPFL) Pipeline transport and storage using facilities with a holding capacity of more than 0.5 ML	**Petroleum and Petrochemicals** Recovery, processing, storage or transport of petroleum requiring a PDL or PL. Liquefaction of natural gas requiring a PPFL. Refining of petroleum or manufacture and processing of petrochemicals requiring a PPFL, except where the activity is a category B, level 2 activity.

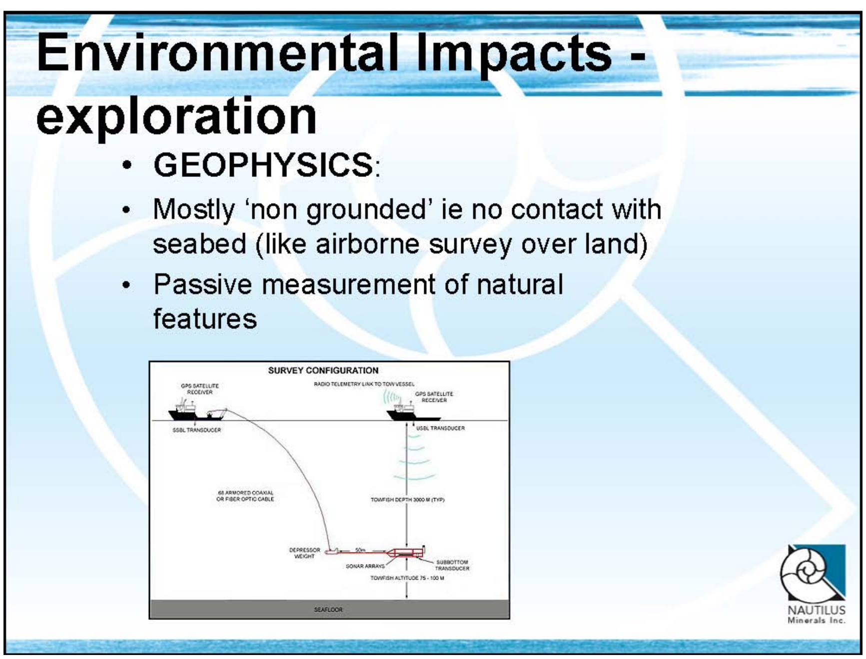
Through another slide, Mr. Johnston summarised the elements of the "mining cycle" as follows:

- Exploration (low impact assessment of resource potential)
- Resource delineation (detailed testing of deposits to determine economic viability)
- Permitting (obtaining the various approvals to mine)
- Mining (extracting the ore)
- Closure (activities and planning to ensure that the site achieves acceptable long term environmental status)

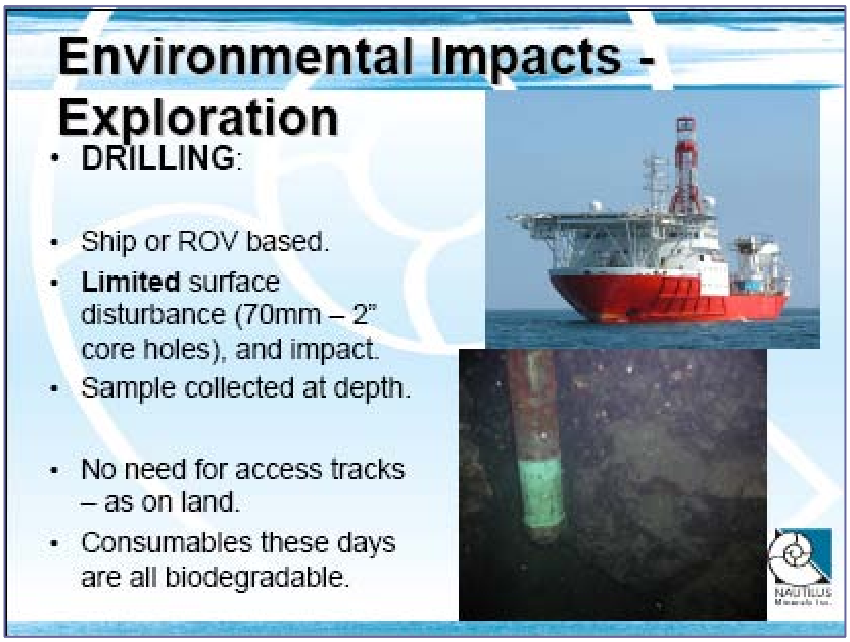
He said that during exploration, a large tract of ground is reduced to a smaller area which ultimately contains the resource which eventually will be mined. Mr. Johnston said that on land, the permitting stage can be significant and take 3-5 years even in "mining-friendly" regulatory environments. With respect to closure of the mine, he said that this last stage can involve significant cost in a land-based operation and can cost in excess of US$ 20 million. He also said that in most countries mine development will not be permitted without the closure plan submitted with the EIS.



Mr. Johnston turned his attention to exploration on the seafloor and noted that initial activities like geophysical surveys, video tows and modest sampling practically do not have any impact at all. He said that subsequent stages such as scout drilling have less impact than on land, since there is no access impact. Mr Johnston said that higher impact activities include bulk sampling which Nautilus Minerals Inc. did in Papua New Guinea with the approval of the regulator.

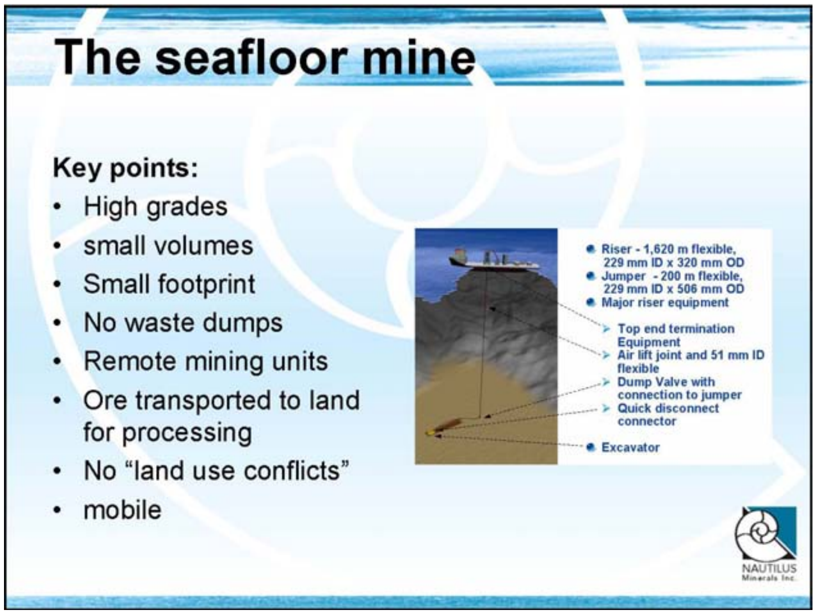


Mr. Johnston said that about 15 tonnes of material were collected and said that the exercise had been video taped and shown to the regulator. He noted that on the seafloor, impacts tend to be area specific. He also informed participants that a worst-case scenario of the potential impacts of the plume from mining has been modelled. Based on this simulation, which was shown to the regulator, Mr. Johnston said that it was determined that the impact of the plume would be below critical levels.



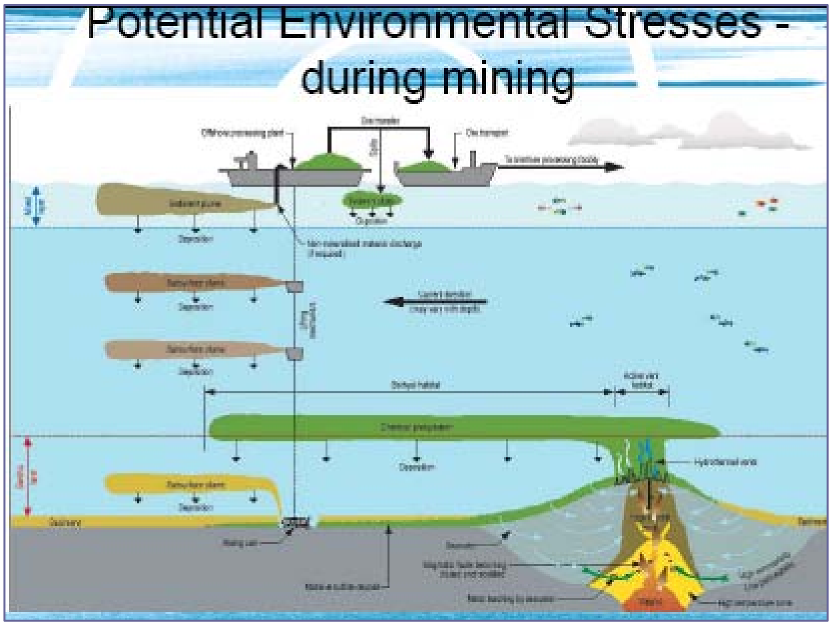
With regard to polymetallic sulphides deposits, Mr. Johnston noted that the key point is that only high grade deposits would be mined, resulting in a smaller impact in terms of the ore volume and the size of the footprint when compared with land-based mining, where the deposits are of low-grade. Other positive aspects compared with land-based operations, according to Mr Johnston, are that there are no waste dumps, there is no ore processing at the mine site and that land-use conflicts are limited.

Mr. Johnston pointed out that land-use conflicts in the mining industry were becoming more and more an issue, especially in industrialised countries where the trend was to relocate mining operations to other countries. He said that the relocation of these operations was not a consequence of limited resources but of environmental policies.



Mr. Johnston outlined the environmental impacts of seabed exploration. In the early survey phases, he said that there was generally no contact between the equipment used and the seafloor and therefore there was no impact at all.

He also said that the impacts of the first drilling campaigns, which are drill holes, do not cause significant disturbances. Mr. Johnston said that trial mining was the activity that caused the first significant impacts.



In this regard, Mr. Johnston said that possible stresses to the environment during this stage as well as during the actual mining operation were mainly related to plumes generated by mining.

According to Mr. Johnston, a company would not mine an active hydrothermal vent system, since it would destroy the equipment, but would operate in the flanks and in the old waning parts of the system. Consequently, Mr. Johnston said impacts would mainly occur at these parts of hydrothermal vent sites. He also said that the impact of plumes can be mitigated by the use of suction pumps.

On the topic of the cost of compliance with environmental regulations for a seafloor mine, he said the location of the mine site had a significant influence on this cost, since the necessary equipment to conduct environmental studies needed to be transported to the site. In this regard, he said, cooperation and cost-sharing with marine scientific research (MSR) groups was highly appreciated, noting that such cooperation also had the potential to increase the knowledge base of all parties. Mr Johnston informed participants that any research group that would like to cooperate would be invited to Nautilus Minerals Inc's seafloor mining project in Papua New Guinea.

With regard to the cost of compliance with environmental regulations for land-based projects, Mr. Johnston said that specific land-use conflicts and the required effort for the EIS determined the final cost. He said that significant costs also arose from solving conflicts with water quality management and from appropriate waste management.

To conclude his presentation, Mr. Johnston summarised the essential aspects for compliance with environmental regulations for seafloor mineral exploration as follows:

- Mobilisation is a major cost for any programme studying seafloor polymetallic sulphides.
- US$2 toUS$5 million per cruise is common. 3 to 4 cruises would be needed to complete a 12 month EIS resulting in costs of US$ 8 to US$20 million.
- Specialist equipment can be expensive.
- Land based exploration programmes have their environmental impact “graded” and accepted before the work starts, and allow “progressive rehabilitation” of the mine site.
- Programmes in the Area should follow a similar pattern so money and resources are used efficiently.
- Collaboration between marine scientific researchers and miners is vital.
- Cost of compliance is significantly reduced once the project is in production.

Mr. Johnston stated that the Authority had a vital role in managing these activities including the management of data and tenements. All environmental data and information should be made available to all parties to improve environmental compliance and monitoring. He further stressed that the expected impacts should be classified and agreed upon in the work programme prior to the commencement of activities. Mr. Johnston emphasised that the Authority should learn from the experiences of the first group of seafloor explorers and miners who are likely to conduct their activities within the territorial waters and/or the Exclusive Economic Zones of countries like Papua New Guinea, which use modified existing “land based” legislation for environmental permitting mining operations.

Summary of the discussions

With respect to the assessment of environmental impacts at hydrothermal vent systems, a participant asked if all kinds of impacts had been considered including physical impacts, noise, light and other disturbances. Mr. Johnston replied that related impact studies were at an early stage, but that it had been found that the biodiversity at the inactive sites was much less compared to the active sites, which would not be mined. He further stated that mining by its nature always had impacts which needed to be mitigated without placing too many constraints so that the operations could become impractical. More data needed to be collected to evaluate the impacts, he said.

Another participant wanted to know if environmental surveys of potential polymetallic sulphides mine sites suggested that due to the nature of the deposits, the environmental impact was less compared to activities related to polymetallic nodules and cobalt-rich crusts. Mr. Johnston said that to his understanding it was too early to draw comparisons. He noted however, that the size of the area that would ultimately be mined was much smaller in the case of polymetallic sulphides deposits. He added that the question also depended on the definition of environmental impacts and that more collaborative efforts were required to better understand in which ways, and to what extent disturbances would occur, for example, as a result of the expected plumes that Nautilus Minerals Inc. has modelled in the context of the activities around Papua New Guinea.

A participant referred to the 2 million tonnes figure of polymetallic sulphides deposits that could be extracted from an area of 200 square metres for one year and noted that due to the 3-dimensional nature of this type of deposit, the size of the mining area would be in a completely different range. Mr. Johnston agreed and noted that a major problem of polymetallic sulphides deposits was that no detailed test drilling had been done so far which would allow for properly estimating the resources.

It was noted by another participant that the size of the area should not be the only consideration, but that the density and diversity of the biological communities were important factors.

Another participant wanted to know whether from an industry point of view it would be a big constraint to require an environmental impact assessment from contractors as part of any application at the beginning of the activities. Mr. Johnston said that this would be a big hurdle for companies at the early stages following prospecting activities, and noted that there was no need to have a full environmental impact statement when contractors were engaged in low impact activities like geophysical surveys and limited sampling.

With regard to ecosystem modelling, another participant argued that due to the complexity of the ecosystems in the case of polymetallic sulphides deposits it would be impossible to quantitatively assess the environmental impact of deep sea mining. This would be especially true in the case of territorial areas with material coming from land and significant biological fluctuations from year to year. Mr. Johnston agreed that assessment of the environmental impact in ultimate detail would be impossible. However, he said that significant fluctuations in biological communities have not been observed in the areas where Nautilus Minerals Inc. has carried out preliminary investigations.

The Secretary-General reminded participants that the Authority had established environmental provisions in the Regulations for Polymetallic Nodules and similar provisions in the draft Regulations for Polymetallic Sulphides and Cobalt-Rich Crusts. According to these Regulations, the Secretary-General said contractors were required to develop baseline information at the beginning of exploration activities and to indicate what programme they have in place for environmental monitoring. He also said that in the annual reports of contractors they have to indicate the environmental monitoring activities they have undertaken. He noted that the requirements were less demanding during the exploration phase. He said that at the end of exploration phase and before applying for an exploitation contract, potential contractors are required to provide the Authority with an impact statement. The Secretary-General mentioned that the Legal and Technical Commission had issued guidelines regarding the collection of environmental data for polymetallic nodule deposits and had also identified the types of activities that were non-invasive or have no impacts. In this respect, he noted that the Authority was following a graded approach with activities classified in the manner mentioned by Mr. Johnston. The Secretary-General said that he expected further clarification in the light of experience that might be gained, and from workshops that brought the relevant scientists together. The Secretary-General also said that collaborative research projects have also been carried out on polymetallic nodules in the Clipperton-Clarion area with the data provided to the Authority, and added that the Authority makes this information available through publications and through its Central Data Repository. He added that environmental data were not proprietary and are to be made available to everyone.

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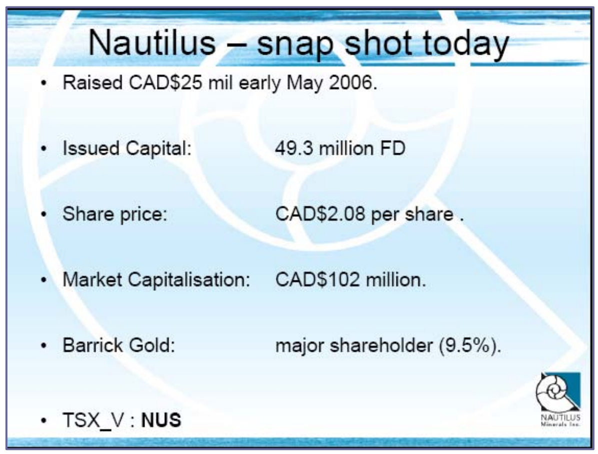
Chapter 12: A hypothetical polymetallic sulphides mine in the Area

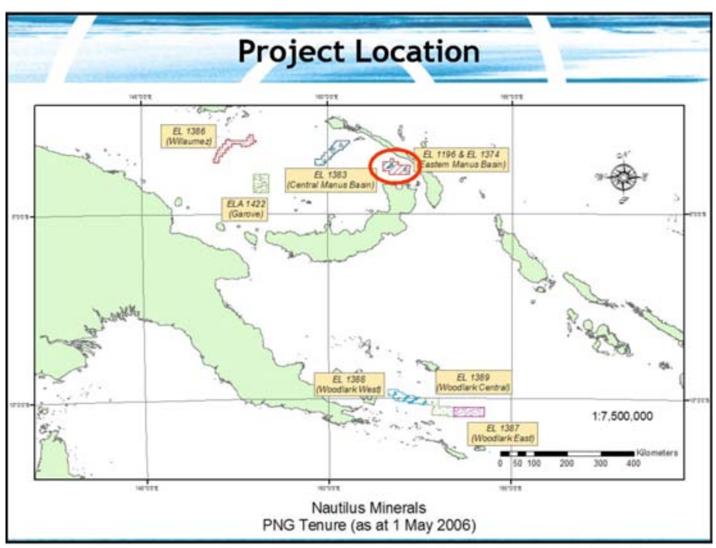
Mr. Mike Johnston, Vice President, Corporate Development, Nautilus Minerals, Australia

Summary of the presentation

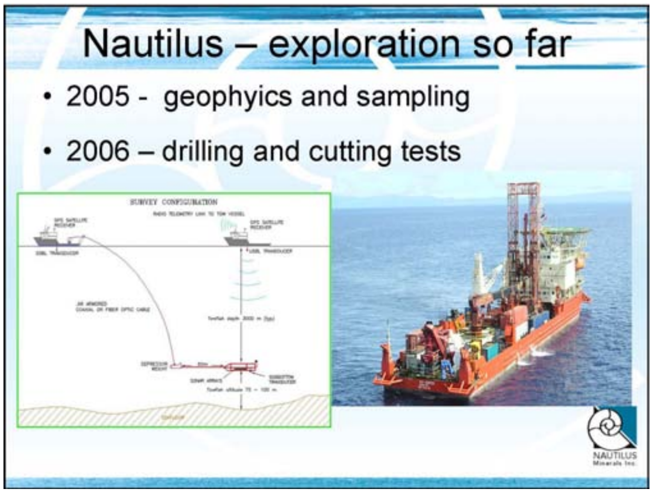
Mr. Johnston gave on overview of Nautilus Minerals Inc.'s seafloor exploration activities in Papua New Guinea and outlined key considerations for a hypothetical polymetallic sulphides mining operation in the Area. He disclosed that in May 2006, Nautilus Minerals Inc. raised an additional budget of CAD$25 million for the exploration for polymetallic sulphides deposits.



He said that the company's 17,500 square kilometres of exploration tenements were all located in the territorial waters of Papua New Guinea and that a lot of effort was required to explore the entire acreage.

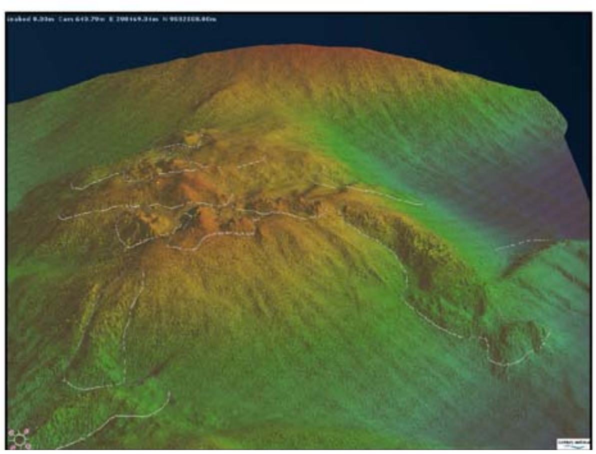


Mr Johnston said that most of the detailed work between New Ireland and New Britain[1] had been completed. He also said that in 2005 the company conducted geophysical surveys and sampling. He further disclosed that earlier in 2006 the company carried out test drilling.



Mr. Johnston said that the company had gained important experience with polymetallic sulphide deposits. This included the finding that common genetic models for deposit formation hold up well in practice. Furthermore, he said that the company found that high grade ores were present locally (grades of 6-10 per cent copper) and that these deposits could be mined with regular "off-the-shelf" mining technology, even though the topography could present some serious engineering challenges.

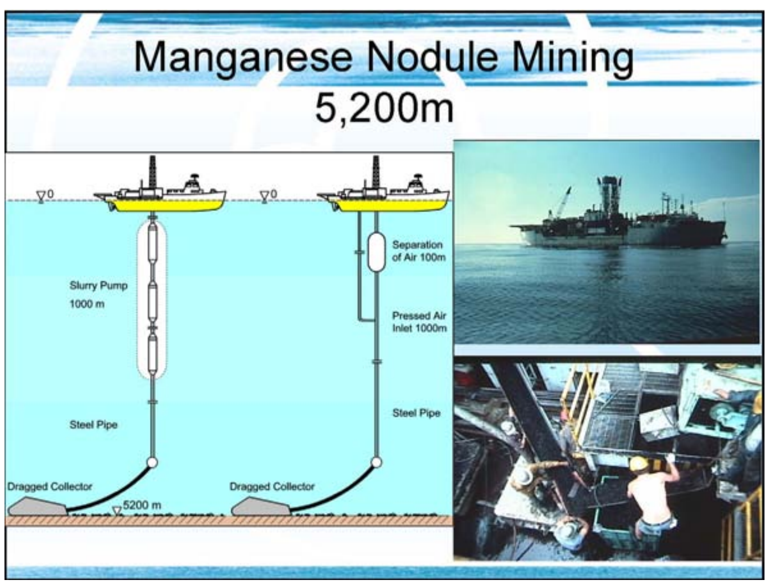
Mr. Johnston presented a 3D image showing the topography of Nautilus' primary exploration target area between about 1,500 and 2,000 meter water depths.



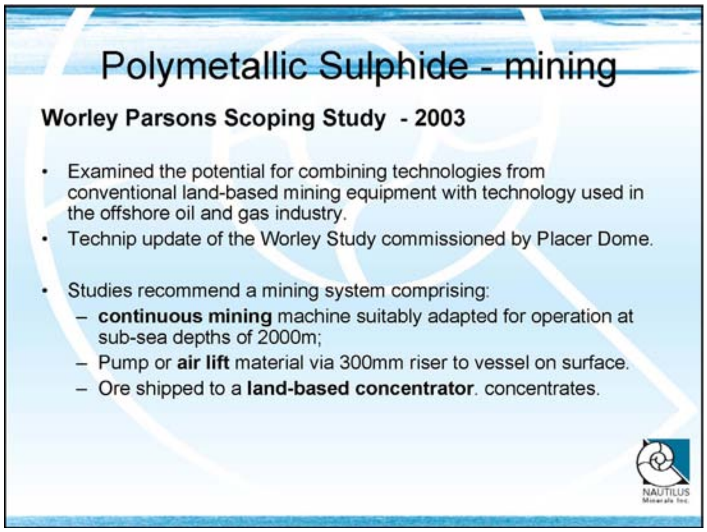
[1] Both islands are part of the Bismarck Archipelago and are separated by the Saint George's channel

The images showed that the terrain structures were relatively rugged. Mr. Johnston showed another image based on high resolution bathymetric data depicting chimneys 10-15 metres high at the hydrothermal vents.

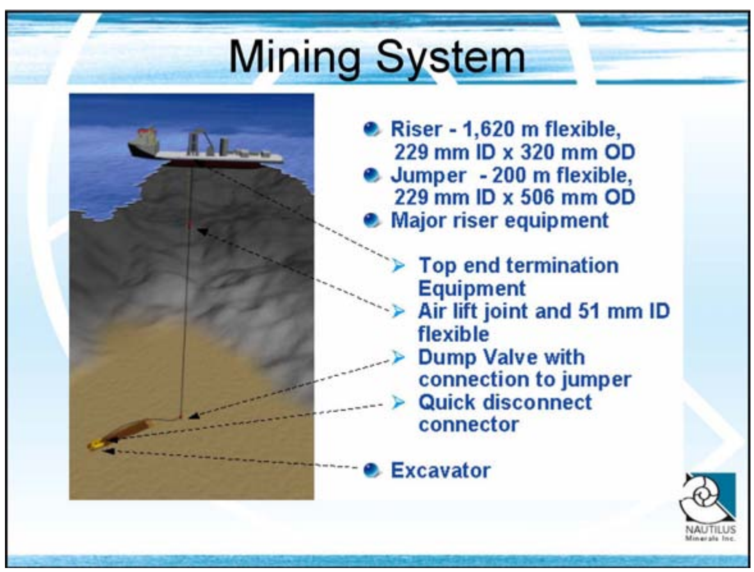
Mr. Johnston outlined the basic characteristics of the different mining technologies under consideration. He said that the lifting technology concepts designed for polymetallic nodules mining were still relevant.



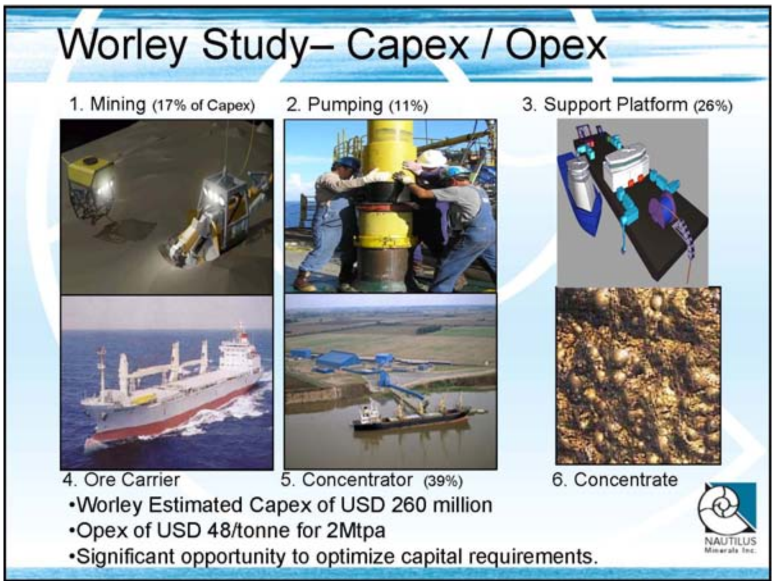
He pointed out that there were also other technologies available that would be suitable for polymetallic sulphides mining. He disclosed that a study in 2003 examined the potential for combining technologies from conventional land-based mining with technologies used in the offshore oil and gas industry.



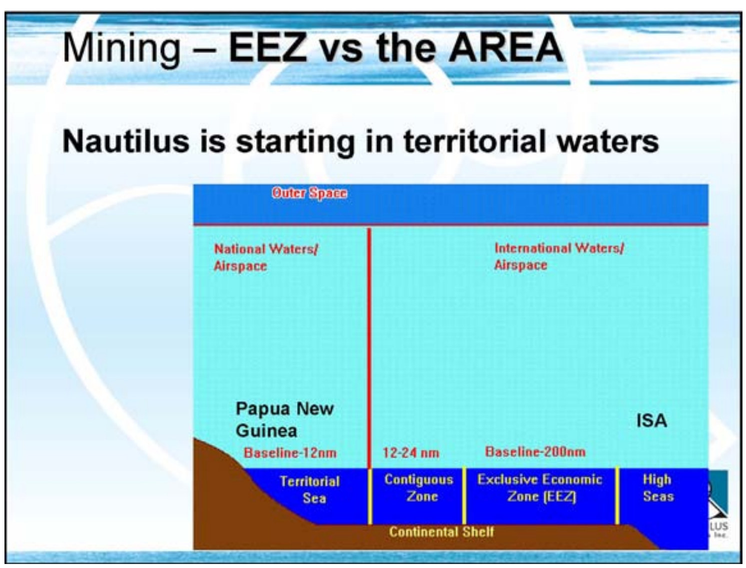
This and other studies recommend a mining system comprising a continuous mining machine suitably adapted for operation at sub-sea depths of 2000 metres and a pump or an air lift to transport the material via a 300 millimetre (mm) riser to the vessel on the surface. The ore would be shipped to a land-based concentrator.



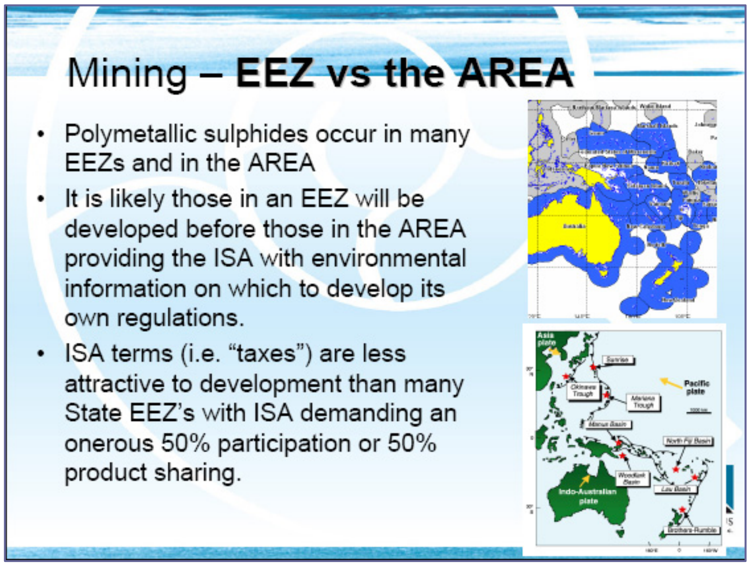
Mr. Johnston gave a breakdown of capital costs (CAPEX) estimated for the mining system components according to the 2003 study: 17 per cent of the cost was accounted for by the physical mining unit; 11 per cent for the pumping equipment; 26 per cent for the support platform and 39 per cent of capital cost was accounted for by the concentration plant on land. Total capital cost was estimated at US$ 260 million for a production of 2 million tonnes per year. Operating cost (OPEX) is estimated to be about USD$48 per tonne. Mr. Johnston noted that there was some opportunity to optimize capital e.g. by outsourcing ore processing.



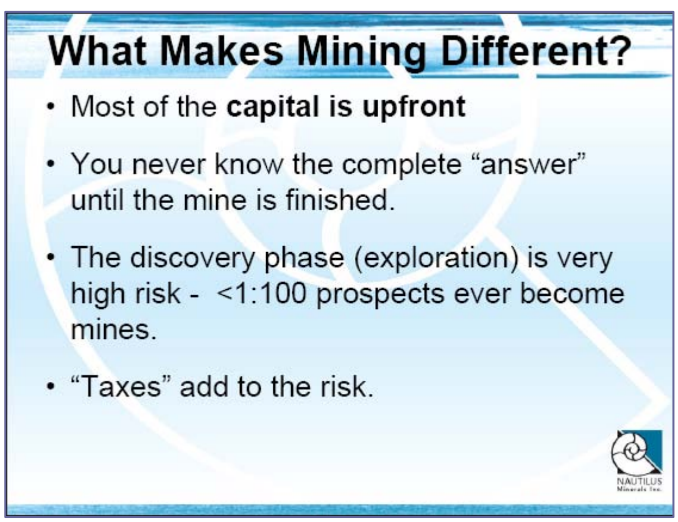
Mr Johnston said that polymetallic sulphides occurred in many Exclusive Economic Zones (EEZs) as well as in the Area. He said that Nautilus Minerals Inc. has started seabed exploration in the territorial waters of Papua New Guinea.



Mr. Johnston stated that with regard to polymetallic sulphides deposits it was likely that many other investors would initially develop resources in the EEZs and within territorial waters. He said that for investors the terms of the Authority might be less attractive than those of some states like Papua New Guinea or Australia.

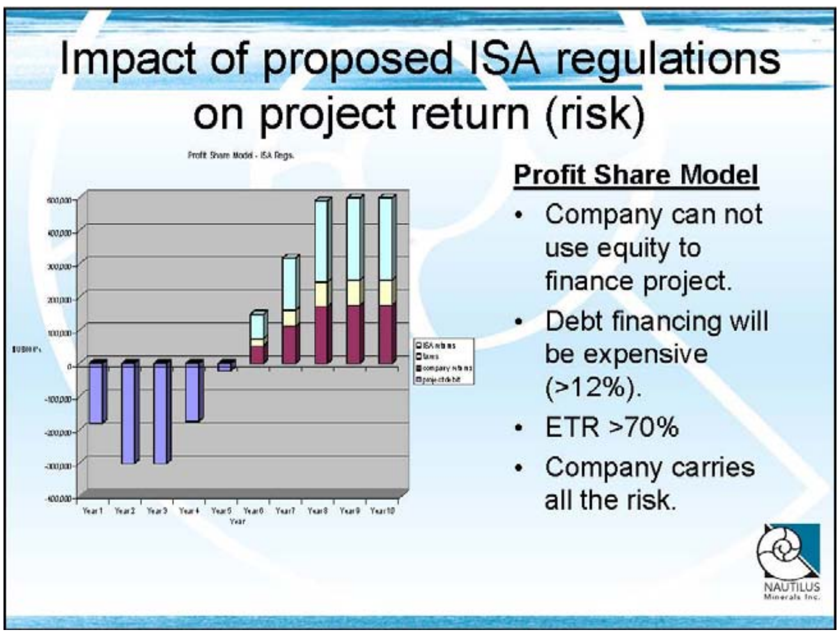


With regard to the economics of mining operations, Mr. Johnston said that mining was more risky than most other forms of investment since all capital had to be invested up front and profitability remained unknown for a long time. He said that the prospecting and exploration phases were associated with high economic risks, and also made the point that the specific tax regime in different countries could become another important risk factor for mining companies.



Mr. Johnston made some remarks on the benefits to mankind of seabed mineral resources and noted that one of the fundamental questions would be if these resources should be developed or kept as deposits of last resort. He said that the advantages of developing these resources were that mining would leave smaller footprints compared to land-based mining and that the metal grades in the deposits were relatively high.

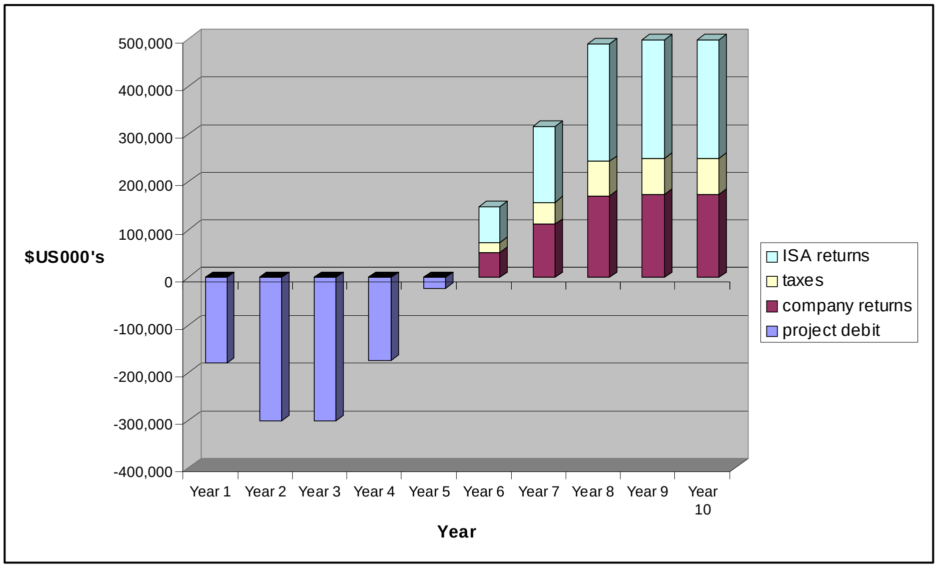
Mr. Johnston embarked on the topic of the economic impact of the draft Regulations. He made the point that in the case of a 50 per cent profit sharing arrangement with the Authority the company would be economically disadvantaged, since it would have to make all investments upfront, carry all the risk and would get revenues only after many years. He noted that the company cannot use the Authority's share to finance the project and that debt financing would be expensive.



Based on an assumed mining venture, Mr. Johnston modelled the economic impact of the production sharing option according to the draft Regulations. He used the same example of a 6 million tonne deposit (6 per cent copper grade and 6 grams of gold per tonne) to compare the impacts of the equity interest option.

With a chart, Mr. Johnston showed the impact on project return in the case of the production sharing option. The chart depicted the profit share of the Authority, the company's profit, taxes to be paid by the company and the project debt in the initial project phases. In his example, he used the Australian tax rate of 30 per cent.

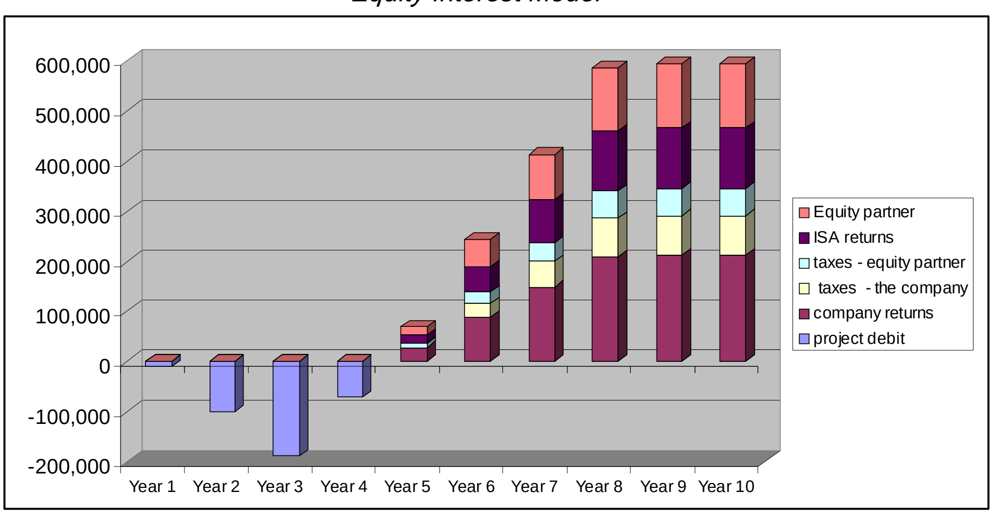
Production Sharing Model



He stressed that the company's profit was reduced by the applicable tax rate and further made the point that a 50 per cent profit share by the Authority needed to be financed through debt at an interest rate of at least 11-12 per cent. He said that dept financing costs would increase the risk and further reduce the company's internal rate of return up to the point where the project becomes uneconomical to the company's shareholders.

Mr. Johnston said that project risk would be less in the case of an equity interest model, which is one of the other proposals the Authority made with respect to participation, and presented a chart showing the returns and taxes for both partners as well as project debt in the initial stage.

Equity Interest Model



In his example of the equity interest split model, the Authority's share was 20 per cent. An additional share of 30 per cent was assumed to be sold to the equity market or to another company. Mr Johnston said that the equity partner would help to pay for the development cost and lower the cost to finance the project. He noted that consequently, the project debt in the initial period decreases significantly and the project becomes less risky and more attractive. He added that the return to the Authority would, however, only be about half of the amount compared to the production sharing case.

Concluding his presentation, Mr. Johnston said that he believed polymetallic sulphides mining would have limited environmental impact. He said that the technology to develop these resources was readily available, but noted that the economic risks were high. He said that the commercial terms of development needed to recognize this, and gave the example of Papua New Guinea where he said the government had the right to apply a tax rate of 30 per cent on any mining project, but had not done so since 1996. As a result of these terms, Mr. Johnston said that mining companies have become very active in Papua New Guinea, with some of them interested in exploration of the seabed. Mr. Johnston emphasised that regulations for seabed mining in the Area need to consider competitiveness with land-based operations.

Summary of the discussions

A member of the Legal and Technical Commission said that according to the principle of production sharing as defined in the draft Regulations only the profit was to be split on a 50:50 basis, and this, only after recovery of the investor's costs.

Mr. Johnston argued however, that the company would get taxed additionally, depending on the applicable tax structure.

The Secretary-General clarified the scheme of equity participation and explained that the Authority would participate according to the following system: It would have a minimum of 20 per cent equity participation in the project. The first 10 per cent accrued at the time of signing without payment. The next 10 per cent would accrue after recovery of the development cost. The Authority then has the option to buy into the project and to obtain up to 50 per cent participation in a joint venture. The Secretary-General noted that the equity share of 20 per cent which the Authority would obtain as a minimum reflected the philosophy that the seabed is considered the common heritage of mankind. He also said that as an alternative to participation by the Authority through equity interest and production sharing, a contractor may provide a second deposit of equal estimated commercial value in its application for an exploration license; a principle which has been applied in the case of polymetallic nodules exploration licenses.

Mr. Johnston said that the latter option would work for manganese nodules, but it would not be possible to identify two deposits of equal estimated commercial value in the case of polymetallic sulphides. With respect to the two models of the economic impacts which he had presented, he said that it was his intention to model the two extremes according to the draft Regulations, assuming the minimum of 20 per cent equity participation by the Authority in the one case and a 50 per cent profit share in the other case. He further noted that financing options were critical to determine whether the project would have a sufficient rate of return for a commercial operation, and he recommended that the draft Regulations be further analysed by experts with respect to the impacts on project financing, taxation and debt management.

Another participant gave some details on the considerations during the development stages of the financial terms for the different options of participation by the Authority.

With regard to the minimum expected internal rate of return for an investor to start an operation on the deep seabed, Mr. Johnston stated that in his opinion a rate of 10 per cent would not be enough and should be closer to 20 per cent.

The Secretary-General noted that the schemes for participation were invented in accordance with the philosophy of the common heritage as alternatives to the parallel system of two equal areas. He said that the idea of a minimum equity participation had been developed because it was understood that it would be difficult to find two sites of equal commercial value in the case of the deposits under considerations. He said the parallel system had been retained as an option as it reflected the original implementation of the common heritage philosophy. He further noted that for the definition of the financial terms it was considered that seabed mining should not be overly advantaged as compared to land-based production. The Secretary-General also mentioned that originally a taxation scheme was selected as the system of participation by the Authority. He said that this system was discarded because it was felt to be too intrusive, since the Authority would have to examine the concerned company's books.

Mr. Johnston said that one of the key characteristics of potential seabed mining was a relatively small size of the undertaking resulting in massive impacts on the revenue in case of wrong estimates e.g. of the metal grade or the metal prices. He therefore suggested considering a royalty system as a system of participation by the Authority, i.e. a system similar to the original taxation system as mentioned by the Secretary-General. The system, Mr. Johnston suggested, should consist of two schemes: a base level of taxation and royalty which would reflect the fact that resources are being extracted within the Area. An additional component of the system should provide for flexibility and take possible metal price fluctuation and changes in profitability into account. He noted that such a system would support competitiveness of the mining company and yet achieve the goals of the common heritage principle.

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Part III

SUPPLY AND DEMAND FOR THE METALS OF COMMERCIAL INTEREST IN POLYMETALLIC SULPHIDES AND COBALT-RICH FERROMANGANESE CRUSTS DEPOSITS

Chapter 13: Review of the Nickel, Cobalt and Manganese Markets

Ms. Caitlyn L. Antrim, Director, Centre for Leadership in Global Diplomacy, USA

Summary of the presentation

In the first of three presentations, Ms. Antrim gave an overview of the market for nickel, cobalt and manganese. She said that a major objective of her presentations was to outline issues with demand projections and to reveal the uncertainties potential investors have to deal with in decision making.

Ms. Antrim told participants that studies of the nickel, cobalt, copper and manganese markets as part of the polymetallic nodules development programme had been carried out since the mid-1960s and that she first got involved in such studies in 1973. She noted that the metal demand was subject to unpredictable factors; both transient and transformational factors e.g. a transient two-year recession or technological developments that completely changed the future trends.

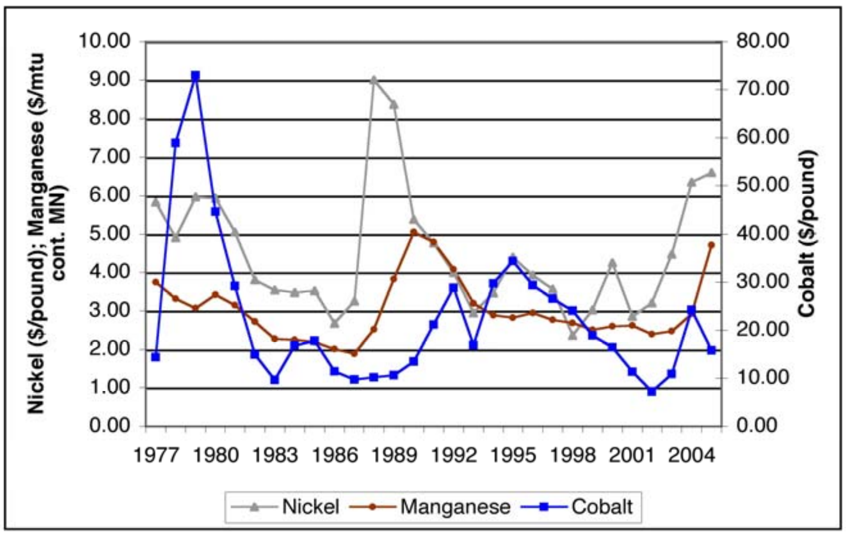
Using four examples of work undertaken in the mid-1970s on supply and demand for metals in the global economy, Ms. Antrim demonstrated the difficulties of projecting demand. The four studies comprised two conducted by the U.S. Geological Survey (at the time "the US Bureau of Mines'), the 'Wassily Leontief Model', a predictive economic model which was used to derive perspectives for the metal markets, and a model by Wilfred Malenbaum, who introduced the concept of "intensity abuse". Ms. Antrim said that "intensity abuse" meant that countries with a low GDP per capita would have a lower consumption of metals, but as they became more developed, would consume these metals until their economies began to diversify and no longer focus on the construction and the manufacturing sector, but on the services and information technology sector. Reaching this target, Ms Antrim said that their demand for metals would decrease.

Ms. Antrim compared the estimates of the four projections for the demand for nickel, copper, cobalt and manganese in 2000.

	Nickel (t)	Copper (t)	Cobalt (t)	Manganese (t)
USGS-Medium	1705	19,500	79.7	22,100
USGS-Low	1290	14,700	57.8	20,000
Leontief	2833	31,300		
Malenbaum	1446	18,523	63.3	18,503
Actual	1290	13,300	37.9	6,960

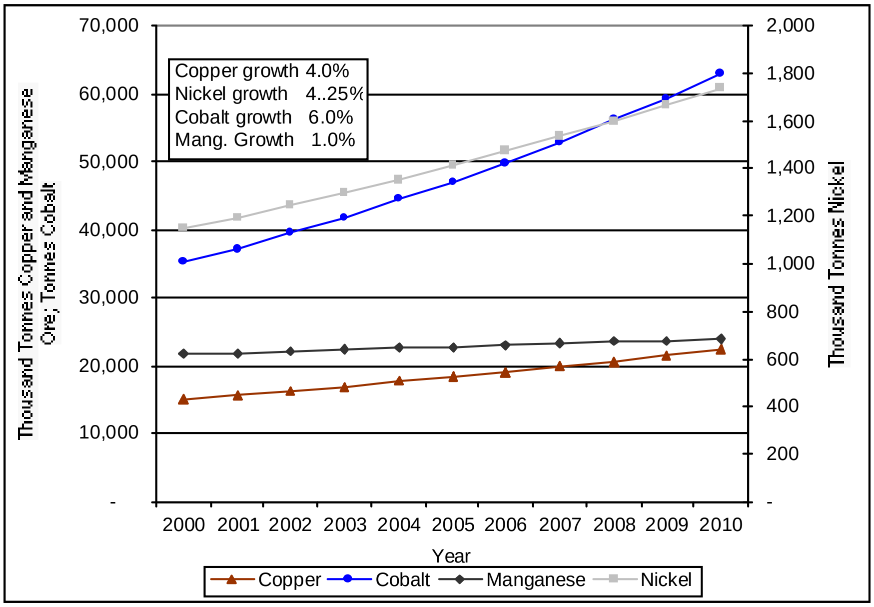
Ms. Antrim said that the USGS made a low and a medium estimate, and that all four studies were confuted in 1975. She said that in general, all four projections were too high although she observed that the USGS estimate came close for nickel and copper. She said that the Leontief general economic model did not capture the realities of the metal market, in particular the substitution of metals in production and the evolution of technology and demand. She also said that estimates of the demand for manganese were exaggerated in all four projections explaining that one of the trace elements that was present during the steel making process and was generally undesirable was sulphur. She said that manganese was used in the production of steel to treat the sulphur. She pointed out that in the 1980s there were significant changes in steel-making technology that reduced the amount of sulphur in steel. As a result less manganese was needed. Based on this example, Ms. Antrim pointed out that such developments were not foreseen making it difficult to plan long term projections. She noted that since mining was such a long-term venture that included years of exploration and construction, such projections were indispensable for ventures expected to last for over 20 years.

Using a graph, Ms. Antrim illustrated price movements for nickel, cobalt and manganese from 1977 to 2005:



She informed participants that prices in the graph were in 2005 US Dollars per pound, and that the indicated values reflected the current US Dollar value. Referring to cobalt, Ms. Antrim described the reasons for the fluctuations in price as a consequence of political disruptions in the former Zaire, now the Democratic Republic of Congo, which was the primary world producer of cobalt. Ms. Antrim said that cobalt was produced as a by-product of either copper or nickel mining, except in the Democratic Republic of Congo, where cobalt production was more flexible, because mining operations could select from different deposits with relatively high variations in the cobalt grade. She noted that supply problems lead to increased efforts to find substitutes for cobalt in industrial applications, and said that permanent substitutes were found keeping cobalt prices at a low level. She also said that the price movements of cobalt reflected other conditions such as periods of economic recession.

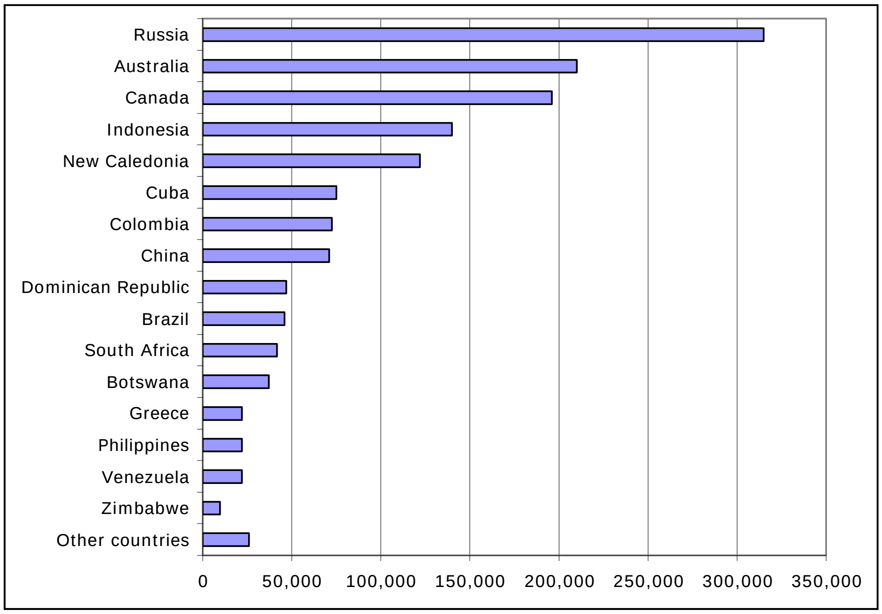
Turning her attention to current demand projections based on recent trends, Ms Antrim showed a demand graph for copper, cobalt, nickel and manganese for the period 2000 to 2010:



Ms. Antrim said that cobalt prices were rising quickly, in part because of the increased production of lithium-ion batteries, which use cobalt in their cathode. She said that nickel prices were also rising significantly; and that manganese prices were steady because it was tied to the steel industry which did not have much variation. Ms. Antrim summarised the current trends by pointing out that all prices were trending up even though ten years ago they were trending down.

Ms. Antrim said that nickel had always been considered the metal of primary interest in polymetallic nodules, whereas cobalt was in the center of interest with regard to ferromanganese crusts. She said that nickel was one of the principal constituents in most stainless steels and that it was a constituent in some steel alloys that were used for plating, and that it was also used in super alloys (high-temperature, high-strength alloys used in turbine blades for jet aircrafts). She also said that a small but growing use for nickel was in nickel metal hydride batteries. She informed participants that in 2005, world production of nickel was 1.5 million metric tonnes. She also informed participants that global reserves of nickel were estimated at 62 million metric tonnes, and noted that this figure referred to ore quantities that had been explored in sufficient detail to guarantee that the deposits could be mined at a profit at the present time.

With regard to world nickel producers, Ms. Antrim used a graph to depict production in 2005 in thousands of tonnes:

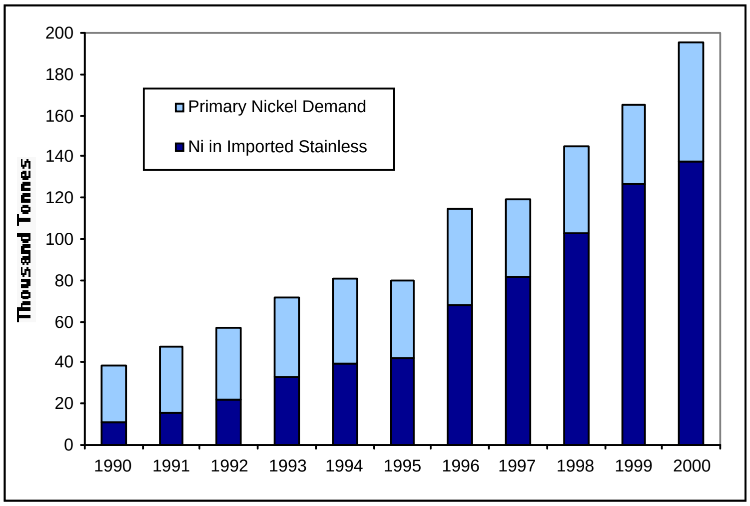


She said that Russia was the largest single nickel producer with Australia, the second largest producer, mainly producing from nickel laterites which have a similar chemistry to polymetallic nodules and cobalt-rich crusts. Ms. Antrium said that processing technology for laterite deposits could be adapted and used to process crusts and nodules from the seabed. Ms. Antrim informed participants that Canada has always been a major producer of nickel, with production from sulphides and oxides deposits. She said that the technologies for processing these two types of nickel deposits could also be applicable to polymetallic sulphides deposits as well as polymetallic nodules and cobalt-rich crusts on the seabed. Ms. Antrim said that Indonesia had recently developed new laterite deposits, and that New Caledonia, a French Territory had been a very dependable low cost producer of nickel oxide deposits. She added that Cuba too, had a productive nickel deposit that produced cobalt as a by-product. She described the other producers as small producers.

Ms. Antrim noted that Russia's nickel production was mainly produced from a platinum mine that happened to produce nickel as a by-product. She noted that at this mine, all investment and operating costs were covered by the production of the platinum group metals that the deposits contained. She informed participants that after the Soviet Union broke into independent countries, the Russian nickel industry had the opportunity to go into the export market with production of more than 300,000 tonnes per year of nickel from a source that other producers could not compete with. As a result, she said that nickel prices were kept at low levels and strongly discouraged other producers from investing in nickel mining. Ms. Antrim further explained that it had taken many years for this sudden and unforeseeable supply to the world market to be integrated into the regular market to a point where investors now look at developing deposits in other regions such as Canada or Indonesia.

Ms. Antrim said that nickel demand and the demand for stainless steel were closely related and developed proportionally to each other. She said that one reason for increasing nickel demand was the Chinese market.

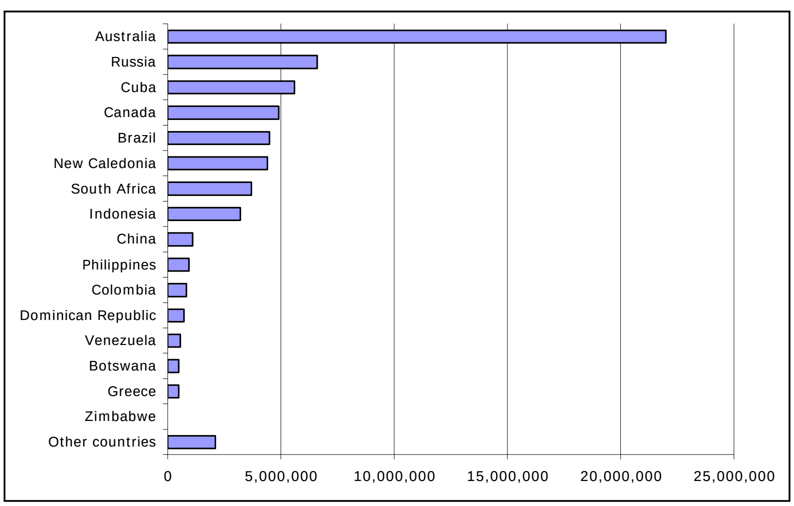
Using the figure below, Ms. Antrim illustrated her point.



Nickel Demand in China

According to Ms. Antrim, between 1990 and 2000, imports of stainless steel grew at a rate of 20-25 percent per year and the proportion of stainless steel compared to the primary nickel demand increased tremendously. She informed participants that the demand for stainless steel was a mark of economic development because stainless steel was needed for the development of chemical industries, in food industries, in construction as well as in transportation and other industries.

Using the figure below, Ms. Antrim gave on overview of world nickel reserves:

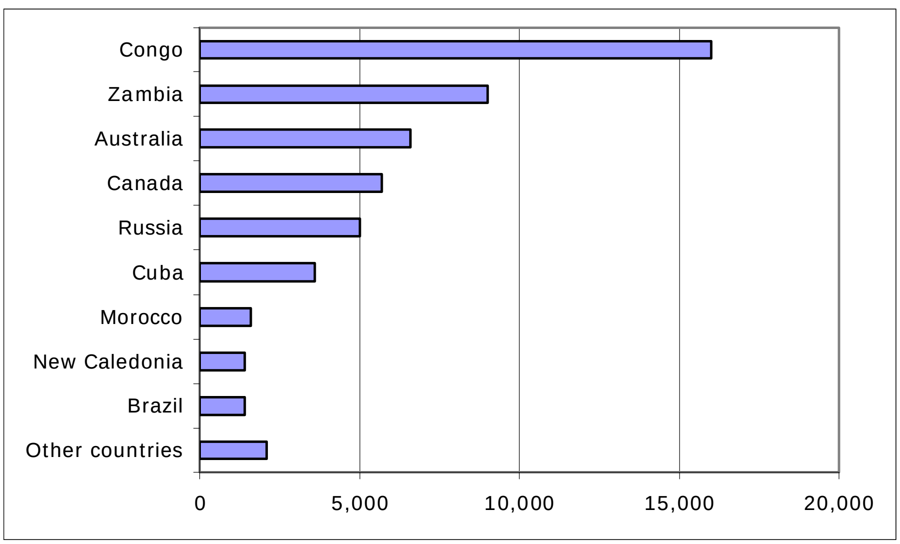


World Nickel Reserves (metric tonnes)

She pointed out that Australia had tremendous reserves of nickel and would always be a major producer. She also said that Russia, Cuba, Canada, Brazil, New Caledonia and South Africa had large reserves. She informed participants that smaller reserves occurred in tropical countries where nickel was mainly produced from laterite ores. Ms. Antrim noted that in the 1980s mining laterite ores were considered as competition for deep sea mining of polymetallic nodules.

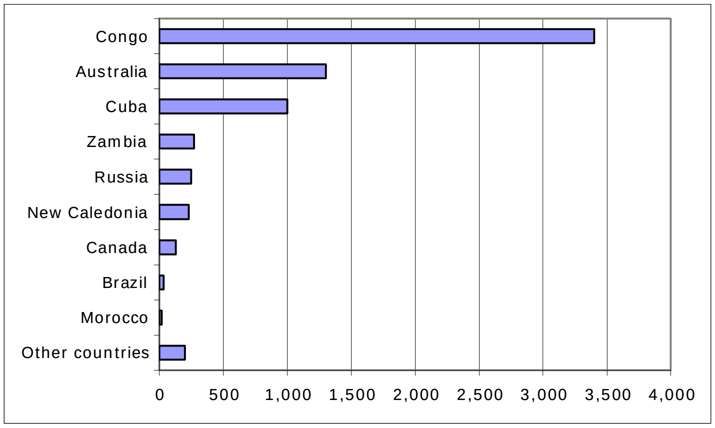
Ms. Antrim outlined the relevant characteristics of cobalt, the metal with the most attention in the framework of the workshop and which made cobalt-rich crusts attractive from an economic point of view. With regard to its uses, she said that cobalt was an essential metal for advanced economies and was mainly used for superalloys, carbide tools, batteries, tool bits, pigments, as a chemical catalyst and for surface treatments for hardening the surface of materials. In some cases, Ms. Antrim said that nickel could substitute for cobalt in alloys, but did not provide as high a performance. On land, Ms. Antrim informed participants that cobalt was generally produced as a by-product of nickel or copper production, except in the case of the Democratic Republic of Congo where it is considered as primary production. She said that world production in 2005 was 52,400 metric tonnes, and that global reserves were in the range of 7 million tonnes.

With the figure below, Ms. Antrim pointed out that the Democratic Republic of Congo and Zambia were the largest cobalt producers. She said that in both countries cobalt was produced from copper deposits. Ms. Antrim said that in Australia, cobalt was mainly produced from laterite deposits.



Cobalt Production 2005 (metric tonnes)

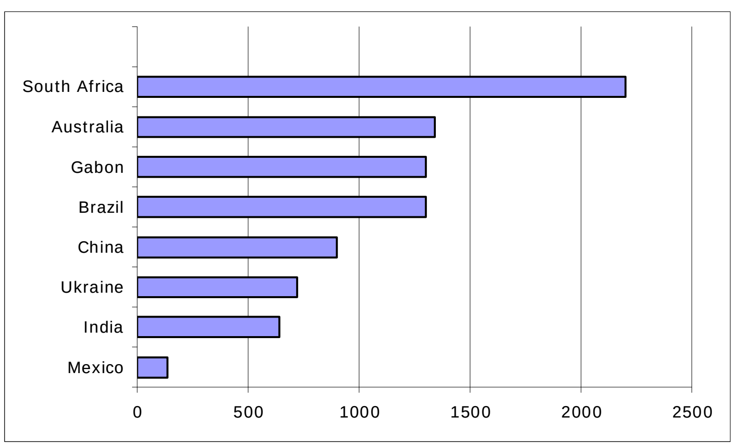
Using the figure below, Ms. Antrim also said that the Democratic Republic of the Congo and Australia had the highest reserves:



Cobalt Reserves (thousands of tonnes)

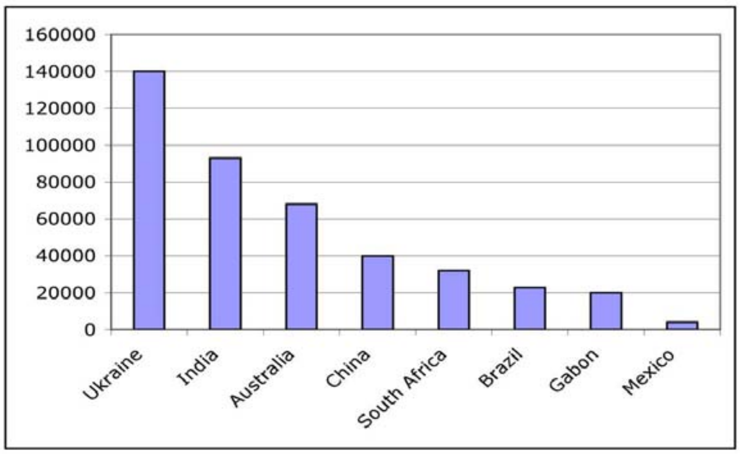
With regard to the manganese market, Ms. Antrim said that the major use of this metal was in steel production, mainly for the 200 series stainless steel, which uses manganese instead of nickel. She said that another important use, which might become more important in future, was in batteries, including conventional alkaline batteries as well as advanced lithium-ion batteries. Ms. Antrim noted that the market for advanced batteries was difficult to predict; pointing out that manganese lithium-ion batteries do not hold as much power as cobalt-based lithium-ion batteries, but were cheaper to manufacture. She said that global production of manganese was about 10 million tonnes in 2005; with reserves in 2005 of about 430 million tonnes.

Ms. Antrim said that the largest producers of manganese were South Africa, Australia, Gabon and Brazil. She said that the former USSR used to be the largest producer; but that those deposits were in the Ukraine, which had the largest reserves. Ms. Antrim noted that Russian investors have plans to produce manganese from polymetallic nodules in the Gulf of Finland



2005 Manganese Production (thousands of tonnes)

Ms. Antrim stated that transformational changes like the use of manganese in the steel industry could drastically affect previous metal demand projections. She outlined how future automobile design could change the current demand for certain metals. She said that rising fuel costs and environmental issues were promoting innovations in automobile design. In this regard, she said that in Europe there was a heavy use of advanced diesel engines and that in the United States the hybrid electric vehicles have received a good market response. She gave the example of a Japanese hybrid vehicle which used a nickel metal hydride battery with about 12 kilograms of nickel in each car. According to Ms. Antrim, hybrid car sales in the United States have risen from 4,000 to 17,200 between January 2004 and June 2006. Furthermore, she said that there have been discussions to increase the battery power of regular cars by moving from a 12 Volt battery to a 36 Volt power system.



2005 Manganese Reserves (thousands of tonnes)

Using the table below, Ms. Antrim illustrated the metal quantities required for the three types of batteries in hybrid vehicles:

Metal/ Battery Type	Battery Weight, 3 kwh battery (Kg)	Metal Content 3 kwh battery (Kg)
Nickel/ NiMH	50	12
Cobalt/ Lithium Ion	22.65	4.08
Lead/Lead Acid	85.71	60

Ms. Antrim noted that the implications of the battery choice could significantly affect metal demand. In this regard, she said that given a world market of about 57 million cars per year, 10 per cent market penetration by hybrid vehicles could require 66,000 tonnes of nickel or 16,500 tonnes of cobalt (4.5 per cent or 31 per cent of current world production respectively).

Ms. Antrim listed other major factors that may affect the nickel, cobalt and manganese supply as being:

- The stability of cobalt exports from the Democratic Republic of Congo
- Export versus increasing domestic consumption in Russia
- Development and expansion of major nickel deposits in Canada and Indonesia, and
- Improved technologies for the production from laterite deposits e.g. in Australia

With regard to the demand side, Ms. Antrim reiterated the major factors affecting the nickel, cobalt and manganese markets as:

- Economic growth in China and other developing countries
- The use of 200 series stainless manganese-based steel in place of nickel-based stainless steels, and
- The adoption of hybrid and electric automobiles with high-capacity batteries

Considering these factors, Ms. Antrim turned her attention to the implications for the prospects of production from the seabed. She informed participants that land-based reserves of cobalt, nickel and manganese were sufficient for a long time, and said that as a result, metals from the seabed must compete for market share. She said that economic growth in China, Russia, India and Brazil, would increase the need for new sources of nickel and cobalt. She said that it would also increase the need for manganese, although not as strikingly. Ms. Antrim stated that by-product relationships were an advantage for seabed minerals, since different metals could be produced at the same time from polymetallic nodules and cobalt-rich ferromanganese crusts. Ms. Antrim suggested that long-term contracts between mining companies and consumers of specialty products from the seabed (such as electrolytic manganese, nickel and cobalt for batteries) could reduce the risk and improve the economic outlook.

Ms. Antrim concluded her remarks by saying that metals would definitely grow in consumption, but that many uncertainties still existed with regard to the extent of growth, the demand for individual metals and the timeline for these developments.

Summary of the discussion

A participant suggested that more attention needed to be paid to advances in land-based mining technology, especially advances in high pressure acid leach technology, and stated that many new land-based nickel and cobalt mining projects were underway using advanced technologies e.g. New Caledonia, Australia and Brazil.

Ms. Antrim replied that according to former estimates in the case of polymetallic nodules, about 80 per cent of the cost of the operation would occur in the processing plant and that seabed mining would benefit by making use of the advances in land-based technologies. She said that seabed mining could become more competitive by using technologies that were being tested, developed and researched for non-seabed applications.

Another participant noted that there was a lack of supply of tellurium which was an inhibitor to developing technologies for solar cells with greater capacity and added that ferromanganese crusts were the most enriched deposits of tellurium.

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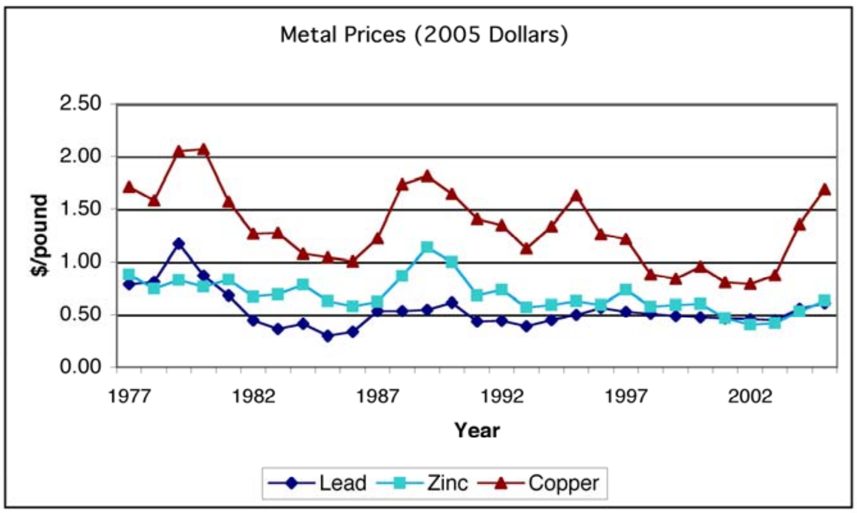
Chapter 14: Review of the Copper, Lead and Zinc Markets

Ms. Caitlyn L. Antrim, Director, Center for Leadership in Global Diplomacy, USA

Summary of the presentation

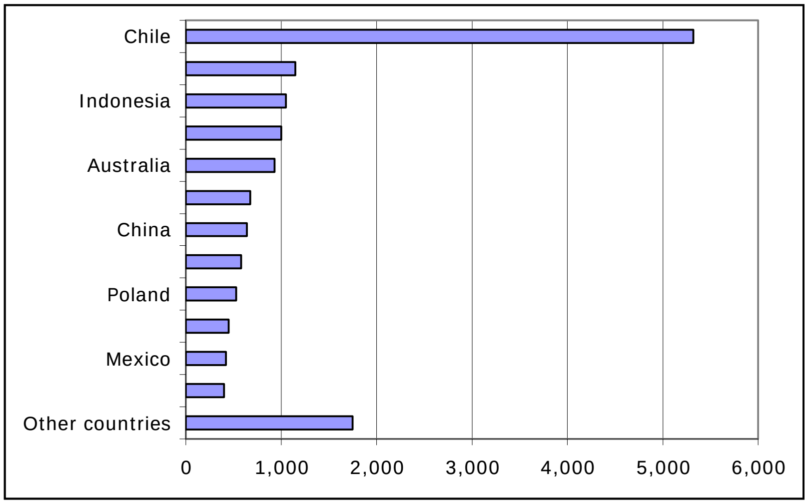
Ms. Antrim said that while nickel, cobalt and manganese would be recovered from polymetallic nodules and cobalt-rich crusts, copper, lead and zinc which were the metals of this presentation were the major metals of interest in polymetallic sulphides deposits. She said that copper, lead and zinc were basic metals that were of importance in the entire industrialisation path of every country in the world.

Using the graph below, Ms. Antrim showed the metal price history of these metals during 1977 and 2002.



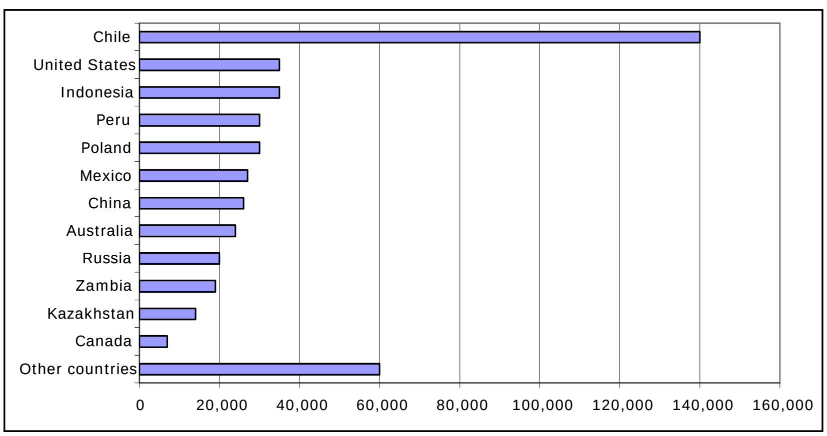
She informed participants that the prices shown in the graph were in 2005 US Dollars, so that the indicated values reflected current dollar values. She said that for all three metals, there had been a gradual decline in prices. She said that copper prices, had been about $1.50/lb (1978), increased to $2/lb (1980) and then decreased to about $1.80/lb (2005). According to Ms. Antrim, the copper price increased during periods of shortage or growth in the world economy when growth overtook available production capacities. For all three metals, Ms. Antrim said that a general increase in growth occurred during the mid to late 1980s, followed by a recession in the 1990s. She said that these events resulted in slightly depressed metal prices. Ms. Antrim stated that zinc and lead prices were very stable. For copper, she said that improvements in technology made it possible to produce copper from lower grade ores and at more competitive prices.

Ms. Antrim said that the main uses of copper were electrical, for roofing, plumbing and in different alloys. She said that copper was a heavily-used metal with annual global production of 14.9 billion tonnes (2005). Through the chart shown below, she presented salient statistics on production. Ms. Antrim informed participants that the USA used to be the largest producer of copper, but that Chile was now by far, the largest producer.



Copper Production 2005 (thousands of tonnes)

She said that the role of Chile as the largest producer was matched by Chile's reserves, and with the figure below, provided data on global reserves of copper. She also said that world reserves of copper were estimated at 470 billion tonnes (2005).

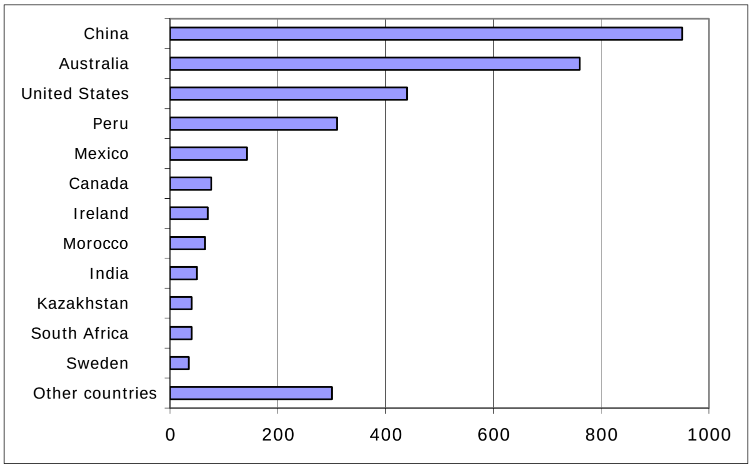


Copper Reserves 2005 (thousands of tonnes)

Ms. Antrim noted that United States, Japan and China had different trends in consumption. In that regard, she said that while consumption was decreasing in the USA and Japan, the use of copper in China would continue to increase.

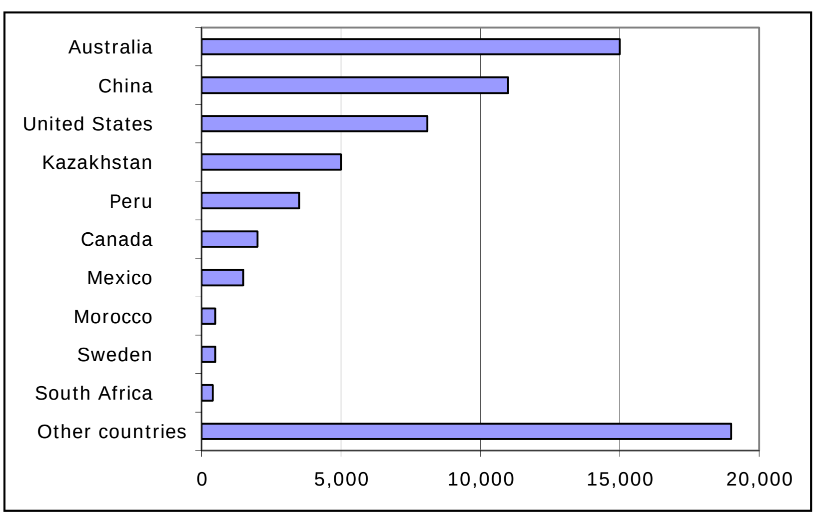
On the topic of the world lead market, Ms. Antrim informed participants that the major uses of lead were in lead acid batteries in vehicles (about 75 per cent of the total lead consumption), gas additives, pigments and compounds as well as some alloys and ammunition. She noted that there was a large secondary market for recycling lead in batteries.

She said that global lead production in 2005 was 3,286 thousand tonnes and that lead reserves were 67 million tonnes in 2005. She said that the leading lead producers in 2005 were China, Australia, USA, Peru, Mexico and Canada. Ms. Antrim provided salient statistics on global lead production as follows:



Lead Production 2005 (thousands of tonnes)

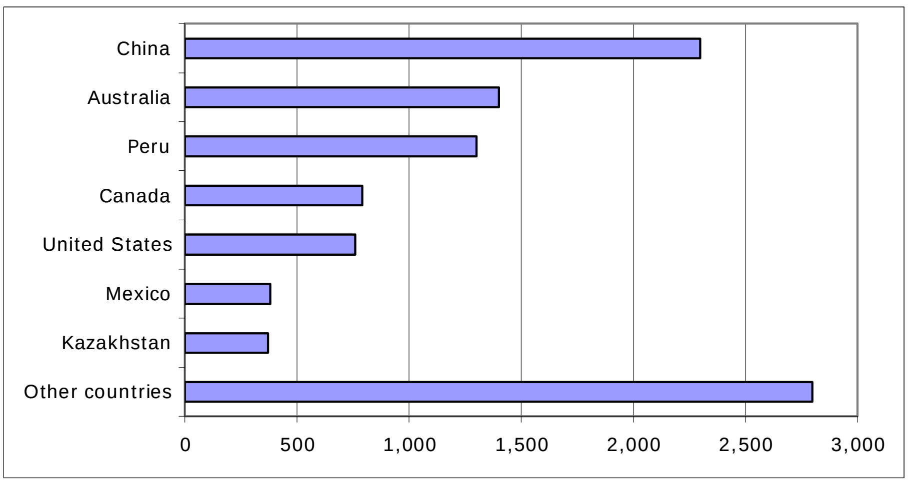
Ms. Antrim also provided relevant statistics on global lead reserves. She said that lead reserves were globally distributed, with major deposits in Australia, China and the USA.



Lead Reserves 2005 (thousands of tonnes)

With regard to zinc, Ms. Antrim informed participants that this metal was mainly used for dye cast components, galvanized steel, brass, alloys and chemical compounds. She said that world production of zinc in 2005 was 10 million tonnes with estimated reserves of 220 million tonnes. She noted that zinc was often produced in conjunction with lead or copper.

Ms. Antrim also provided salient statistics on global production of zinc in the figure below. She said that the largest producers in descending order were China, Australia, Peru and Canada, and added that the United States still remained a major player for most base metals.



Zinc Production 2005 (thousands of tonnes)

Ms. Antrim told participants that between 1997 and 2001 zinc production fell in Europe, but remained at the same level in the Americas and Africa, and increased in Asia and Oceania.

Turning to factors affecting the demand for copper, lead and zinc, Ms. Antrim stated that these were metals that countries in an early stage of industrial development heavily consume, so that demand strongly depended on the growth and the transformation of economies in developing countries. She informed participants that generally these metals were by-products, so mining operations mostly considered several of the base metals at the same time as gold and silver to be mined as by-products. As a consequence, she said, when defining their objectives, mining companies need to have a sophisticated understanding of how the metal markets work and how the metals interplay with each other.

Ms. Antrim repeated that there was potential for a major redesign of automobiles in terms of moving from 12 volts to 36 volts power systems and noted that this could cause severe disarray in the lead industry because of the use of nickel metal hydride or lithium ion batteries instead of lead acid batteries. She said that this would be another example of significant transformational changes in the metal markets that were difficult to predict.

Summary of the discussions

A participant stressed that competitiveness was essential for starting any mining venture on the seabed. Ms. Antrim agreed and said that investors would be more confident if metal prices would continuously rise over a longer period. She also noted that precious metals as by-products could be essential for seabed deposits to be considered potential mining operations.

Another participant asked how recycling of metals was taken into consideration for demand projections and noted that in Japan recycling obligations came into force for electric appliances as well as for automobiles. Ms. Antrim replied that recycling mechanisms were very efficient for lead; unlike galvanized metals which were much harder to recycle. Where the metal is able to be separated, recycling would become more and more important. She said that batteries could always be recycled no matter what metals were used in their manufacture.

It was noted by a participant that there were a number of undeveloped copper deposits with economic potential in Chile and in different parts of Asia. This participant further noted that these deposits would require significant investments, since the grade of the ore was generally lower compared to the ones that were currently in production. Consequently, they could only be developed if prices increased significantly. This participant further noted that capital costs for developing these deposits had drastically increased for all base metals.

Another participant raised the point that it was expected that the worldwide number of motor vehicles would double in the next 20 years or so because of the increased demand in China, India and other countries, and wanted to know what the impact could be in terms of demand and use for copper and other metals.

A participant stated that he was very concerned about the copper supply in the future and picked up on the point of rising consumption in the automobile industry. In this regard, the participant said that in Russia, China and India, huge amounts of automobiles would be required. Considering, that 10 kg-12 kg of copper was usually used in each car, and in the case of the hybrid-type cars, about double that amount; a significant increase in demand for copper was to be expected.

A participant asked how progress in processing technologies, e.g. in leaching technology or biological technology, resulting in lower cut-off grades, was taken into account in supply projections.

Ms. Antrim replied that she expected the trend of using lower grades due to improved technologies to continue and that it was debatable whether the ratio of declining grade and increase in volume would offset each other or result in a higher production. She noted that mining operations could also be restricted by political measures to limit areas for surface mining

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Chapter 15: Review of the Silver and Gold Markets

Ms. Caitlyn L. Antrim, Director, Center for Leadership in Global Diplomacy, USA

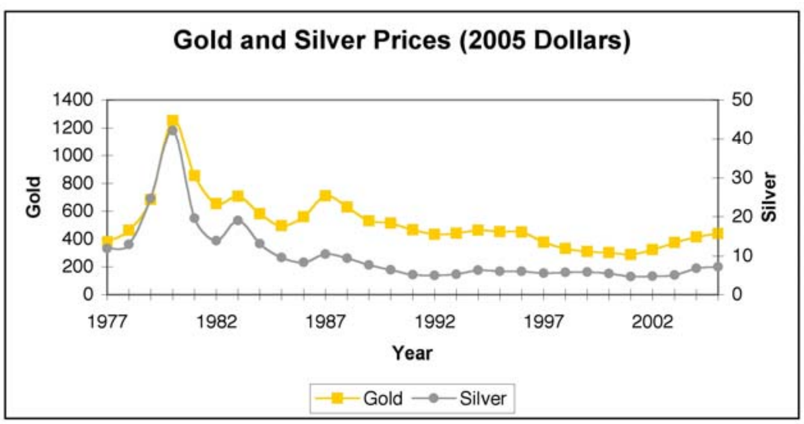
Summary of the presentation

In her final presentation, Ms. Antrim reviewed the precious metals markets and drew conclusions on the prospects for nickel, cobalt, manganese, copper, lead, zinc, gold and silver.

Based on an annual publication of the United States Geological Survey, Ms. Antrim gave an overview of the noteworthy exploration activities for these metals by region in 2004. Her primary interest was exploration for precious metals. According to Ms Antrim, in 2004, out of 98 notable exploration operations, 82 were for gold, either as the principal metal or as a by-product; 14 were for silver; and the other two were for copper. She said that many of the exploration efforts involved both copper and gold, and stressed that precious metals were a major driving factor that also made the mining of other metals attractive.

With regard to precious metals in seabed minerals, Ms. Antrim said that gold and silver were potential by-products in polymetallic sulphides deposits exploitation, and noted that precious metals often contributed significantly to the profitability of sulphides ores. In this respect, she said that gold and silver were major incentives to exploration on land and potentially also for seabed minerals.

Using the figure below on gold and silver prices during the period 1977 to 2002, Ms. Antrim informed participants that with the exception of an economic spike in 1979/1980 the prices for gold and silver have been relatively stable.

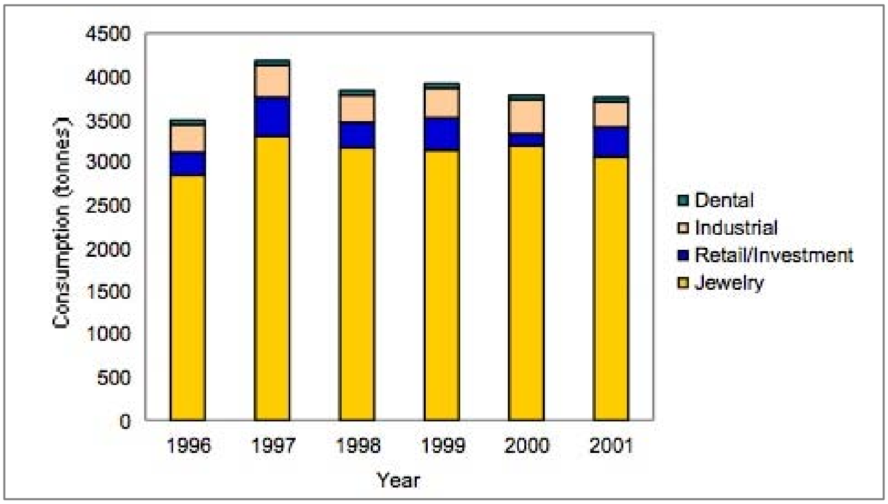


Gold and Silver Prices per Ounce (converted to US Dollar value in 2005)

She noted that silver prices were constant from 1990-2005, that gold prices, while decreasing a bit, have likewise been constant and predictable and have not been affected by economic cycles and by major technological shifts.

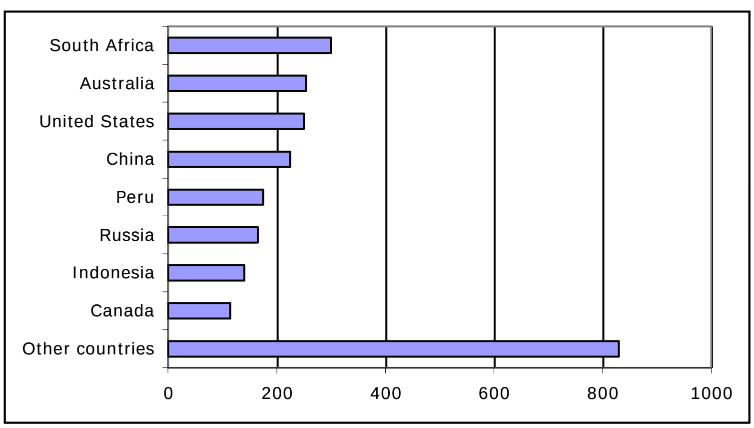
Ms. Antrim said that gold was mainly used in jewellery, dental work, electronics, and as investment. She said that in 2005, gold production was 2,450 metric tonnes and world reserves were estimated at 42,000 metric tonnes ensuring supply for about 15 years.

Through the figure below, Ms. Antrim illustrated that jewellery was by far the dominant application and noted that one area with a technological shift was the improvement of ceramics in dental work partly replacing gold, which, however, barely affected total consumption.



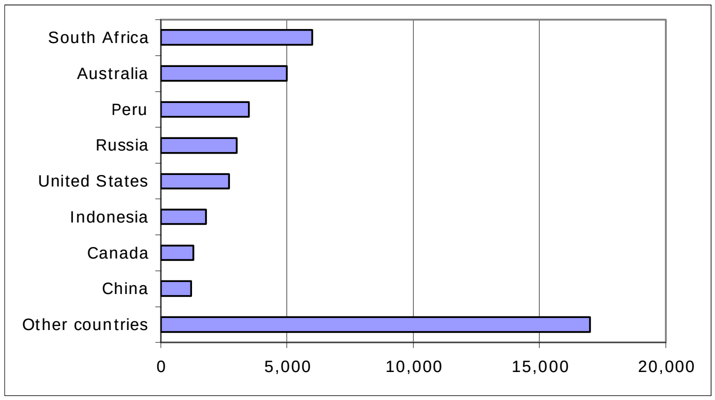
Gold Applications

Ms. Antrim reproduced salient statistics on global gold production adding that the major producers in descending order were South Africa, Australia, the United States and China.



Gold Production in 2005 (metric tonnes)

With regard to gold reserves, she said that South Africa, Australia, Peru, Russia and the USA had the largest reserves.



Gold Reserves 2005 (metric tonnes)

For silver, Ms. Antrim said that its major uses were jewellery (33 per cent); photography (24 per cent); industrial applications (40 per cent) and coins (3 per cent). She said that world production of silver in 2005 was 20,300 tonnes whereas reserves stood at 270,000 tonnes for the same year. She said that at current consumption levels, reserves were sufficient for less than 15 years.

She informed participants that silver production by region showed a slight growth in the Americas and Oceania with a slight decline in Europe and Africa. Generally, she said that production rates and the regional share of global production have remained relatively stable during the 1977 to 2001 period. .

Depicting prices of selected metals in 1977, 1980 and 2005, Ms. Antrim summarised the demand projections for nickel, copper, cobalt and manganese as follows:

Metal prices in US Dollar (converted to the value in 2005)

	1977	1980	2005
Copper ($/lb)	1.71	2.07	1.69
Nickel ($/lb)	5.82	5.93	6.59
Cobalt ($/lb)	14.42	44.62	15.80
Manganese ($/MTU)	3.75	3.41	4.71

She said that prices for these metals had not significantly increased over this period, but that the cost of labour, energy and construction increased consistently with inflation. The overall economics of a seabed mining venture as it was conceived in the 1970s was less profitable now than it was at that time. She also said that on the other hand, progress in extractive metallurgy, especially the development of pressure acid leaching and adapting it to seabed mining operations could reduce costs significantly. Referring to previous slides Ms. Antrim further noted that in the last 5 five years a trend of rising prices could be observed, but that it was, however, difficult to make a forecast on such a short term dataset.

Some of the key factors that affected prices:

- The supply-demand balance.
- Risk (technical risk of the mining operations; economic risk; or political risk).
- Alternative investments e.g. investments in expansion of existing deposits or improved processing efficiency, and
- Changes in consuming technologies e.g. transformational changes in the steel industry.

Based on her analysis, Ms. Antrim gave an outlook of future trends for certain metals and summarised the following changes which she thought could occur:

- A strong growth in demand and continuing price increases in response to the progress of advanced developing countries (especially China, India and Brazil) as a dominant factor over the next 20 years.
- A reduction of Russian exports due to increasing domestic consumption.
- The development of advanced auto batteries as major new markets for nickel, cobalt and manganese.
- An increased demand for other specialized manganese products.
- A potential reduction in demand for lead in auto batteries.
- A continued cyclical market behaviour in response to general economic trends, recessions, impacts of disasters etc., and
- Further development of PAL (Pressure Acid Leaching) technology and its applicability to seabed minerals as well as to laterites.

On the matter of risk factors that could affect the potential development of seabed mineral deposits, Ms. Antrim compared factors relating to industrial demand to factors relating to land-based mining and the risk factors of seabed mining itself. She said that industry-related risk included market changes due to end user technology or preferences together with the uncertainty of demand projections. She said that the development of land-based minerals could also be affected by the political uncertainty of some major mineral regions. Ms. Antrim said that while seabed mining was associated with technical risks and greater geological uncertainty, the political risk could be less than some of its land-based competition.

Ms. Antrim summarised the current trends in the supply and demand of the relevant metals as follows:

- Significant amounts of nickel and cobalt are currently being recovered from land-based oxide laterite deposits.

- In Voisey's Bay, Labrador, Canada large nickel, cobalt and copper deposits are being developed.[1]
- Some land-based producers of copper, lead and zinc are significantly expanding existing mining sites, and
- A continued demand growth for minerals to support the development of China's industrial and commercial economy.

Ms. Antrim stressed that for demand projections, industrial transformational factors and the uncertainties associated with them needed to be taken into account, and pointed out her key findings and conclusions in relation to future seabed mining:

1. The rising GDP of China and other developing countries will lead to higher than average growth of demand for major metals that could be derived from deep seabed minerals.

2. The Automobile sector demand will expand conventional uses (copper and lead) and will open new demand for nickel, cobalt and manganese in high energy batteries.

3. Precious metals are an important driving force in mineral exploration. Prospects for the recovery of gold and silver from polymetallic sulphides will be a factor in building interest in early seabed mining operations, and

4. Legal and regulatory conditions are a major factor in the evaluation of attractiveness of mineral deposits for development. Demonstration of an effective and efficient legal and regulatory regime for the deep seabed will compliment factors that make seabed mineral resources technically and economically attractive

In conclusion, Ms. Antrim stated that seabed minerals had the opportunity to become a major source of supply to the world economy. She added that the demonstration of feasibility and an appropriate regulatory climate by the initial operations would ease the way for subsequent development of seabed minerals.

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[1] The Voisey's Bay deposit is a nickel-copper-cobalt deposit located approximately 35 kilometres southwest of Nain in northern Labrador. It was formed about 1.3 billion years ago and is contained within igneous rocks typical of those that host major nickel deposits elsewhere in the world. The Voisey's Bay deposit consists of a series of individual nickel-copper-cobalt deposits that are known as the Reid Brook, Discovery Hill, Ovoid and Eastern Deeps. The Ovoid is close to the surface beneath 2.5 to 30 metres of overburden. The other deposits are deeper and plunge to the east-southeast at about 20 degrees. Their depth varies between 100 and 1,000 metres below surface. The only deposit that has had sufficient exploration work done to be regarded as a proven resource is the Ovoid. This is a bowl-shaped deposit that measures 950 by 500 metres across, and is over 100 metres deep at the center. It contains proven reserves of 31.7 million tonnes of ore, 2.83 per cent of which is nickel, 1.68 per cent copper and 0.12 per cent cobalt. It is the only deposit that can be developed by surface open-pit mining techniques. The other deposits contain a total of 118 million tonnes of indicated and inferred resources, however, further exploration work (including underground work) will be required to determine how much of these resources can be mined. Most will have to be developed using underground mining techniques. All mineralization consists of nickel sulphide (pentlandite), which also contains the cobalt, copper-iron sulphide (chalcopyrite) and iron sulphide (pyrrhotite). The style of mineralization varies from massive (i.e. over 90 per cent sulphides minerals) to disseminated (i.e. the sulphides are mixed with other minerals). (Source: Government of Newfoundland, Labrador, Canada.)

Summary of the discussions

The Secretary-General raised the point that in the 1970s when the United Nations Convention on the Law of the Sea was being negotiated, a set of articles dealing with production policy including a formula for dividing the market between seabed production and land-based production were formulated. He said that the background for these articles was the land-based producers' concern that they would be displaced from the market by rapid growth of production from the seabed. Seabed production was thus limited to permitting an annual growth rate of 50 per cent of the growth of nickel. He said that assumptions of the annual metal market growth rates had been made based on the historical growth in nickel at this time of about 3.5 per cent to 4 per cent over the previous 15-20 years. The Secretary-General wanted to know if Ms. Antrim had recently calculated the rate of growth in nickel in light of current demands.

Ms. Antrim replied that the growth rate over the previous 5 years was about 4 per cent for nickel and 2-3 per cent for the base metals. She added that it was difficult to project the current growth on the basis of the last few years when prices for some metals started to significantly increase.

The Secretary-General added that the earlier provisions made in respect of a maximum number of production sites for seabed producers were abandoned in the 1994 Agreement on Implementation of the Seabed Provisions of the Convention on the Law of the Sea. He said that due to the lower growth in metal demand, it was decided to allow a free market situation with provisions against subsidization in the 1994 Agreement.

Another participant was interested in obtaining more details on gold prices and the potential effect it could have on the development of hydrothermal polymetallic sulphides deposits. He noted that since June 2006, gold prices had increased dramatically to about US$640 per ounce at the time of the workshop and quoted three different projections which anticipated gold prices to rise to between US$1,000 and US$8,000 per ounce in the next 4-6 years. The participant stated that this was an important situation in respect of the potential development of hydrothermal polymetallic sulphides deposits and added that he believed that mining would be feasible if the gold price reached US$1,000 per ounce.

Ms. Antrim noted that one needed to take into account the time frames for which these projections had been made and further stated that some projections may not be objective and unbiased.

On the expanding cobalt market, a participant noted that the market size was still small and that cobalt-rich crusts mining as well as polymetallic nodule mining were economically risky. He further stated that polymetallic sulphides mining could take place at a smaller production scale and could economically be less risky. As a mining engineer, he added that mining polymetallic sulphides was technically easier than mining ferromanganese cobalt-rich crusts deposits.

Ms. Antrim agreed and said that the experience from the development of polymetallic sulphides deposits could also be applied to crusts and nodule mining.

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Chapter 16: Demand for Mineral Resources in the People's Republic of China – Short, Medium and Long-Term Projections

Dr. Hongtao Zhang, Deputy Director-General, China Geological Survey, Beijing, People's Republic of China. Presented by Mr. Haiqi Zhang of the China Geological Survey..

Summary of the Presentation

Mr. Zhang apologized for the absence of Dr. Hongtao Zhang, who could not be at the workshop due to pressing engagements.

Dr. Haiqi Zhang provided participants with an overview of the China's Geological Survey and the mining industry of the People's Republic of China. He informed participants that a geological map of China at a scale of 1:250,000 was completed in 2005. In addition, he said that regional geochemical exploration, hydro, geological, gravity and airborne magnetic surveys had been carried out for China but at different scales. Mr. Zhang disclosed that 171 minerals had been discovered in China and reserves for 158 of them had been established. He also said that over 200,000 mineral occurrences had been identified. He further informed participants that more than 10,000 large and medium-scale mining enterprises existed in China. Additionally, he said that there were 240,000 small-size mining operations in the country. Dr. Zhang said that the total production of solid mineral ores was more than 5 billion tonnes per year, translating into an annual value of the mining industry and related industries of over 2,000 billion Yuan, which made China the third largest producer of mineral ores in the world.

In the first part of his presentation Dr. Zhang outlined the exploitable reserves and the domestic supply of metallic minerals in China. He made the following points to characterize the current situation:

- The reserves of iron, manganese, aluminium and copper are large, but metal grades of the ores are generally low and the metals are associated with other minerals which makes them difficult to process;
- There are rich deposits bearing tungsten, tin, rare earth elements, molybdenum and antimony, which are, however, not heavily consumed in China;
- The proved reserves of interested metals are mostly located in areas where little geological survey work has been done;
- China has high potential areas for mineral prospecting, as the country is located in the cross region of the three metallogenetic belts of the Pan Pacific Ocean, the Paleo Asia Ocean and the Paleo Tethy's Ocean.
- Since 1990 the consumption of mineral commodities is increasing faster than national production;
- National production is increasing at a greater rate than the discovery of new reserves, so the reserves of petroleum, coal, copper, iron, manganese and chromium have been decreasing in relative terms;
- The shortage of petroleum, natural gas, coal, iron, manganese, chromite and copper is increasing;

- Of the current reserves of 45 main minerals, only 24 of them can meet the consumption demand until 2010 and only six of them can meet the consumption demand until 2020;
- Compared to the year 2001 the reserves decreased at a great speed in the recent five years. The proved reserves of copper, zinc, nickel, cobalt, tungsten, molybdenum and rare earth elements decreased in 2005.

Using the table below, Dr. Zhang presented salient statistics of the proved reserves and the exploitable reserves of relevant metals as of the end of 2004, and compared to 2001.

PROVED RESERVES AND EXPLOITABLE RESERVES OF METALS BY THE END OF 2004

	Unit (* thousand tonnes)	Proved Reserve	Compared to 2001	Exploitable Reserves	Compared to 2001
Iron	Billion tonnes (ores)	581.51	+0.22	117.33	-3.97
Manganese	10 (ores)	72456.9	+698	12558.7	-106
Copper[1]	10* (metal)	6659.0	-258.0	1753.6	-188.3
Bauxite[1]	10* (ores)	25.95	+1.24	5.59	+0.53
Lead[1]	10* (metal)	3906.5	+166.8	824.4	+111.3
Zinc[1]	10* (metal)	9224.9	-537.0	2686.8	+305.0
Nickel[1]	10* (metal)	795.67	-32.22	239.83	-20.91
Cobalt[1]	10* (metal)	63.33	-1.32	3.88	-1.02
Tungsten[1]	10*	572.53	-10.7	144.24	+8.83
Tin[1]	10* (metal)	481.23	-25.67	78.92	-9.87
Molybdenum[1]	10* (metal)	875.65	-86.24	162.32	-32.69
Gold	Tonnes (metal)	4560.24	+92.34	1362.33	-22.47
Silver	Tonnes (metal)	126102	+6497	28770	+5444
Rare Earth[1]	10* (oxide)	8882.9	-170.0	2015.6	-113.31

[1] In thousands of tonnes

Dr. Zhang explained that only proved reserves of iron, manganese, bauxite, lead, silver and gold increased during the period.

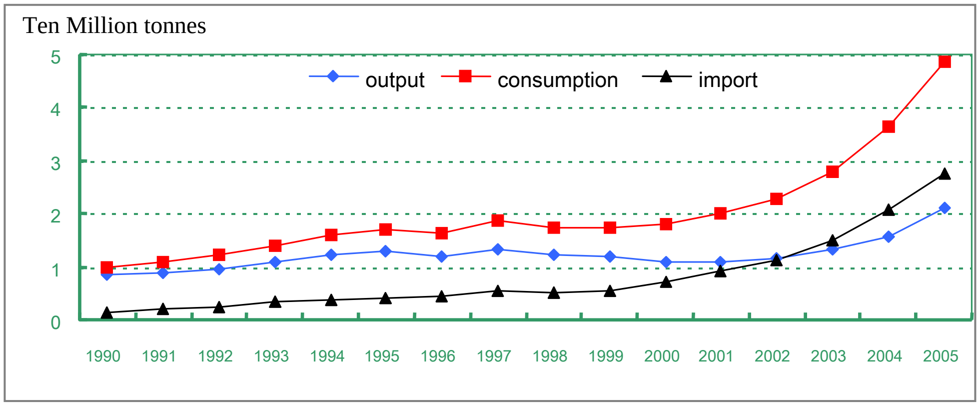
In the second part of his presentation Dr. Zhang discussed the supply and demand situation in the People's Republic of China. He said that due to the rapid development of the Chinese economy and the domestic shortage in the main mineral resources, the reliance on imports was continuously increasing and China had become the biggest importer of mineral metals. Through the use of the figure below, he provided salient statistics on export and import values for selected mineral commodities in 2005.

IMPORT AND EXPORT OF MAIN METAL MINERALS IN CHINA
(VALUES IN TEN THOUSAND US DOLLAR)

Commodity	Amount Unit (in 1000 tonnes unless otherwise specified	Export		Import	
		Amount	*Value*	*Amount*	*Value*
Iron ore (washed sands) and concentrates				27526	1837278
Pig iron and iron glance		223	66651		
Steel scrap				1014	261049
Billet and forged piece		707	267284	131	68054
Steel products		2052	1307968	2582	2460845
Manganese sands and concentrates				458	68348
Not forged manganese		29	42433		
Chromium sands and concentrates				302	59557
Copper sands and concentrates				406	370672
Copper scrap				482	317991
Not forged copper (including copper hardener)		14	54982	142	494967
Copper products		46	207366	112	437824
Aluminum oxide for refinery		2	1386	702	259717
Scrap aluminum				169	136859
Not forged aluminum (aluminum alloy)		132	237952	64	101849
Aluminum products		71	195089	65	225102
Zinc oxide	tonnes	62205	6920		
Lithopone	tonnes	79697	2938		
Not forged zinc and alloy		15	19583		
Not forged tin and alloy		2.7	19865		
Not forged antimony, powder scrap		2.9			

Dr. Zhang gave details of the supply and demand of iron, manganese, chromium, bauxite/aluminium, copper, and the rare earths as follows:

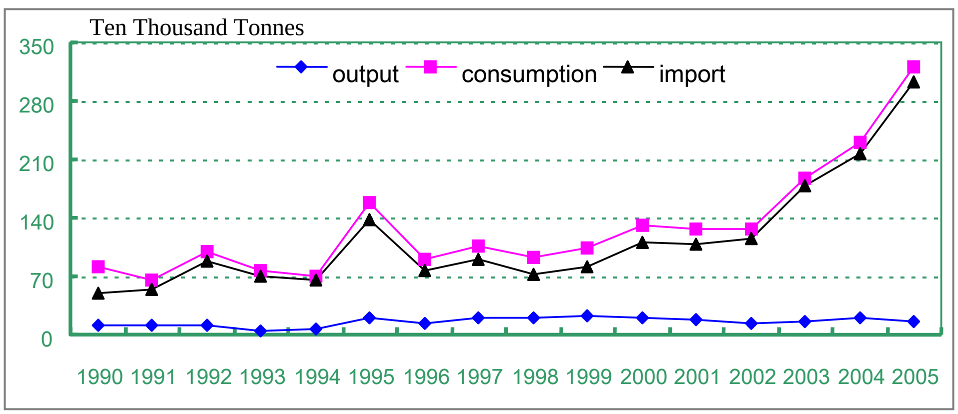
(i) In respect of iron ore, he said that the domestic production (blue line in the figure below) was 420 million tonnes in 2005; about double the output of 2001. About 275 million tonnes of iron ore was imported (black line); and 485 million tonnes were consumed in total (red line). The percentage of imported iron ore increased from 14.15 per cent in 1990 to 57 per cent in 2004.



Domestic Production, Consumption and Import of Iron Ore from 1990 to 2005

(ii) With regard to manganese, domestic production was 7.185 million tonnes in 2005; 4.58 million tonnes of manganese sands were imported, which corresponds to about 60 per cent of the total consumption (10.77 million tonnes).

(iii) About 150,000 tonnes of chromium was produced in China in 2005. Imports were 3.02 million tonnes, representing about 90 per cent of total consumption.



Domestic Production, Consumption and Import of Chromite from 1990 to 2005

(iv) 790,000 tonnes of copper concentrate was produced domestically in 2005, and 3.665 million tonnes of fine copper was consumed. 4.06 million tonnes of copper sand was imported in 2005. At the same time, significant amounts of raw copper, refinery copper, copper hardener, copper products and copper scrap was imported. In total, about 60 per cent of the copper demand in 2005 was met by imports.

(v) Domestic output of aluminium oxide in 2005 was 8.609 million tonnes; 7.02 million tonnes of aluminium oxide was imported in 2005.

(vi) The outputs of lead and zinc concentrates in China in 2005 were 1.04 million tonnes and 2.52 million tonnes respectively. Imports of lead and zinc concentrates in 2005 amounted to 1.03 million tonnes and 568,000 tonnes respectively.

(vii) In respect of rare earth elements, China has the largest reserves in the world. In 2005 domestic output was 103,000 tonnes; domestic consumption was 51,900 tonnes. The balance of 55,300 tonnes was exported.

On the topic of demand projections for China, Mr. Zhang stated that the supply of mineral resources was not secure and that the situation was getting severe. He gave the following reasons:

- Domestic reserves of the required mineral resources are insufficient. Most minerals such as iron, manganese, copper, lead, zinc, cobalt, tin and gold cannot satisfy projected demand in 2010.
- Most mines are small-sized operations. Metal grades are relatively low; mining and processing is comparatively difficult and expensive.
- The recovery rate of metals is lower than at the international level. About two-thirds of the minerals which are associated with other minerals have not been used comprehensively as by-products; only about 10 per cent of the tailings are used.
- Consumption is increasing rapidly and it is expected that the demand will continue to increase.

In conclusion, Mr. Zhang said that China was pursuing the following strategies to meet its challenges of insufficient supply of resources:

- Improve resource management, reduce waste of mineral resources and increase the recovery rate by the use of new technologies.
- Intensify resource exploration in the western part of China.
- Carry out exploration of deep resources as well as new potential mine sites
- Increase recycling.
- Extend international cooperation and set up multi-channel import of a variety of mineral commodities.

Summary of the discussion

The Secretary-General sought more clarification on Mr. Zhang's statement that most of the local resources in China would be exhausted by 2010 unless new resources were found. He asked if China was in the process of establishing supply channels from other countries and wanted to know at what point the supply would be secured to sustain China's development.

Mr. Zhang replied that in 20 years China would need to develop mineral resources from the seabed such as polymetallic nodules, cobalt-rich ferromanganese crusts and polymetallic sulphides.

The Secretary-General asked whether the development of resources from the seabed could take place sooner.

A member of the Chinese delegation replied that the question was a difficult one but confirmed Mr. Zhang's comment that that by the year 2010 or 2020 some of the main metals would be exhausted in China. He said, however, that by the year 2020 consumption of some metals could also decrease by way of technological development. He said that exploration of mineral resources on the seabed was a goal, although at this particular point in time, it was not possible to state where or when commercial mining on the seabed would take place.

Another member of the Chinese delegation commented on the demand and supply situation and the strategy of the Chinese government. He outlined four official mid-term and long-term strategies that the government of the People's Republic of China would focus on. He said that one strategy was the expansion of exploration in the western part of China, which was expected to result in significant discoveries of copper and other important minerals. Another strategy was to use low-grade minerals by means of improved mining technologies. The participant said that China had large deposits of low-grade iron, copper, lead, zinc, gold and aluminium. The third strategy he said was international cooperation and noted that in the last few years China had made great efforts to establish ties with Australia, South American and African countries in terms of long-term supply relationships. A fourth strategy, the participant said, was to save minerals through more efficient use of, for example, manganese in steel production. Apart from these strategies, the participant pointed out that in his opinion, that the fifth strategy to overcome the shortage of resources was to promote prospecting and exploration for minerals on the seabed.

In reply to a question on whether recycling would be an important part of the policy and if there were programmes in place to initiate recycling, a member of the Chinese delegation advised that recycling was an important measure and part of the official industry policy of the People's Republic of China.

On the subject of international cooperation as a major strategy to help meet domestic demand, another participant asked if the Geological Survey of China itself planned to carry out exploration overseas, e.g. for copper in Chile or zinc in Australia.

In response, participants were advised that the policy of the Chinese government was to use foreign resources in different ways. Buying commodities from the metal markets would be the most important way and another would be to establish joint ventures to develop oil and gas resources as well as hard rock minerals. Participants were also informed that China is already participating in joint ventures in Australia, Peru, Tanzania and in some other projects.

Referring to the five strategies outlined by the participant from China, another participant asked about the priority of these strategies, especially the strategy to develop seabed minerals. He also wanted to know what could be done to make seabed minerals more attractive to China and noted that instruments need to be developed to promote deep sea mineral development.

The response was that deep sea mineral development was a long-term strategy and that in the short term more emphasis would be placed on recycling and on the development of low-grade minerals on land. The point was also made that deep sea mineral development was an economic problem, not a technical one. He said that if the economic factors changed dramatically in terms of commodity prices, the existing mining systems could be improved immediately. A critical factor identified as an impediment was the competitiveness of seabed mining.

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Part IV

RECOMMENDATIONS OF THE WORKING GROUPS ON POLYMETALLIC SULPHIDES DEPOSITS AND ON COBALT-RICH FERROMANGANESE CRUSTS DEPOSITS

Two working groups were formed to investigate the impacts of the draft Regulations in practice and to develop recommendations for changes if required. One of the working groups dealt with polymetallic sulphides and the other with cobalt-rich ferromanganese crusts. The mandates of both working groups included an examination of the economic feasibility of mining the resource, the appropriate sizes of exploration and mining areas as well as the provisions for relinquishment, application fees and the participation by the Authority. A plenary was subsequently held to discuss intermediate results. The cobalt-rich ferromanganese crusts working group was led by Dr. James Hein and the polymetallic sulphides group was led by Dr. Charles Morgan. The reports of the working groups and the subsequent discussions are summarised below.

Chapter 17: Report of Polymetallic Sulphides Working Group

Presented by Dr. Charles Morgan, Environment Planner, Planning Solutions Inc., Mililani, Hawaii, United States of America

Dr. Morgan reiterated the mandate of the working group which was to work with the existing draft Regulations and examine the economic feasibility of mining polymetallic sulphides resource. He said that a single set of regulations for polymetallic sulphides and cobalt-rich ferromanganese crusts together with issues related to exploration area restrictions and relinquishment procedures as well as subject participation by the Authority were to be addressed.

Dr. Morgan noted that with respect to equity participation by the Authority, the working group did not feel competent enough to suggest an appropriate formula and that the working group suggested deferring the particular issue to experts in this field.

With regard to the working group's recommendations for characteristics of exploration areas, Dr. Morgan said that the working group supported the original concept of the draft Regulations with blocks of 10 by 10 kilometres as the basic unit for initial exploration and the group accepted the fact that an exploration area would consist of a maximum of 100 such blocks located in a contiguous cluster to prevent "cherry picking" of best known sites.[1]

With respect to the application fees contained in the draft Regulations, he said that the working group suggested adding an option that could make other investors, besides States parties, more interested in investing in the development of the resource. Therefore, in addition to the option of paying a fee of USD$250,000 to be paid at the time of the application, investors could select the option of paying a lower application fee plus annual rental fees per block that increased over time. Dr. Morgan added that the basic principle was to encourage the explorer to examine, study, and explore the license area thoroughly in an early manner so that the explorer could relinquish parts of the area as soon as possible. He added that this would also provide an economic incentive, since entry fees would be lower at the initial stage where the risks were highest, which would encourage of more investment.

On the matter of rental fees for the second option the working group suggested the following amounts per block:

- US$250 in the first year
- US$500 after the first year
- US$1,000 after the first relinquishment
- US$2,000 after the second relinquishment
- After each 5-years of contract extension the amount should be doubled

According to the suggestions, Dr. Morgan explained that in the first year, each block would cost US$250 which would result in US$25,000 for 100 blocks plus an application fee of US$25,000. After the first year the amount per bock would rise to US$500 so that the annual fee for 100 blocks would be US$ 50,000.

[1] The Activity of pursuing the most lucrative, advantageous, or profitable among various options and leaving the less attractive ones for others

Assuming that a contractor wanted to seek a five-year extension, Dr. Morgan explained that each time an application for such an extension was made, the contractor would pay double the price of each block (US$4000) as an incentive to move forward with its activities. He noted that the suggested amounts were thought to be reasonable but nevertheless arbitrary and were open to change as appropriate

He presented the table below indicating fee development and the cumulative total fees over a 20 year period based on the suggested fees.

EXAMPLE OF RENTAL FEE OPTION

Year	*# of blocks*	*$/Block*	*Application Fee*	*Area Rental Fee*	*Total Fees*	*Cumulative total*
1	100	250	25,000	25,000	50,000	50,000
2	100	500		50,000	50,000	100,000
3	100	500		50,000	50,000	150,000
4	100	500		50,000	50,000	200,000
5	100	500		50,000	50,000	250,000
6	50	1000		50,000	50,000	300,000
7	50	1000		50,000	50,000	350,000
8	50	1000		50,000	50,000	400,000
9	50	1000		50,000	50,000	450,000
10	50	1000		50,000	50,000	500,000
11	25	2000		50,000	50,000	550,000
12	25	2000		50,000	50,000	600,000
13	25	2000		50,000	50,000	650,000
14	25	2000		50,000	50,000	700,000
15	25	2000		50,000	50,000	750,000
16	25	4,000		100,000	100,000	850,000
17	25	4,000		100,000	100,000	950,000
18	25	4,000		100,000	100,000	1,050,000
19	25	4,000		100,000	100,000	1,150,000
20	25	4,000		100,000	100,000	1,250,000

Dr. Morgan outlined the recommendations of the working group in respect of relinquishment. He said the group suggested that no requirement for contiguity of blocks after relinquishment needed to be defined. He said that this was to allow investors to focus on the areas of high promise and to eliminate areas that were not interesting, taking into account that the deposits were highly irregularly spaced and that it would be an undue burden and somewhat inefficient to require contiguity beyond the first stage. Dr. Morgan said that the working group was of the opinion that this suggestion is consistent with the existing draft Regulations.

The working group suggested relinquishment to take place according to the following scheme:

- After a maximum of 5 years, the areas should be reduced to 50 per cent of the original area

- After a maximum of 10 years, the areas should be reduced to 25 per cent of the original area

- After a maximum of 15 years, the areas should be reduced to the equivalent of 25 blocks, where blocks could be subdivided as appropriate by the Authority

Dr. Morgan noted that a contractor could relinquish areas earlier and if it took the second option, it would be to its economic advantage to relinquish earlier. He also said that the group felt it would be to the advantage of the Authority to free up areas for other explorers as early as possible. He explained that the only addition that the working group made to the existing draft Regulations in relation to the relinquishment procedures was the possibility of subdividing the remaining blocks and changing the area to the equivalent of 25 blocks. This would give the Authority the ability to break a 10 by 10-kilometre block into smaller sections as is appropriate to permit efficient exploitation and not constrain the developer to arbitrary blocks. He noted that mining companies at this stage would have identified the actual mine sites and would be able to delineate them. This option would allow for flexibility and efficient usage of the licence territory for subsequent development efforts.

Summary of the discussion

In relation to the proposed subdivision of final exploration blocks after relinquishment a participant commented that the wording "subdivided as appropriate by the Authority" might be misleading and suggested that the subdivision of the block in a generic sense should be done by the Authority, whereas the selection of sub-blocks should be up to the contractor.

Dr. Morgan said that the intent was that the Authority would divide the final mining area into 1 km by 1 km sub-blocks and the contractor would then pick from these to define his mine site.

The Secretary-General suggested that blocks could be subdivided as appropriate by the contractor in consultation with the Authority.

Another participant commented on the payment scheme for the block rental option and said that according to this suggestion, his understanding was that the Authority would give the contractor the rights to exploit the remaining 25 blocks only after the 15th year. He said that a contractor may have finished exploration by the 10th year, but would have to pay the fees for five more years.

Dr. Morgan pointed out that it was important to understand that the proposed timelines with respect to relinquishment were maxima, i.e. an explorer could relinquish earlier and ask for an exploitation licence earlier. Dr. Morgan stressed that doubling the fee after 15 years to USD$4,000 per block should be an incentive to finish exploration in less than 15 years.

The Secretary-General noted that an exploration contractor could accelerate its activities and pay fees only until it finished exploration. Thereafter, there would be a different contract dealing with the exploitation phase and the contributions to be made under that scheme. He said that there was a need to establish another scheme for exploitation.

Another member of the polymetallic sulphides working group reminded participants that the rental fee scheme was a second option and that contractors were free to select the option of paying US$250,000 up front for 15 years of exploration. The participant said that for an applicant that decided on the second option it was reasonable to assume that by the 15th year it would have paid more than a contractor who had initially decided to pay the money up front.

After 15 years, this participant continued, the contractor would be making annual payments of US$100,000, if it still had not decided to start mining. With respect to the timelines for relinquishment and the related fees according to the second option, this participant suggested adding a clause saying that in the case of rapid exploration where the equivalent of US$250,000 has not been yet been fully paid the difference would have to be paid when the contractor completed exploration and moved on to exploitation.

With respect to the two options, a participant commented that it might not be fair to grant a contractor who paid US$ 250,000 up front 5 year extension terms at no costs while another contractor which selected the second option would have to pay for any extension of the exploration phase.

Responding to this comment, another participant said that from a company's point of view it would be expected to pay for an extension of the exploration term.

Dr. Morgan stated that given the fact that a company did not make profit until the exploitation phase, it would be unlikely that a company which decided to use the second option would carry out exploration for more than 15 years and ask for an extension.

The Secretary-General stated that the issue of procedures for extension and the associated fees needed to be addressed. He said that the existing draft Regulations did not exclude the possibility to charge fees for the extension of the exploration contract.

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Chapter 18: Report of Cobalt-Rich Ferromanganese Crusts Working Group

Presented by Dr. James Hein, US Geological Survey, Menlo Park, CA, United States of America

Dr. Hein introduced his report by stating that the cobalt-rich ferromanganese crusts working group came to consensus with respect to some recommendations whilst other issues remained without consensus. He said that the only regulation for which there was consensus was the base exploration block unit of 100 square kilometres. He said that all other regulations for which consensus was reached were new.

He summarised the consensus regulations in relation to exploration areas as follows:

- Exploration blocks should be 100 square kilometres, consisting of five 20 square kilometres contiguous sub-blocks

- Exploration blocks need not be contiguous but should be clustered within a local geographic area

- Relinquishment should be based on the 20 square kilometres sub-blocks and should occur during two stages

- The final set of 20 square kilometres sub-blocks that define the mine site need not be contiguous

Dr. Hein noted that the concept of sub blocks was new and had been introduced to decrease the necessary amount of exploration territory as well as to decrease the amount of mine site territory by eliminating uninteresting territory within the lease areas.

With respect to the relinquishment procedures, he said it would be more efficient to relinquish on a per sub-block basis which better reflected the size of mining sites according to the geological conditions, rather than the initial 100 square kilometres block size. He noted that it was agreed upon by all working group members that the final set of sub blocks that defined a mine site did not need to be contiguous.

Dr. Hein proceeded to stipulate the recommendations for which the working group did not come to a consensus. He said that the contentious issues were the sizes of the exploration areas and the final mine sites, and noted that the range of values suggested for the exploration area was between about 2,000 square kilometres -10,000 square kilometres and between 100 square kilometres -2,800 square kilometres for mine sites. He disclosed that most of the discussions of the working group were related to the question on how much un-mineable areas could occur in a mine site.

In relation to the exploration area and mine site area, Dr. Hein reiterated the suggestions he had prepared prior to the workshop:

- An exploration area should consist of up to about 25 exploration blocks of 100 square kilometres each comprising a maximum area of about 2,500 square kilometres

- A mine site should consist of up to about 25 sub-blocks of 20 square kilometres each comprising a maximum area of about 500 square kilometres

He stated that according to some model calculations the suggested size of 500 km² for a mine site was five times larger than what could actually be needed by a commercial mining company. He said that the working group was, however, unable to reach a consensus on this issue.

Dr. Hein presented the group's recommendations for relinquishment of leased exploration territory as follows:

- No requirement for contiguity after relinquishments
- After a maximum of 5 years, reduce area to 50 per cent of the original
- After a maximum of 10 years, reduce area to 25 per cent of the original
- After a maximum of 15 years, reduce area to 25 sub-blocks

Dr. Hein said that the only deviation from the draft Regulations was the use of sub-blocks of 20 km² rather than the 100 km² blocks. Referring to the recommendations of the polymetallic sulphides working group, he noted that the concept of 10 km² sub-blocks could be applied to cobalt-crusts as well and added that the smaller the sub-blocks, the more unusable territory could be eliminated in the leased site.

The working group developed a model mine site as a basis to suggest recommendations as per the group's mandate. In order to evaluate the impacts of the draft Regulations and to develop modifications, a "reverse" approach was chosen. He said that starting from assumptions on the required production rates of a mining operation and other conditions for commercially-viable activities, the theoretical mine site was presented.

Dr. Hein reiterated the model parameters and model assumptions which had been used for the model mine site:

- 20 years of operation
- 1 million wet tonnes of annual ore production (670,000 dry tonnes)
- Mean crust thickness of 6 centimetres
- 0.6 % cobalt grade (0.5 per cent nickel as a by-product)
- 78 kilograms of cobalt per square meter
- 4,020 tonnes cobalt production per year
- 12.82 square kilometres mining area per year resulting in 256 square kilometres over 20 years
- Size of exploration area 2,500 square kilometres
- Exploration costs (early exploration): 60 days at US$75,000 resulting in USD$ 4.5 million.

He noted that the tonnage values per year were based on the premise of not being too intrusive in the cobalt market. He said that the group selected a maximum of 10 per cent market penetration for cobalt. Dr. Hein further noted that for the purpose of the theoretical model the working group agreed upon these parameters, however, there were different opinions on the values for a real mining venture, and cited a group member who said that in normal engineering practice, three times the mining area was used as a safety margin, which would increase the mining area to about 750 square kilometres. Dr. Hein stated that based on scientific evidence he suggested a final mine area of 500 square kilometres, although the key question of how much additional territory was needed to get 256 square kilometres of mineable area could not be answered until a commercial venture was initiated and completed.

Dr. Hein further mentioned practical considerations of the working group. These were that the actual production rate may be limited by the mining equipment, and the size of the exploration area. In this regard, he noted that with the introduction of escalating fees for blocks, the exploration area of 2,500 square kilometres results in costs for the initial phase of exploration of about USD$4.5 million. In the case of the larger exploration area, at 10,000 square kilometres, the fees for exploration would rise to about USD$20 million which could be prohibitive to a commercial enterprise.

With regard to the issues of application and/or rental fees which the working group did not address in detail, Dr. Hein said that he supported the polymetallic sulphides working group's concept of having two options, i.e. an up-front fee and variable fees based on the number of retained blocks. He concluded his report by stating that in his opinion cobalt-crusts mining would be further down the line than polymetallic sulphides mining, so there was still time to discuss these issues.

In relation to the effect of the system of participation, the working group produced the report below.

A preliminary cost model of a cobalt-rich ferromanganese crusts mining venture in the Area, and an examination of the effects of the system of participation by the Authority

The Working Groups on polymetallic sulphides and cobalt-rich ferromanganese crusts deposits in the Area were requested to examine the effects of the proposed system of participation of the Authority in the development of cobalt-rich crusts and polymetallic sulphides deposits in the Area. It is recalled that the draft regulations provide an alternative to the requirement of reserved sites by contractors for these resources. This alternative is contained in regulation 16 of the draft regulations on Prospecting and Exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area proposed by the Legal and Technical Commission (ISBA/10/C/WP1). In accordance with this regulation, each applicant shall, in its application, elect either to:

(a) Contribute a reserved area to carry out activities pursuant to Annex III, article 9, of the United Nations Convention on the Law of the Sea (regulation 17 of the draft regulations) or

(b) Offer an equity interest in accordance with regulation 19 of the draft regulations.

Regulation 19 of the draft regulations states that where the applicant elects to offer an equity interest, the equity interest, which shall take effect at the time the applicant applies for a contract for exploitation, shall include the following:

The Enterprise shall obtain a minimum of 20 per cent of the equity participation in the venture arrangement on the following basis:

(a) Half of such equity participation shall be obtained without payment, directly or indirectly, to the applicant and shall be treated *pari passu* for all purposes with the equity participation of the applicant;

(b) The remainder of such equity participation shall be treated pari passu for all purposes with the equity participation of the applicant except that the Enterprise shall not receive any profit distribution with respect to such participation until the applicant has recovered its total equity participation in the venture.

The draft regulations also state that notwithstanding the above (paragraph 3), the applicant shall nevertheless offer the Enterprise the opportunity to obtain up to 50 per cent participation in a joint venture on the basis of *pari passu* treatment with the applicant for all purposes:

(a) In the event the Enterprise elects not to accept 50 per cent of such equity participation, the Enterprise may obtain a lesser per cent on the basis of pari passu treatment with the applicant for all purposes for such lesser participation;

(b) Except as specifically provided in the agreement between the applicant and the Enterprise, the Enterprise shall not by reason of its participation be otherwise obligated to provide funds or credits or issue guarantees or otherwise accept any financial liability whatsoever for, or on behalf of, the joint venture arrangement, nor shall the Enterprise be required to subscribe for additional participation so as to maintain its proportionate participation in the joint venture arrangement.

In this alternative, the Enterprise is able to purchase equity participation in the proposed project at a cost of at least 10 per cent and as much as 40 per cent of total equity value. In its purchase, the Enterprise would receive an additional 10 per cent of the equity in the project, giving a range of equity share of 20 per cent -50 per cent.

The Working Group on cobalt-rich ferromanganese crusts deposits in the Area established a preliminary cost model for such a venture, and examined the effects of the system of participation by the Authority on the operation.

The Group noted that without an actual operation upon which to base values and schedules, and without prior implementation of the terms and provisions of the equity system, its analysis incorporated assumptions based on interpretation, study and experience that may differ from actual practice. Its assumptions regarding duration of prospecting, exploration and mining are presented below. The Working Group stated that the comparative analysis of the effects of various levels of the Enterprise's equity participation should be indicative of how the system will work in practice.

Assumptions

The Working Group identified the type of operation as a fully integrated cobalt-rich ferromanganese crusts mining venture producing 1,000,000 dry metric tons of crusts per year for twenty years, and producing refined nickel and cobalt. It assumed that the average metal grades of crusts deposits would be 0.4 per cent for nickel and 0.6 per cent for cobalt. The metallurgical processing efficiency for both metals was assumed to be 95 per cent. The model assumes that prospecting will be of two year duration, exploration of five-year duration, and mining will be for twenty years.

With regard to revenues, the model assumed that the 2006 average nickel and cobalt prices in 2006, $6.6 per pound and $15.4 per pound respectively will be applicable.

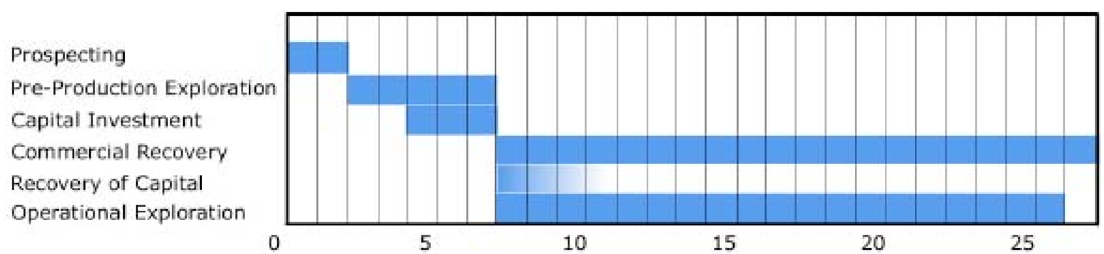
These parameters were defined as the base case scenario by the Group.

Scheduling of Costs and Revenues

The Working Group pointed out that the model has three major time divisions: a prospecting period of two years, an exploration and development period of 5 years and a production period of 20 years (see *Figure 1*). The Working Group spread exploration expenses equally over the 5-year exploration and development period while capital expenses were scheduled as 20 per cent in the fifth year of the project, 50 per cent in the sixth year, and 30 per cent in the seventh year.

It also pointed out that production is scheduled from year eight through year 27. The Working group assumed that the first two years of production sales are calculated as a fraction of total sales at full capacity as the system ramps up to full efficiency in the third year of production. Capital investment is recovered from the beginning of commercial production until fully recovered. The Group noted that while there is no set end date for capital recovery, it assumed that capital recovery would be complete between the third and sixth years of commercial production. It also assumed that operational exploration would be completed at the end of the penultimate (26th) year.

Figure 1 — Schedule of Activities



Values Used in the Model

Costs

Prospecting cost was estimated at USD $2.5 million per year for two years. Pre-Production exploration was estimated at USD $2.5 million per year, for five years (years 3-7).

The Working Group divided capital construction costs into at-sea (mining vessel and equipment, and the transportation system) and processing plant costs, then totaled and disbursed the costs over years 5, 6, and 7, in the following proportions; 20 per cent, 50 per cent and 30 per cent respectively. It defined total capital cost as capital construction cost (the at-sea and processing construction capital cost) plus prospecting, exploration and Research and Development costs. The Working group estimated at-sea and processing capital costs as USD$500 million in the base case and $600 million in cases with increased costs, giving total investment of $517.5 million and $617.5 million respectively.

The Working Group was of the view that operational exploration would be conducted from the beginning of commercial production (year 8) and would cease one year before the end of commercial production. It estimated annual exploration cost as USD$5 million per year. It also estimated operating costs in the at-sea and processing components to be 20 per cent of the total capital cost. Defining total annual operating costs as comprising exploration costs and operating costs for the at-sea and ore processing component, the Working Group estimated total annual operating costs for the base case as USD$105 million/year. It also estimated cases with increased costs to have total annual operating costs of USD$125 million.

Revenues

The Group estimated that gross revenues from metal sales would begin in year 8 at 40 per cent of full production, rising in year 9 to 75 per cent and reaching full capacity in year 10. In the base case (the 2006 metal prices noted above), annual gross revenues were USD$248.29 million. Where metal prices are 20 per cent higher, the Group estimated revenues to be USD$306.99 million per year.

The Working Group determined that the USD$250,000 fee payable to the Authority would be paid during the third year (the beginning of exploration). It noted that this would be handled as a separate cost that is not included in either the operating or capital costs, but would be included in the overall calculation of the Internal Rate of Return (IRR).

Equity Participation

The Working Group indicated that in the model, capital contributions by the Contractor and the Enterprise were calculated as separate variables, as were cumulative capital contributions. It also indicated that the Enterprise's contributions were calculated at 10 per cent intervals from 0 to 40 per cent of total equity investment.

The Group distributed net revenues (after deduction of operating expenses and capital recovery) according to equity share. In this regard, it noted that for the Enterprise the possible values of equity share are 0 per cent, 20 per cent, 30 per cent, 40 per cent and 50 per cent, corresponding to equity investments of 0 per cent, 10 per cent, 20 per cent, 30 per cent and 40 per cent respectively.

Financial Analysis

The Working Group analyzed four cases in its study. In case 1, the Group used the set of base assumptions for costs and revenues. In case 2, the Group increased the capital and annual operating costs for the at-sea system and the processing plant by 20 per cent. In case 3, the Group used the base assumptions for costs and increased gross sales revenues by 20 per cent. Finally, in case 4 the Group used the increased cost and revenues in cases 2 & 3.

The Working Group reported the results for each case in *Tables 1 to 4* below. It also reported the IRRs for each case including the level of equity share in *Figure 2*. These were reported for the project as a whole, for the Contractor and for the Enterprise.

Table 1: Base case

Calculation Assumptions and Results

Case 1: Base Cost, Base Revenue

For this case, variables are as follows:

Capital

Prospecting:	5.0 million
Pre-Operation Exploration:	12.5 million
At-Sea Capital	100 million
Processing Capital:	400 million
Annual Operating Costs	
Operational Exploration:	5 million
At-Sea Operating:	20 million
Processing Operating:	80 million
Revenues	
Total Gross Revenue at full capacity:	248.29 million/year

Results:

Enterprise Equity Share	0%	20%	30%	40%	50%
Overall Project	17.56%	17.56%	17.56%	17.56%	17.56%
Enterprise	0%	23.23%	20.76%	19.80%	19.28%
Contractor	17.56%	16.69%	16.57%	16.43%	16.22%

Table 2: High Cost, Base revenue

Case 2: High Cost, Base Revenue

For this case, variables are as follows:

Capital

Prospecting:	5 million
Pre-Operation Exploration:	12.5 million
At-Sea Capital:	120 million
Processing Capital:	480 million
Annual Operating Costs	
Operational Exploration:	12.5 million
At-Sea Operating:	24 million
Processing Operating:	96 million
Revenues	
Total Gross Revenue at full capacity:	248.29 million/year

Results:

Enterprise Equity Share	0%	20%	30%	40%	50%
Overall Project	12.78%	12.78%	12.78%	12.78%	12.78%
Enterprise	0%	17.07%	15.22%	14.49%	14.09%
Contractor	12.78%	12.11%	12.03%	11.96%	11.76%

Table3: Base Cost, High Revenue

Case 3: Base Cost, High Revenue

For this case, variables are as follows:

Capital

Prospecting:	5.0 million
Pre-Operation Exploration:	12.5 million
At-Sea Capital	100 million
Processing Capital:	400 million

Annual Operating Costs

Operational Exploration:	5 million
At-Sea Operating:	20 million
Processing Operating:	80 million

Revenues

Total Gross Revenue at full capacity:	306.99 million/year

Results:

Enterprise Equity Share	0%	20%	30%	40%	50%
Overall Project	23.49%	23.49%	23.49%	23.49%	23.49%
Enterprise	0%	30.89%	27.65%	26.39%	25.72%
Contractor	23.49%	22.37%	22.22%	22.03%	21.77%

Table 4: High Cost, High Revenues

Case 4: High Cost, High Revenue

For this case, variables are as follows:

Capital

Prospecting:	5 million
Pre-Operation Exploration:	12.5 million
At-Sea Capital:	120 million
Processing Capital:	480 million

Annual Operating Costs

Operational Exploration:	12.5 million
At-Sea Operating:	24 million
Processing Operating:	96 million

Revenues

Total Gross Revenue at full capacity:	306.99 million/year

Results:

Enterprise Equity Share	0%	20%	30%	40%	50%
Overall Project	18.61%	18.61%	18.61%	18.61%	18.61%
Enterprise	0%	24,63%	22.00%	20.98%	20.43%
Contractor	18.61%	17.69%	17.57%	17.41%	17.20%

Analysis

The results of the calculations made by the Working Group are summarized in *Figure 2*. From the graphical display, the Group observed that the greatest impact on profitability comes from the initial Enterprise investment of 10 per cent equity purchase and 20 per cent equity participation. The Group noted that for the Enterprise, the IRR achieves its highest rate at the 20 per cent level of equity participation. It concluded that this is due to the high ratio of equity participation to share of investment of 200 per cent. It noted that as the ratio declines of equity participation to share of investment declines to 150 per cent, 133 per cent and 120 per cent, the IRR also declines. Similarly, as the Contractor's equity to investment ratio declines from 100 per cent to 89 per cent, 87.5 per cent, 85.7 per cent and 83.3 per cent, its IRR declines as well.

Finally the Group stated that this relationship also indicates that there is an inverse relationship between the scale of participation by the Enterprise and the return on its investment, with increased investment resulting in a lower IRR even though the total financial return still increases with increasing equity share.

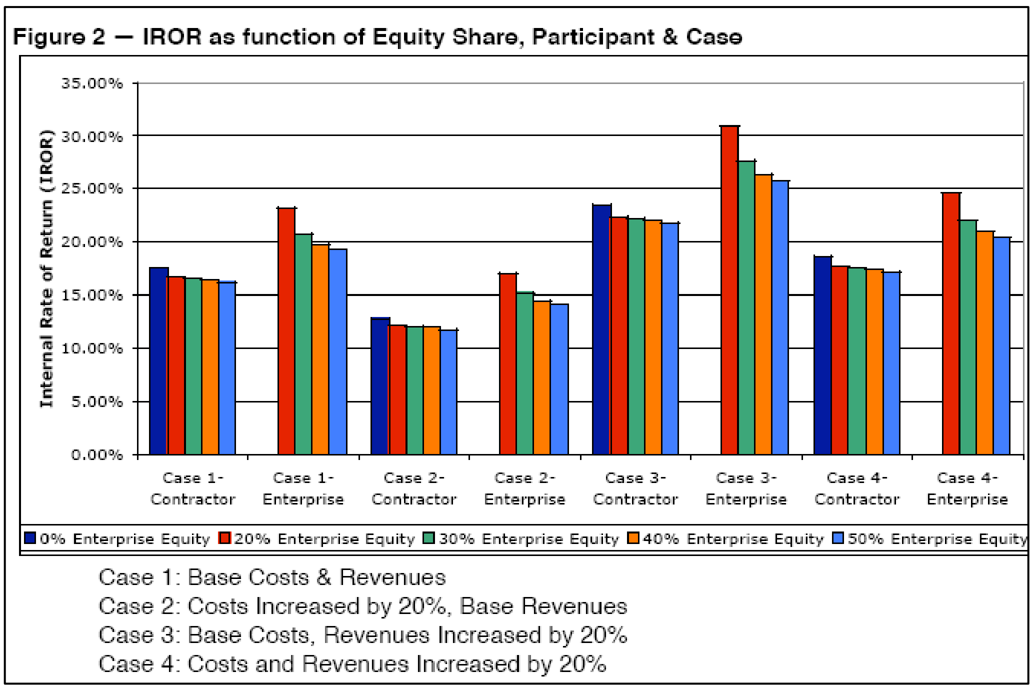


Figure 2 *Internal Rate of Return as a function of equity share of contractor and Enterprise for each case.*

The Working Group stated that in cases where investment capital is scarce or where the Contractor is increasingly risk averse at higher levels of investment, the Contractor may find the reduction of IRR to be balanced or overshadowed by the investment injection by the Enterprise. The Working Group also stated that the analysis suggests that if the Enterprise has limited funds available for investment and there are multiple projects of similar return and risk in which to invest, the Enterprise would benefit by spreading its investment across the opportunities to keep its investment at the higher levels of return and spread its risk across multiple projects.

Year	Prospecting	Exploration	R & D	*Sea-based Capital*	*Land-based Capital*	Total Capital	Recoverable Capital	Recovered this year	end of Year Cumulative Capital.	Sea-based Operations	Land-based Operations	Fees	Total Operating Costs	Recovery Rate	Total Sales	Net Revenues	Net Annual cash flow	Net Annual Cash Flow from Equity page
1	2500000					2500000	2500000	0	2500000				0	0	0	0	-2500000	-2500000
2	2500000					2500000	5000000	0	5000000				0	0	0	0	-2500000	-2500000
3		2500000				2500000	7500000	0	7500000			3E+05	250000	0	0	-250000	-2750000	-2750000
4		2500000				2500000	10000000	0	10000000				0	0	0	0	-2500000	-2500000
5		2500000		*20000000*	*80000000*	102500000	112500000	0	112500000				0	0	0	0	-102500000	-102500000
6		2500000		*50000000*	*200000000*	252500000	365000000	0	365000000				0	0	0	0	-252500000	-252500000
7		2500000		*30000000*	*120000000*	152500000	517500000	0	517500000				0	0	0	0	-152500000	-152500000
8		5000000				0	517500000	0	517500000	20000000	80000000		105000000	0.4	99316800	-5683200	-5683200	-5683200
9		5000000				0	517500000	81219000	436281000	20000000	80000000		105000000	0.75	186219000	81219000	81219000	81219000
10		5000000				0	436281000	143292000	292989000	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
11		5000000				0	292989000	143292000	149697000	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
12		5000000				0	149697000	143292000	6405000	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
13		5000000				0	6405000	6405000	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
14		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
15		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
16		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
17		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
18		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
19		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
20		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
21		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
22		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
23		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
24		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
25		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
26		5000000				0	0	0	0	20000000	80000000		105000000	1	248292000	143292000	143292000	143292000
27		0				0	0	0	0	20000000	80000000		100000000	1	248292000	148292000	148292000	148292000
																IROR:	17.56%	17.56%
														1	2	0.659754	Capital Cost Scaling Factor	

Summary of the discussions

A participant who was also a member of the working group made the point that the contentious issue of area sizes should not only be reported as a recommendation without consensus but incorporated as two alternative recommendations in the report of the working group reflecting the different opinions. The participant stressed that in his opinion the size of exploration areas and mining areas as suggested by Dr. Hein were not sufficient and that important risk factors and uncertainties were not taken into account in Dr. Hein's suggestions. He added that it would be hard to reach a consensus in this respect, so the best way would be to provide decision makers with two recommendations.

Dr. Hein agreed to this proposal and said, however, that based on his experience, even a mine site area of only 100 square kilometres would be sufficient. Companies would be able find 'mineable areas' with thick crusts, without sediment cover, and with subdued topography. He said that these sites had already been identified.

Another participant supported the idea of providing optional recommendations with respect to the exploration and mine site areas. The participant said that an investor intending to embark on a large scale programme should be given the possibilities with certain reservations regarding appropriate financial investments and adherence to the rules for relinquishment.

Another participant commented that he agreed that there was a need to make alternative recommendations, but that it would not be credible to suggest options for the mine site in such a wide range between 500 to 2,500 square kilometres.

Dr. Hein concurred and stated that the recommendations should reflect a certain level of confidence. He also noted that his suggestions were based on scientific evidence and the best available data. He said that the data that the other suggestion was based on, remained largely unknown.

Dr. Hein was asked how many suitable mining areas of 2,500 square kilometres size could possibly be found within the region of primary interest which he had earlier identified in the Central Pacific Ocean. He replied that he had not measured the total area potentially feasible for mining yet. He reminded participants that less than 1 per cent of the number of seamounts in the Pacific Ocean had been explored. However, he said that given the fact that market penetration for cobalt from the seabed should not exceed 10 per cent, there would be high-quality mine sites to sustain cobalt mining operations for hundreds of years.

Another participant said that the options in terms of area sizes should not vary in range to up to five times the amount of territory in the regulations, and added that from the point of the Legal and Technical Commission all options should be supported by an equivalent amount of data. He said that to judge between the recommendations and to make rational decisions, the data that alternative recommendations were based on should be examined in the same way as Dr. Hein's data.

The Secretary-General said that he preferred a compromise between the two approaches, i.e. Dr. Hein's approach and the suggestions presented by Mr. Shengxiong. If there was no agreement between the parties, it should be stated in the report that there were two opinions. He added that this should be avoided and encouraged Dr. Hein and Mr. Shengxiong to come to an understanding on reasonable figures.

Dr. Hein invited the interested parties to meet again and to further discuss the matter.

A participant stated that there is a fundamental discrepancy between the case where an investor might establish a profitable mine site from a small area of 100 square kilometres and the case of another entity that might have considerably more resources at their disposal to develop a much larger area. He said that both these strategies should be encouraged in such a way that development of the resources and early relinquishment of unwanted territory are promoted. The participant further stated that the Authority should be able to allocate and manage contracts in an equivalent manner, and also said that this would be difficult for contract areas of between 100 square kilometres and 2,500 square kilometres. To solve the issue, this participant suggested defining a basic contract area and to make it possible for an entity to have several contracts with the Authority. To avoid monopolies the participant said that an upper limit for the number of contracts should be established, and further suggested that each contract would be managed separately by the Authority under the same terms and conditions.

Dr. Hein supported this proposal and said that this concept could solve most of the contentious issues.

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ANNEXES

Annex I

INTERNATIONAL SEABED AUTHORITY WORKSHOP ON MINING OF COBALT-RICH FERROMANGANESE CRUSTS AND POLYMETALLIC SULPHIDES : TECHNOLOGICAL AND ECONOMIC CONSIDERATIONS

Background Paper prepared by the Secretariat

1. The International Seabed Authority will convene a workshop on technical and economic considerations for mining cobalt rich ferromanganese crusts (CRFCs) and polymetallic sulphides (PSDs) resources of the international seabed area ("the Area") in Kingston, Jamaica, from 31 July to 4 August 2006.

I. Issues to be Addressed

2. During the fourth session of the International Seabed Authority in August 1998 the delegation of the Russian Federation requested that the Authority adopt regulations for mineral resources other than polymetallic nodules, namely polymetallic sulphides and cobalt crusts. Until 2000 the main focus of the work of the Authority was the completion of regulations for prospecting and exploration for polymetallic nodules in seabed areas beyond the limits of national jurisdiction (the Area).

3. At the tenth session of the Authority, the Legal and Technical Commission submitted "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. Document ISBA/10/C/WP.1 comprises 43 regulations and four annexes. Annex 1 is on "Notification of intention to engage in prospecting", Annex 2 is on "Application for approval of a plan of work for exploration to obtain a contract", Annex 3 "Contract for exploration", and Annex 4 contains standard clauses for exploration contracts.

4. At the eleventh session of the Authority (August 2005), following the first reading of "Draft regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area", the Council requested the Secretariat to clarify the technical content of some of the regulations.

5. The purpose of the workshop is to examine the prospects for the development of cobalt-rich ferromanganese crusts and polymetallic sulphides deposits in the Area, and to provide the members of the Authority with relevant and up-to- date data and information on, inter alia,

(a) The process through which occurrences of cobalt-rich ferromanganese crusts and polymetallic sulphides in the Area may be converted to commercially exploitable deposits;
(b) The geologic characteristics and geographic distribution of potential cobalt-rich ferromanganese crusts deposits/occurrences in the Area;

(c) The geologic characteristics and geographic distribution of potential polymetallic sulphides deposits/ occurrences in the Area;
(d) Technological issues associated with commercializing cobalt-rich ferromanganese crusts deposits in the Area;
(e) Technological issues associated with commercializing polymetallic sulphides deposits/occurrences in the Area;
(f) Economic and financial issues associated with commercializing cobalt-rich ferromanganese crusts deposits in the Area;
(g) Economic and financial issues associated with commercializing polymetallic sulphides deposits in the Area;
(h) The market outlook for the base and precious metals to be found in these two potential ores;
(i) Financial terms of exploration/production contracts for the relevant base metals in terrestrial mining;
(j) A comparison of the costs for environmental protection in land-based mining of the relevant base metals and for cobalt-rich ferromanganese crusts and polymetallic sulphides in the Area;
(k) A hypothetical cobalt-rich ferromanganese mining venture in the Area, and
(l) A hypothetical polymetallic sulphides mining venture in the Area.

6. As part of the workshop, it is proposed to use the two hypothetical mining ventures as the basis for a practical application of the system of participation by the Authority in either venture, should a contractor select this option.

7. Though these subjects have not all been addressed explicitly in previous workshops by the Authority, a number of presentations and papers at these workshops provide valuable information in this regard. This background paper contains excerpts that are relevant to the various workshop topics, from papers presented at some of the Authority's previous workshops.

II. Relevant Information from the Authority's Previous Workshops and its Central Data Repository

8. The Authority's workshop in June 2000, on the subject **"Minerals other than polymetallic nodules of the Area"**, was focused on polymetallic sulphides and cobalt-rich ferromanganese crusts (occurrences/deposits), their environments of deposition, associated flora and fauna, measures that could be taken to protect associated flora and fauna from future mining, and issues related to the differences between these two mineral resources and polymetallic nodules, that would impact the application of the common heritage principle in relation to the development of the latter resources. In addition, the workshop was informed of international programmes researching various aspects of polymetallic sulphides and cobalt-rich ferromanganese crusts (occurrences/deposits).[1]

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[1] Minerals other than Polymetallic Nodules of the International Seabed Area - Proceedings of the International Seabed Authority's workshop held in Kingston, Jamaica 26-30 June 3000

9. Some of the papers presented at the 2000 workshop that are of relevance to the current workshop include, inter alia,

- "Metallogenesis of Marine mineral resources" – Dr Peter Rona
  (This paper encompassed a wide-range of topics on the marine minerals industry, and the types of marine mineral resources that have attracted commercial interest from coastlines to the deep ocean basins. In relation to seafloor mineralization, he addressed the discovery, origins, and the distribution of both polymetallic sulphides and cobalt-rich ferromanganese crusts deposits. He also addressed the exploration methods for both types of deposits subdividing exploration into finding and characterizing the deposits).

- "A comparison of possible economic returns from mining deep seabed polymetallic nodules, seafloor massive sulphides (polymetallic sulphides) and cobalt-rich ferromanganese crusts" – Jean-Pierre Lenoble.

  (This paper undertook a comparison of the possible economic returns from mining a polymetallic nodule deposit, a polymetallic sulphides deposit and a cobalt-rich ferromanganese deposit. It examined the characteristics of each deposit (nature of the deposits, parameters needed to estimate the tonnage and metal content of each type of deposit and the state of the art of mining and processing technologies), and based on an average of metal prices for the period 1960 to 1999, compared the value of the three types of deposits based on the value of a tonne of *in situ* ore).

10. At this workshop, papers were presented that dealt exclusively with polymetallic sulphides. In that regard, the following papers are relevant:

Polymetallic Sulphides

- "Seafloor massive sulphides deposits and their resource potential" Professor Peter Herzig, S. Petersen and Mark D. Hannington.
  (This paper addressed the origin, occurrence, metal composition, size, tonnage, resource potential and global distribution of polymetallic sulphides deposits).

- "Hydro thermal sulphide mineralization of the Atlantic – Results of Russian investigations" – G. Cherkashev. A. Ahsadze and A. Glumov.
  (This paper informed the workshop about polymetallic sulphides deposits that had been found in the Mid-Atlantic Ridge. The paper highlighted areas showing promise for new hydrothermal fields, provided metal content information for three deposits (Logachev 1 and 2, and the MIR mound) and informed participants of the results of metallurgic tests of samples recovered from the MIR mound).

- Technical requirements for exploration and mining seafloor massive sulphides deposits and cobalt-rich ferromanganese crusts" – Professor Herzig and S. Petersen.
  (This paper described the technical requirements for exploration and mining of polymetallic sulphides and cobalt-rich crusts deposits).

- “Financing exploration for seafloor massive sulphides deposits” – Julian Malnic
(This paper addressed issues involved in raising finance for the exploration of polymetallic sulphides deposits in Papua New Guinea’s marine jurisdiction).

- “Status report on the data and information requirements of Papua New Guinea’s seafloor massive sulphides deposits” – James Wanjik.
(This paper addressed the data and reporting requirements for exploring for polymetallic sulphides deposits under Papua New Guinea’s Mining Act. It provides information on the terms of an exploration license, including duration, size of exploration areas, and the role of marine scientific research in the development of these resources).

11. Similarly, some of the papers presented at this workshop dealt exclusively with cobalt-rich ferromanganese crusts. In that regard, the following papers are relevant to the current workshop:

Cobalt-rich ferromanganese Crusts

- “Regional and local variability in the spatial distribution of cobalt-bearing ferromanganese crusts in the world’s ocean” – V.M. Yubko and Y.B. Kazmin.
(This paper presents data and information on cobalt-rich ferromanganese crusts provinces in the oceans from a multi-tiered graphical database created from 2217 sampling stations from which parameters on ore abundance from 20 ore provinces and 64 regions where crusts deposits are known to occur. It provides data on a typical crusts ore field, and it also presents critical statistics for the eight main areas of cobalt-rich crusts in the North-West Pacific Ocean).

- “Cobalt-rich ferromanganese crusts: Global distribution, composition. Origin and research activities” - James R. Hein.
(This paper provided information on the origin, composition and distribution of cobalt-rich ferromanganese crusts deposits in the world’s oceans. It provided ranges for the cobalt content of crusts deposits, objectives to meet during the initial and later stages of exploration for crusts deposits, twelve criteria that have been developed for the exploration and mining of such deposits and recommendations for future research on the subject).

12. In 2004, the Authority convened a workshop on the establishment of environmental baselines at deep seafloor cobalt-rich ferromanganese crusts and deep seabed polymetallic sulphides mine sites in the Area, for the purpose of evaluating the likely effects of exploration and exploitation of these resources on the marine environment.

13. Some of the papers of the 2004 workshop of relevance to the current workshop include, inter alia,

Polymetallic Sulphides

- Proposed exploration and mining technologies for polymetallic sulphides. *Professor Steven Scott, Scotiabank Marine Geology Research Laboratory, University of Toronto.*
  (This paper reviews prospecting and exploration methodologies for polymetallic sulphides deposits, the prospects and economics of polymetallic sulphides mining and possible mining technologies).

- "Exploration for and pre-feasibility of mining polymetallic sulphides – a commercial case study" - *Mr. David Heydon, Chief Executive Officer of Nautilus Minerals Ltd.*
  (This paper presents the steps being taken by Nautilus Minerals Ltd, a company that has an exploration license for polymetallic sulphides deposits in the territorial sea of Papua New Guinea to commercialize sulphides deposits in that area. The company is in a technical alliance with six companies that have expertise in different aspects of the integrated operation. These are: Worley as Project Manager, Perry and Voest-Alpine Bergtechnik providing the required expertise in Remote Operated Vehicles and Miner cutting tool respectively: Siemag is in the alliance for ore hoisting, and Seacore and Williamson Associates bring their expertise in drilling and resource geophysics to the alliance. The paper describes the exploration methods being used (water column testing to locate evidence of active plumes for the purposes of identifying older and mature orebodies along strike or rift), geophysical tools (such as resistivity, self potential, magnetics, induced polarization, gravity and video cameras), and sampling and drilling. The paper also compares sulphides exploration with crusts exploration and identifies the amount of seafloor area required to obtain 2 million tons of ore in each case. The paper provides information on the foreseen mine (annual production, mine life, the characteristics of ore bodies to support the operation and specifications of its ROV miner).

- "Mining on land versus the seafloor – a case study. Antamina Mine comparison" - *Mr. David Heydon, Chief Executive Officer of Nautilus Minerals Ltd.*
  (This paper compares the Nautilus Seafloor project (grades of copper, zinc and gold, and annual production) to the Antamina mine (zinc and copper producer) being undertaken by Teck Cominco, Noranda and BHP-Billiton in Peru. The paper states that the seafloor project compares favourably to the land-based operation).

Cobalt-rich ferromanganese Crusts

- Proposed exploration and mining technologies for cobalt-rich crusts - *Dr. Rahul Sharma, National Institute of Oceanography, Dona Paula, Goa, India.*
  (This paper evaluates mining scenarios for cobalt-rich ferromanganese crusts deposits and associated environmental considerations. Using data contained in the 1987 Hawaii Department of Planning and Economic Development publication on "Mining Development Scenario for cobalt-rich Manganese Crusts in the Exclusive Economic Zones of the Hawaiian Archipelago and Johnston Island", this paper outlines the possible environmental impact of

crusts mining. The paper also provides the estimates of the resource potential of crusts within the EEZ of the Hawaiian archipelago and Johnston Island).

14. At the Authority's eleventh workshop which was convened in March 2006 on the subject "Cobalt-rich ferromanganese crusts and the diversity and distributions patterns of seamount fauna", Dr. Hein presented a paper on the characteristics of seamounts and cobalt-rich ferromanganese crusts which provided an update of his 2000 paper. This paper also provides information that is of particular relevance to the current workshop.

- Characteristics of Seamounts and cobalt-rich ferromanganese crusts. *James R. Hein, Senior Geologist United States Geological Survey, USA.*
  (This paper provides relevant information on the factors that lead to the formation of cobalt-rich ferromanganese crusts in the oceans, the metals that they contain, and identifies the different regions of the world's oceans where the metals of commercial interest in cobalt-rich crusts are highest. The paper provides criteria that have to be met by cobalt-rich bearing ferromanganese crusts seamounts to meet the requirements of likely first generation mine-sites, pointing out that seamounts in the Central Pacific Ocean region best meet these criteria. The paper provides data on the surface areas of typical equatorial guyots and conical seamounts and estimates that based on a crust thickness of 26 kilograms per square meter, 77 square kilometres of crusts had to be mined to satisfy a production rate of 2 million tonnes of crust per year. The paper also estimates the area of crusts (with an average crust thickness of two centimetres) that would be required to meet a twenty year mining operation and the number of seamounts (large and average-sized) that would undertake the project).

III. The Authority's Central Data Repository

15. The Authority continues to maintain and upgrade its Central Data Repository (CDR) on marine mineral resources. The CDR presently has mineral data on cobalt-rich ferromanganese crusts occurrences on seamounts from over 1130 locations. The data on polymetallic sulphides occurrences are from around 50 locations (with several additional entries showing detailed sampling in most of the stations). The Authority has used these data sets along with additional data from workshops that it convened, and data available in the public domain (the InterRidge web site for the PMS data) to prepare several maps showing the occurrences of these two types of marine minerals in the world's oceans and in the International Seabed Area. The Authority has used the data in its repository to produce the two maps contained in Annex I on world-wide distribution of cobalt-rich ferromanganese crusts and polymetallic sulphides occurrences/deposits in the Area.

IV. The Draft Regulations on Prospecting and Exploration for Polymetallic Sulphides and Cobalt-Rich Crusts in the Area (ISBA/10/C/WP.1)

16. The draft Regulations on prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts in the Area, document ISBA/10/C/WP1, provides definitions for prospecting, exploration and exploitation of these minerals as follows:

(a) "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;[1]

(b) "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, and

(c) "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;

Prospecting

17. In accordance with the draft Regulations,

- Prospecting shall be conducted in accordance with the Convention and the Regulations and may commence only after the prospector has been informed by the Secretary-General that its notification has been recorded pursuant to regulation 4, paragraph 2.

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

- Prospecting shall not be undertaken in an area covered by an approved plan of work for exploration for polymetallic sulphides or cobalt crusts or in a reserved area; nor may there be prospecting in an area which the Council has disapproved for exploitation because of the risk of serious harm to the marine environment.

- Prospecting shall not confer on the prospector any rights with respect to resources. A prospector may, however, recover a reasonable quantity of minerals, being the quantity necessary for testing, and not for commercial use.

- There shall be no time limit on prospecting except that prospecting in a particular area shall cease upon written notification to the prospector by the Secretary-General that a plan of work for exploration has been approved with regard to that area, and

- Prospecting may be conducted simultaneously by more than one prospector in the same area or areas.

Exploration

18. With regard to applications for approval of plans of work for exploration in the form of contracts, in addition to meeting requirements with regard to the form of applications, a certificate of sponsorship[2] and financial and technical capabilities[3] the

draft Regulations specify that the total area covered by the application should meet the following conditions:

- The area covered by each application for approval of a plan of work for exploration shall be comprised of not more than 100 blocks.

- For polymetallic sulphides or cobalt crusts the exploration area shall consist of contiguous blocks. For the purposes of this regulation two blocks that touch at any point shall be considered to be contiguous.

- Notwithstanding the provisions in paragraph 1 above, where a contractor has elected to contribute a reserved area to carry out activities pursuant to annex III, article 9, of the Convention, in accordance with regulation 17, the total area covered by an application shall not exceed 200 blocks.

19. Where the applicant elects to contribute a reserved area, the area covered by the application shall be sufficiently large and of sufficient estimated commercial value to allow two mining operations. The applicant shall divide the blocks comprising the application into two groups of equal estimated commercial value and composed of contiguous blocks. The area to be allocated to the applicant shall be subject to the provisions of regulation 27.

20. Each such application shall contain sufficient data and information, as prescribed in section III of Annex 2 to these Regulations, with respect to the area under application to enable the Council, on the recommendation of the Legal and Technical Commission, to designate a reserved area based on the estimated commercial value of each part. Such data and information shall consist of data available to the applicant with respect to both parts of the area under application, including the data used to determine their commercial value.[4]

21. The Council, on the basis of the data and information submitted by the applicant pursuant to section II of Annex 2 to these Regulations, if found satisfactory, and taking into account the recommendation of the Legal and Technical Commission, shall designate the part of the area under application which is to be a reserved area. The area so designated shall become a reserved area as soon as the plan of work for exploration for the non-reserved area is approved and the contract is signed. If the Council determines that additional information, consistent with these Regulations and Annex 2, is needed to designate the reserved area, it shall refer the matter back to the Commission for further consideration, specifying the additional information required.[5]

22. Once the plan of work for exploration is approved and a contract has been issued, the data and information transferred to the Authority by the applicant in respect of the reserved area may be disclosed by the Authority.[6]

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2 Regulations 10 and 11
3 Regulation 13
4 In accordance with article 14, paragraph 3, of annex III of the Convention
5 Regulation 28
6 Regulation 27

23. A plan of work for exploration shall be approved for a period of 15 years. Upon expiration of a plan of work for exploration, the contractor shall apply for a plan of work for exploitation unless the contractor has already done so, has obtained an extension for the plan of work for exploration or decides to renounce its rights in the area covered by the plan of work for exploration.

24. Not later than six months before the expiration of a plan of work for exploration, a contractor may apply for extensions for the plan of work for exploration for periods of not more than five years each. Such extensions shall be approved by the Council, on the recommendation of the Commission, if the contractor has made efforts in good faith to comply with the requirements of the plan of work but for reasons beyond the contractor's control has been unable to complete the necessary preparatory work for proceeding to the exploitation stage or if the prevailing economic circumstances do not justify proceeding to the exploitation stage.[7]

25. The contractor shall relinquish the blocks allocated to it as follows:

(a) By the end of the fifth year from the date of the contract, the contractor shall have relinquished:

(i) At least 50 per cent of the number of blocks allocated to it; or

(ii) If 50 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

(b) By the end of the tenth year from the date of the contract, the contractor shall have relinquished:

(i) At least 75 per cent of the number of blocks allocated to it; or

(ii) If 75 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

(c) At the end of the fifteenth year from the date of the contract, or when the contractor applies for exploitation rights, whichever is the earlier, the contractor shall nominate up to 25 blocks from the remaining number of blocks allocated to it, which shall be retained by the contractor. Relinquished blocks shall revert to the Area.[6] [7]

(d) The Council may, at the request of the contractor, and on the recommendation of the Commission, in exceptional circumstances, defer the schedule of relinquishment. Such exceptional circumstances shall be determined by the Council and shall include, *inter alia*, consideration of prevailing economic circumstances or other unforeseen exceptional circumstances arising in connection with the operational activities of the Contractor.

[7] The Council may at the request of the contractor, and on the recommendation of the Commission, in exceptional circumstances, defer the schedule of relinquishment. Such exceptional circumstances shall be determined by the Council and shall include, *inter alia*, consideration of prevailing economic circumstances or other unforeseen exceptional circumstances arising in connection with the operational activities of the Contractor. (Regulation 27, paragraph 6).

26. Under the regulations, the maximum areas that will be allocated to contractors for exploration for cobalt-rich ferromanganese crusts and polymetallic sulphides deposits in the Area will be 100 blocks or 10,000 square kilometres. The possible mining operations from these exploration areas are expected to occur on 2500 square kilometres of the seafloor.

V. Mining Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides in the Area - Technological and Economic Considerations

27. As noted in section II, some of the papers and presentations made during the Authority's previous workshops provide useful information pertinent to this workshop. This section contains relevant excerpts on the two types of mineral resources from the workshops. The excerpts address some of the topics to be discussed at the workshop, including the geologic characteristics and geographic distribution of potential cobalt-rich ferromanganese and polymetallic sulphides deposits in the Area, technological, economic and financial issues that need to be addressed in their development, the market outlook for the metals of commercial interest in these two types of potential orebodies and hypothetical mining ventures for cobalt-rich ferromanganese crusts and polymetallic sulphides that might impact prospecting, exploration and subsequent mining of these mineral resources. For ease of comprehension, for each mineral resource, the relevant excerpts are presented under the topic to be discussed at the workshop. Part I contains excerpts relevant to cobalt-rich ferromanganese crusts and Part III contains excerpts relevant to polymetallic sulphides.

Part I : Excerpts from papers presented at ISA workshops on cobalt-rich ferromanganese crusts Occurrences/deposits

1. Geologic characteristics and geographic distribution

"Metallogenesis of marine minerals" *- Peter Rona, Professor Marine Geology and Geophysics Institute of Marine and Coastal Sciences Rutgers University*

28. "Sources of metals that form cobalt-rich ferromanganese crusts of the deep ocean are derived from both continental and deep ocean sources and are precipitated from seawater like manganese nodules. The metals in addition to iron and manganese include cobalt, nickel, platinum, and titanium depending on proximity to different sources. These metals precipitate at slow rates over millions of years as crusts up to about 25 cm thick on hard-rock substrates of seamounts and submerged volcanic mountain ranges between ocean depths of 400 and 4000 meters. These crusts are most widespread in the Pacific Ocean because of the large number of seamounts present."

"***Cobalt-rich ferromanganese crusts: Global distribution, composition, origin and research activities"*** *- James Hein, Senior Geologist, United States Geological Survey, USA*

29. "Cobalt-rich ferromanganese crusts occur throughout the global ocean on seamounts, ridges, and plateaus where currents have kept the rocks swept clean of sediments for millions of years. Crusts precipitate out of cold ambient seawater onto hard-rock substrates forming pavements up to 250 mm thick. Crusts are important as a

potential resource for primarily cobalt, but also for titanium, cerium, nickel, platinum, manganese, thallium, tellurium, and others. Crusts form at water depths of about 400-4000 m, with the thickest and most cobalt-rich crusts occurring at depths of about 800-2500 m, which may vary on a regional scale."

"Fe-Mn crusts have been recovered from seamounts and ridges as far north as the Aleutian Trench in the Pacific and Iceland in the Atlantic and as far south as the Circum-Antarctic Ridge in the Pacific, Atlantic, and Indian Oceans. However, the most detailed studies have concerned seamounts in the equatorial Pacific, mostly from the EEZ (200 nautical miles) of island nations including the Federated States of Micronesia, Marshall Islands, Kiribati, as well as in the EEZ of the USA (Hawaii, Johnston Island), but also from international waters in the Mid-Pacific Mountains."

"Compared to the estimated 50,000 or so seamounts that occur in the Pacific, the Atlantic and Indian oceans contain fewer seamounts and most Fe-Mn crusts are associated with the spreading ridges. Crusts associated with those spreading ridges usually have a hydrothermal component that may be large near active venting, but which is regionally generally a small (<30%) component of the crusts formed along most of the ridges. Those types of hydrogenetic-hydrothermal crusts are also common along the active volcanic arcs in the west Pacific, the spreading ridges in back-arc basins of the west and southwest Pacific, spreading centres in the south and east Pacific, and active hotspots in the central (Hawaii) and south (Pitcairn) Pacific. Very few (<15) of the approximate 50,000 seamounts in the Pacific have been mapped and sampled in detail, and none of the larger ones have been so studied, some of which are comparable in size to continental mountain ranges."

"The distribution of crusts on individual seamounts and ridges is poorly known. Seamounts generally have either a rugged summit with moderately thick to no sediment cover (0-150 m) or a flat summit (guyot) with thick to no sediment cover (0-500 m). The outer summit margin and the flanks may be terraced with shallowly dipping terraces headed by steep slopes meters to tens of meters high."

"The thickest crusts occur on summit outer-rim terraces and on broad saddles on the summits. Estimates of sediment cover on various seamounts range from 15% to 75%, and likely average about 50%. Crusts are commonly covered by a thin blanket of sediments in the summit region and on flank terraces. In the Pacific, the thickest crusts occur at water depths of 1500-2500 m, which corresponds to the depths of the outer summit area and upper flanks of most Cretaceous seamounts. The water depths of thick high cobalt content crusts vary regionally and are generally shallower in the South Pacific where the OMZ is less well developed; there, the maximum cobalt contents and thickest crusts occur at about 1000-1500 m. Thick crusts are rarely found in the Atlantic and Indian Oceans, with the thickest (up to 125 mm) being recovered from the New England seamount chain (NW Atlantic), and a 72 mm-thick crust being recovered from a seamount in the Central Indian Basin."

"The characteristics of crust deposits that would influence mining 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 (Cobalt (Co) +Nickel (Ni) +Manganese (Mn) + Iron (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 its depth of occurrence (500-5000 m), location (whether on axis or off axis), the slopes on which they occur (0-40^0) and micro topographic undulations (1-100 cm)."

“The surface areas of 34 typical equatorial Pacific guyots and conical seamounts were measured. Surface areas were determined using Arc Map’s 3-D analyst and the amount of sediment versus hard-rock areas were calculated from side-scan sonar back-scatter images. The surface areas of 19 guyots and 15 conical seamounts varied from 4,776 to 313 square kilometres. The total area of the 34 seamounts is 62,250 square kilometres, which cover a geographic region of 506,000 square kilometres. The average surface area of the 34 seamounts is 1,850 square kilometres. The amount of surface area above 2500 m water depth, where mining is likely to occur, averages 515 square kilometres (range 0-1,850 square kilometres). Guyots are bigger than conical seamounts because guyots at one time grew large enough to be islands before erosion and subsidence took place. The conical seamounts never grew large enough to breach the sea surface.”

“In the Pacific, the thickest crusts occur at water depths of 1500-2500 m, which corresponds to the depths of the outer summit area and upper flanks of most Cretaceous seamounts. The water depths of thick high cobalt content crusts vary regionally and are generally shallower in the South Pacific where the OMZ is less well developed; there, the maximum cobalt contents and thickest crusts occur at about 1000-1500 m.”

“Thick crusts are rarely found in the Atlantic and Indian Oceans, with the thickest (up to 125 mm) being recovered from the New England seamount chain (NW Atlantic), and a 72 mm-thick crust being recovered from a seamount in the Central Indian Basin.”

“The thickest crusts occur on summit outer-rim terraces and on broad saddles on the summits. Estimates of sediment cover on various seamounts range from 15% to 75%, and likely average about 50%. Crusts are commonly covered by a thin blanket of sediments in the summit region and on flank terraces. It is not known how much sediment can accumulate before crusts stop growing. Crusts have been recovered from under as much as 2 m of sediment without apparent dissolution. Based on coring results, Yamazaki estimated that there are 2-5 times more Fe-Mn crust deposits on seamounts than estimates based on exposed crust outcrops because of their coverage by a thin blanket of sediment. Those thinly veiled crusts would be within reach of mining operations.”

“Within the central Pacific, a great many seamounts occur within the Area (international waters), and promising locations for potential mining occur within the Mid-Pacific Mountains, such as between Wake and Minami Torishima (Marcus) Islands, the Magellan Seamounts, seamounts between the EEZs of Johnston Island and the Marshall Islands and Johnston Island and Howland and Baker Islands, Shatsky Rise farther to the north might also be promising. Figure 1 prepared with the assistance of Dr. Hein shows this area.

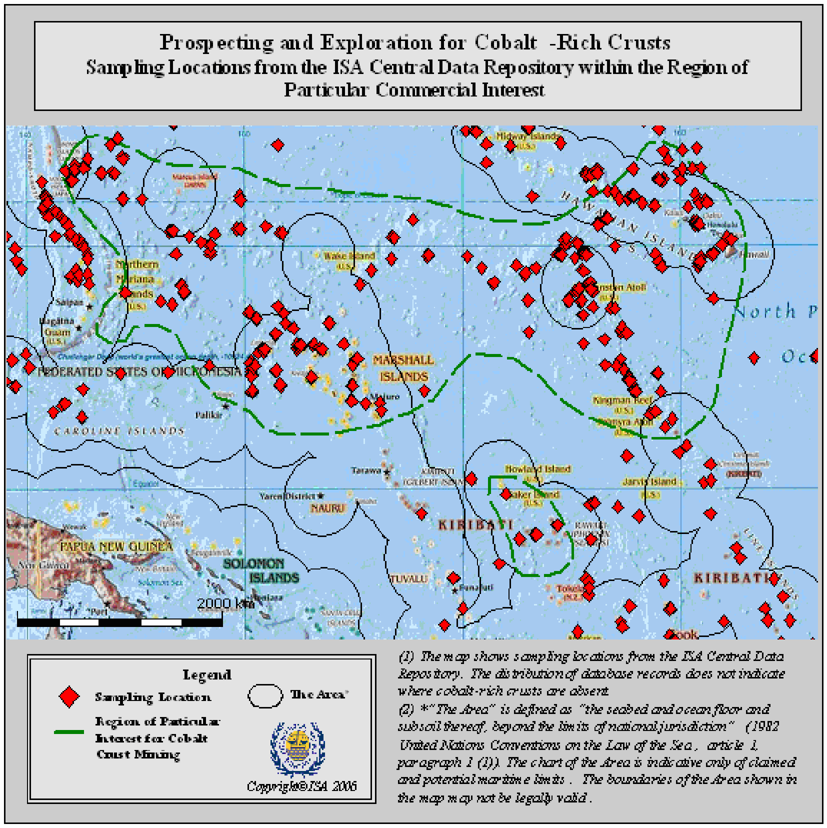


Figure 1: Sampling locations for Cobalt Rich Ferromanganese crusts in the Pacific. The green line shows the region of interest for Cobalt Crust Mining.

"A Comparison of the Possible Economic Returns from Mining Deep Seabed Polymetallic Nodules, Seafloor Massive Sulphides and Cobalt-Rich Crusts"

- Jean-Pierre Lenoble, Ingenieur Geologue, Legal and Technical Commission (ISA) Chatou, France

30. "Encrustations of ferromanganese hydroxides have been found in many areas of the seafloor, but more particularly, where consolidated sediments and hard rocks outcrop. Most of them were discovered on seamounts or plateaux that constitute elevations of the seafloor in abyssal areas. These summits are frequently linked with volcanic structures and sometimes are sunken atolls."

"Since the beginning of the 1980s, ferromanganese crusts deposits have attracted the attention of explorers, as potential resources for cobalt. Although several exploration surveys have been carried out in different parts of the world's oceans, mostly by scientific institutions, the state of knowledge is still limited."

"Cobalt-bearing crusts are often associated with low-grade nodules. Both these deposits have relatively low manganese to iron ratio (1-2.5) in comparison to polymetallic nodules of economic interest (4-6). Their nickel and copper contents are also lower (0.3-1%). While the cobalt content of crusts can reach 3%, on average it is only 0.6-0.8%, or three to four times greater than the average cobalt content of "good" nodules (0.25%). Other metals occur as trace metals. These include vanadium (0.06%), molybdenum (0.05-0.1%), and platinum (0.14 to 5 ppm)."

"The richest cobalt-crusts deposits appear to be concentrated at water depths of 800-2000 m. Some scientists have considered a link with the oxygen minimum zone as a possible reason for their formation. However, as in fossil stratigraphy, such crustification is an indication of a lacuna of sedimentation, either by a hiatus (no deposition) or by intermediate erosion. Similar encrustations, associated with nodules, were found in cores made on top of seamounts in the Indian Ocean and later in many DSDP cores. They were proved lacunae of sedimentation. Observations of current activities that prevent sediment deposition have been recorded during several surveys."

"It seems that there are two kinds of cobalt-rich crusts deposits:

- Flat deposits on top of sunken atolls, where the crust covers old coral reef formations;

- Inclined deposit on the flanks of volcanic seamounts, where the crust covers volcanic breccias and associated sediments.

1. Economic and financial issues associated with commercializing Cobalt-rich ferromanganese crusts in the Area

"Characteristics of Seamounts and Cobalt-Rich Ferromanganese Crusts"
- James R. Hein, Senior Geologist, United States Geological Survey, USA

31. "The greatest potential economic value of Fe-Mn crusts has always been their unprecedented high contents of cobalt. However, Fe-Mn crusts contain high concentrations of a great variety of metals that could become important by-products of cobalt recovery. Recently, significant increased demands for metals in the rapidly growing economies of China and India have pushed up the metal prices, notably copper, nickel, and cobalt. This upward trend in prices will fluctuate, but should not be ameliorated anytime soon. Nickel consumption in China has increased five fold in the decade of the 1990s and continues to grow. The projected annual rate of growth of world consumption is expected to range from 4-6% for cobalt, copper, and nickel. Shortages of copper supplies have been projected to occur within the next decade. The price of copper has more than tripled since 2001, and the price of nickel has likewise increased significantly, although with large fluctuations. These increased metal demands may have an impact on the three main deep-seabed mineral-deposit types in that nodules and crusts have high copper, nickel, and cobalt contents, and polymetallic sulphides have high copper contents. Increased metal demand and higher prices make the potentiality for marine mining more likely."

"The combined cobalt (Co), nickel (Ni), and copper (Cu) contents are highest in the open Pacific Ocean, intermediate in the Indian and Atlantic Oceans, and lowest along the continental margins in the Pacific Ocean. The highest copper contents occur in Indian Ocean crusts because they are generally from deeper water areas and copper contents increase with increasing water depth of crust occurrence. Shatsky Rise Fe-Mn crusts, mid-latitudes of the northwest Pacific, have a surprisingly high mean copper content, as well as the highest copper value yet measured in a bulk crust, 0.4% (4000 ppm). Platinum (Pt) contents are highest in the Atlantic and open South Pacific crusts, intermediate in the open North Pacific and Indian Ocean crusts, and lowest in crusts from continental margins. Cerium (Ce) and the other rare-earth elements are generally highest in Indian and Atlantic Ocean crusts."

"Cobalt-rich ferromanganese crusts: Global distribution, composition, origin and research activities" *– James Hein, Senior Geologist, United States Geological Survey, USA*

32. "Bulk crusts contain cobalt contents up to 1.7%, nickel to 1.1%, and platinum to 1.3 parts per million (ppm), with mean iron/manganese ratios of 0.4 to 1.2. Cobalt, nickel, titanium, and platinum decrease, whereas iron/manganese, silicon, and aluminium increase in continental margin crusts and in crusts with proximity to west Pacific volcanic arcs. Vernadite- and CFA-related elements decrease, whereas iron, copper, and detrital-related elements increase with increasing water depth of crust occurrence. Cobalt, cerium, thallium, and maybe also titanium, lead, tellurium, and platinum are strongly concentrated in crusts over other metals because they are incorporated by oxidation reactions. Total rare-earth elements (REEs) commonly vary between 0.1% and 0.3% and are derived from seawater along with other hydrogenetic elements, cobalt, manganese, nickel, etc. Platinum-group elements are also derived from seawater, except palladium, which is derived from detrital minerals."

"Proposed Exploration and Mining Technologies For Cobalt-Rich Crusts"
- Dr. Rahul Sharma, Scientist, National Institute of Oceanography, Dona Paula, India

33. "Although many studies have evaluated their metal contents and geological setting, a study undertaken by the Department of Planning and Economic Development of Hawaii in 1987 entitled "Mining Development Scenario for Cobalt-rich Manganese crusts in the Exclusive Economic Zones of the Hawaiian Archipelago and Johnston Island. Honolulu" addressed several aspects of the deposits, such as mining criteria, techno-economic feasibility and infra-structural requirements. The study area was estimated to have an overall in-place resource potential of 2.6 million tonnes of cobalt, 1.6 million tonnes of nickel, 81 million tonnes of manganese, and 58 million tonnes of iron with an average content of 0.73% Co, 0.45% Ni, 23% Mn and 16.5% Fe. This estimate is based on mean crust coverage of 40%, crust thickness ranging from 0.5-2.5 cm in different areas, and average density of 1.95g/cm^3 (wet) or 1.34 g/cm^3 (dry)."

3. Technological issues associated with commercializing cobalt-rich ferromanganese crusts in the Area

"Proposed Exploration and Mining Technologies for Cobalt-Rich Crusts"
- Dr. Rahul Sharma, Scientist, National Institute of Oceanography, Dona Paula, India

34. "The characteristics of crust deposits that would influence mining 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 (Cobalt (Co) +Nickel (Ni) +Manganese (Mn) + Iron (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 its depth of occurrence (500-5000 m), location (whether on axis or off axis), the slopes on which they occur (0-40^0) and micro topographic undulations (1-100 cm)."

"The Hawaiian and Johnston islands 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. Also metal concentrations of Co, Ni, and

Mn increase with increase in latitude, whereas Fe decreases. Similarly, crusts on sediments have higher concentrations of Aluminium (Al) and Copper (Cu), and lower concentrations of Mn, Co, and Zinc (Zn) than those on basalt substrates."

"A detailed study on occurrence of these deposits (Yamazaki and Sharma, 2000) has classified zones depending on seabed slopes, such as nodule dominant ($0\text{-}3^0$), sediment dominant ($3\text{-}7^0$), transitional zone ($7\text{-}15^0$) wherein crusts and nodules co-exist at most locations, and crust dominant ($>15^0$) . Such a classification of the distribution of crusts deposits on the seafloor would provide critical inputs for designing the mining device and help in optimum utilization of the capability of the mining system. Besides manoeuvrability on different seabed slopes, a mining device would also be required to negotiate the micro topographic undulations associated with different types of crust surfaces, such as step like (100-200 cm), large outcrops (50-100 cm), cobble type (20-50 cm), nodular (10-20 cm) and also nodules (1-10 cm) and sediments (0-5 cm). It has also been suggested if buried crusts are also considered for mining, the resource potential could increase many fold, hence improving the overall efficiency of the mining system (Yamazaki et al., 1994)."

"Besides these, there are several geotechnical properties of crusts that would play a role in mining these deposits. These include their density, hardness, porosity, void ratio, as well as their compressive and tensile strengths that would determine the collection mechanism of the mining device."

Exploration techniques

35. "There are various parameters that need to be evaluated for resource estimation as well as designing a suitable mining device, for which different techniques would have to be employed. 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 current meters and CTD sensors and collection of water samples at discrete depths would provide critical environment data for operation of mining system as well as environmental impact prediction and assessment. Whereas, the weather recorder would help tracking the meteorological conditions for optimizing mining duration during the year, the position fixing instruments provide the basic location and navigation data."

Estimation of area to be mined and impacted

36. "It is expected that a number of individual crust deposits will be required to sustain a commercial mining operation over the 15 to 20-yr period. It is estimated that roughly 600 km^2 area would sustain one commercial mining operation for 15-20 years (Hawaiian study, 1987), which at the mining rate of 1 million tones / year should have a deposit of 15-20 million tones. The Hawaiian study suggested that to estimate the tonnage of in-place crust resources in an area, multiply the appropriate tonnage number times 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 is:

*19,500 * 425 = 8,775,000 t (wet)"*

"Regional and local variability in the spatial distribution of cobalt bearing ferromanganese crusts in the world's ocean. (Description of the Marcus-Wake underwater rise)" *- V.M Yubko, Yuzmorgeologiya; and Y.B Kazmin, Russian Federation*

37. "A typical ore field can be separately located guyots, whose base is 120 to 80 km. The top is at a depth interval between 1300 and 1500m, and the slope brow confined to a depth of 1500m. The configuration of the summit plateau is similar to that of the base and has dimensions of 65 to 35 km at a depth of 3000m. The diameter of the structure at this depth is 15 km. The average dip of the slopes in between 1500 and 3000 m varies from 20 to 30 degrees, whilst the deeper slopes are more gentle, varying between 5 and 10 degrees."

"Cobalt-rich ferromanganese crusts: Global distribution, composition, origin and research activities" *- James Hein, Senior Geologist, United States Geological Survey, USA*

38. "For many guyots and seamounts, the surface area that is likely to be mined is less than the area that exists above 2500 m water depth, because of sediment cover. As a worst-case scenario, about 210 square kilometres (range ~210-410 square kilometres) of the average seamount would have crust exposed (not covered by sediment) that could potentially be mined; and about 530 square kilometres (range ~530-1060 square kilometres) of the largest seamount measured would be available for mining. Those areas would likely be further reduced because of prohibitive small-scale topography, un-mined biological corridors, and other impediments to mining. Consequently, for the largest seamount measured, as little as 130 square kilometres (range ~130-265 square kilometres) might be available for mining; and for the average seamount, as little as 50 square kilometres (range 50-105 square kilometres) might be available for mining. Seamounts and guyots do exist that have little sediment cover and relatively subdued topography and those are the ones that are likely to be mined."

Implications for Mine Site Characteristics

"Based on the data presented, it is proposed that a future crusts mine site will have the following characteristics.

(i) Mining operations will take place around the summit region of guyots on flat or shallowly inclined surfaces, such as summit terraces and saddles, which may have either relatively smooth or rough small-scale topography. These are the areas with the thickest and most cobalt-rich crusts; much thinner crusts occur on steep slopes;

(ii) The summit of the guyots will not be deeper than about 2200 meters, the terraces not deeper than about 2500 meters;

(iii) Little or no sediment will occur in the summit region, which implies strong and persistent bottom current;

(iv) The summit region will be large, more than 600 square kilometers (see next section);

(v) The guyots will be Cretaceous in age;

(vi) Areas with clusters of large guyots will be favoured;

(vii) Guyots with thick crusts and high grades (cobalt, nickel, copper) will be chosen;

(viii) The central Pacific best fulfils all the above criteria.

"The basic mine-site characteristics listed above can be utilized in the design of mining equipment, and in considering biological and environmental issues. For example, sessile biota and fish may be more important concerns than sediment in fauna. Mining equipment will probably not have to be designed to operate on steep slopes, although that capability would offer greater flexibility."

Implications for available mine sites

"Based on a conservative estimate of 26 kilograms of crust per square meter of seafloor (range ~25-78 kilograms per square meter-based on dry bulk density of 1.3 grams per cubic centimetre and mean range of crust thicknesses of 2-6 centimetres), it would require the mining of 77 square kilometres (range ~26-77) per year to satisfy a rate of production of 2 million metric tons of crust per year. This would translate to 1,540 square kilometres (range ~520-1,540) of crust removal for a 20 year mining operation. From the data on seamount sizes and likely areas available for mining presented above, it can be concluded that about 3-12 large guyots would be needed for a 20 year mining operation, or about 10-31 average size seamounts based on an average crust thickness of two centimetres. However, it is likely that large areas can be found with twice that average crust thickness."

"A Comparison of the Possible Economic Returns from Mining Deep Seabed Polymetallic Nodules, Seafloor Massive Sulphides and Cobalt-Rich Crusts"
- Jean-Pierre Lenoble Ingenieur Geologue Legal and Technical Commission (ISA) Chatou, France

39. "The dimensions of flat deposits can be 50-200 km^2 with 70-90% of the area covered by encrustations. Their topography is relatively even, with slopes less than 5%. Cracks form an irregular pattern that cup up the crust and the underlying material to several decimetres deep. The corresponding slabs are one to several square meters wide."

"Slope deposits are inclined up to 25%, as the flanks of old volcanoes. Crusts cover more or less consolidated sediments as well as hard basaltic rock and breccias. Evidence of sliding along the slope has been recorded."

"The thickness of the crust can be 2 to 10 cm, sometimes up to 20 cm, but the structure and composition varies from top to bottom. Generally, only the few first millimetres have very high cobalt content (up to 3%). Cobalt grade decreases with depth, as well as manganese and iron, because of mixing with the underlying material. When this material is composed of calcareous phosphorite, there is a corresponding increase of the phosphorus and calcium contents. Therefore, only the first few centimetres (2 to 3) of a deposit have an economic value. Phosphatisation has also been found in slope deposits, probably in relation with up-welling phenomena."

"The wet specific gravity of crust material is reported to vary from 1.6 to 2.1 g cm^{-3}. The crust material, as is the case with polymetallic nodules, is very porous (43-74%). Accordingly, in the Tuamotu area, the average dry specific gravity was 1.4 g cm^3."

"During the surveys made by CNEXO (1970) then IFREMER in this area a submerged old atoll was discovered near Niau Island. The depth of the plateau is 1000-1200 m limited by steep flanks of 400 m where the slope is more than 25%. Of the total area of 270 km^2, at least 80 km^2 are coated with encrustations, with an apparent coverage ratio of 70%. The surface of the crust is bumpy with smooth decimetric microtopogaphy. Sandy sediments with ripple marks occupy enclosed sectors. One can suspect the existence of buried crust beneath this sediment, as found in other deposits. The large blocks of crust, that have been dredged, showed a phosphatic-calcareous core, light brown and well consolidated. Fossil foraminifers give an age of 45 Ma (middle Eocene). The outer part is altered with micro fissures impregnated by ferromanganese hydroxides. The crust, dark black and 2 to 5 cm thick, is more continuous and compact at the top part of the blocks. From the surface of this crust, the cobalt content decreases from 2% in the first 3 mm to 1.7% in the next 15 mm and 0.6% in the following 15 mm. A bulk sample taken from the crust had average grades of 0.33% Co, 0.2% Ni, 0.06% Cu, 9.7% Mn, and 7.9% Fe. In 1986, an attempt was made to sample the deposit with a pyrotechnic multicorer with relative success."

"The representativeness of such sampling versus future mining is questionable, as is the case for many of the surveys conducted elsewhere. An attempt to be more effective was made using a large gravity corer. However, the penetration through the crust and its substrate is limited and consequently does not show a fair picture of the deposit."

"At Niau, the tonnage of material with economic merit has been estimated to be 1 million dry tonnes with average cobalt content of 1.2%, based on recovering only the first 2 cm of the crusts. Dilution of this layer by the underlying material will certainly occur, but it seems possible to separate the crust by ore processing techniques. Several similar deposits have been discovered in the vicinity that could increase this speculative inferred resource to five Mt, which could then produce 50 000 t of cobalt."

"Total resources of cobalt from Co-rich crusts in the central Pacific have been estimated to 500 million tonnes (100 deposits similar to Niau)."

"The exploration techniques must be improved considerably in order to provide the necessary parameters for the design of mining and processing methods. A better knowledge of the micro topography can be obtained by using deep-towed multibeam sonar associated with continuous high resolution TV recordings. Sampling methods must be completely retailored. Rotary diamond drilling machines equipped with a multicorer system must be developed to provide a fast and cheap sampling method with better recovery."

Mining and processing technologies

"Several engineering studies have been carried out to define possible methods of mining and processing cobalt-rich crusts. The studies highlight the current lack of knowledge and the need for better information to be able to design efficient systems."

"A revised continuous line bucket (CLB) system was proposed by its inventor for crust recovery. Besides the apparent simplicity of the system, strong reservations must be made about its efficiency. It is doubtful that the buckets will be able to extract large slabs of crust that are firmly attached to their substrate. Buckets could be also severely damaged when they impact the bottom of the deposits. The blocks containing crusts will be low grade, retaining a significant amount of waste material. In slope deposits, blocks of lava and volcanic breccias will also be retrieved, as the buckets cannot be manipulated to discriminate between ore and waste."

"In 1985, Halkyard proposed a hydraulic lifting system with a self-propelled bottom crawler equipped with cutting devices as suitable technology for mining crusts. The cutting devices would create incisions on the surface layers of the crust, permitting their extraction by suction to the pipe system."

"In a study conducted during the same year by Gemonod for the Niau deposit, a similar system was envisaged. The proposed cutting device would be a set of hammer drills or a row of rotary cutting drums. A crusher would also be installed on the self-propelled crawling dredge, in order to produce slurry (60% solid) to be pumped to the surface."

"Chung considered the possibility of using water-jet cutting or fracturing to slice or break the crust top-layers. He also considered adopting a hydraulic lifting system, with a towed or self-propelled bottom collector."

"Zaiger proposed an innovative system in 1994, known as "solution mining". A large "containment and regulation cover" (CRC: up to 40 000 m^2), consisting of an impermeable membrane, is sealed on the bottom by tubes filled with a heavy medium such as barite mud. A leaching solution is introduced between the CRC and the seafloor. After sufficient time, the enriched solution is pumped to the surface platform for metal extraction. The CRC is then moved to another area. Preliminary tests have raised more problems than providing solutions."

"Research on processing has been limited owing to the lack of information on the composition and physical properties of the possible raw ore. However, some studies have shown possibilities of using ore processing to concentrate the minerals. Magnetic separation, followed by froth flotation, can separate the ferromanganese hydroxides from the calcareous phosphorite or the siliceous volcanic fragments, and form an enriched concentrate. Heavy liquid separation was also proposed to obtain the same result."

"Minemet Recherché studied this method under a contract from Afernod/Gemonod in 1986. A concentrate grading 1.2% Co, 0.6% Ni, 0.1% Cu and 26% Mn was obtained from the raw ore. The recovery could be better than 70%."

"Extraction of the metals from the concentrate can be also effected by hydrometallurgy. For polymetallic nodules, both ammoniacal and sulphuric acid leaching were proposed. Japanese institutions studied the dissolution of the valuable metals (Co, Ni, and Cu) in a mixture of ammonium sulphite and ammonium carbonate, or in ammonium thiosulphate. The metals are then extracted from the pregnant solution by selective organic solvents. The refined metals are obtained by final electro winning."

"Minemet Recherché proposed to use sulphuric leaching in a closed cell under one MPa pressure at 180°C temperature. The introduction of Mn^{++} ions favours cobalt recovery. The process derives from the SRM2 tested for polymetallic nodules by the French CEA. Selective extraction of the different metals (Co, Ni, Cu) is made by organic solvents. Sulphide concentrates are prepared by precipitation for further refining. Cobalt recovery could be 93%. Manganese is confined in a low-grade ferromanganese residue, rich in iron, which could be (doubtfully) used as a manganese ore."

Part II: EXCERPTS FROM WORKSHOP PAPERS ON SEAFLOOR POLYMETALLIC SULPHIDES OCCURRENCES/DEPOSITS

Geologic Characteristics and Geographic Distribution

"Seafloor Massive Sulphides deposits and their resource potential"

Prof. Herzig and Mr S. Petersen, Institute for Mineralogy Brennhausgasse, Germanyand Dr Hannington Geological survey of Canada, Ottawa, Canada

40. "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 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 m continuously precipitate metal sulphides in response to mixing of the high-temperature hydrothermal fluids with ambient seawater. The metal sulphides including pyrite, sphalerite, and chalcopyrite eventually accumulate at and just below the seafloor and have the potential to form a massive sulphide deposit. It has also been documented that circulation of seawater through the oceanic crust is the principal process responsible for the formation of massive sulphide deposits in this environment. Seawater which deeply penetrates into the oceanic crust at seafloor spreading centers is being modified to a hydrothermal fluid with low pH, low Eh, and high temperature during water-rock interaction above a high-level magma chamber. This fluid is then capable of leaching and transporting metals and other elements which eventually precipitate as massive sulphides at the seafloor or as stockwork and replacement sulphides in the sub-seafloor. The resulting massive sulphide deposits can reach considerable size ranging from several thousand to about 100 million tonnes. High concentrations of base (copper, zinc, lead) and in particular precious metals (gold, silver) in some of these deposits have recently attracted the interest of the international mining Industry."

"In the 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 at water depths up to 3,700 m. Polymetallic sulphide 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 (see *Figure 2* below)."

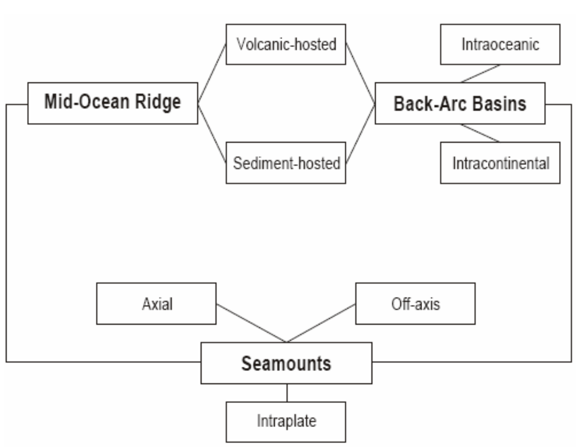


Figure 2. Geological environments for the occurrence of seafloor hydrothermal systems. Polymetallic massive sulphides deposits have been found in all settings except for intraplate seamounts.

“The majority of sites so far have been located at the East Pacific Rise, the Southeast Pacific Rise, and the Northeast Pacific Rise, mainly because the first discovery of an active high-temperature hydrothermal system was made at 21°N at the East Pacific Rise off shore Baja California. Only one site has so far been located at the ridge system of the Indian Ocean, close to the Rodriguez Triple Junction. The scarcity of sulphides deposits on the Mid-Atlantic Ridge and in the Indian Ocean is, at least to a large extent, a function of restricted exploration activity in these areas. It has been assumed that today only about 5% of the 60,000 km of oceanic ridges worldwide have been surveyed and investigated in some detail.”

“During 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 is converted into an ore-forming hydrothermal fluid in a reaction zone which is situated close to the top of a sub axial magma chamber (*Fig. 3*). Major physical and chemical changes in the circulating seawater include (i) increasing temperature, (ii) decreasing pH, and (iii) decreasing Eh. The increase in temperature from about 2°C to values >400°C31,32 is a result of conductive heating of a small percentage of seawater close to the solidified top of a high level magma chamber. This drives the hydrothermal convection system and gives rise to black smokers at the seafloor.”

“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 polymetallic sulphides mounds. The sulphides precipitation within the up flow zone (stockwork) and at the seafloor (massive sulphides) is a consequence of changing physical and chemical conditions during mixing of high temperature (250-400°C), metal-rich hydrothermal fluids with cold (about 2°C), oxygen-bearing seawater (Fig. 3).”

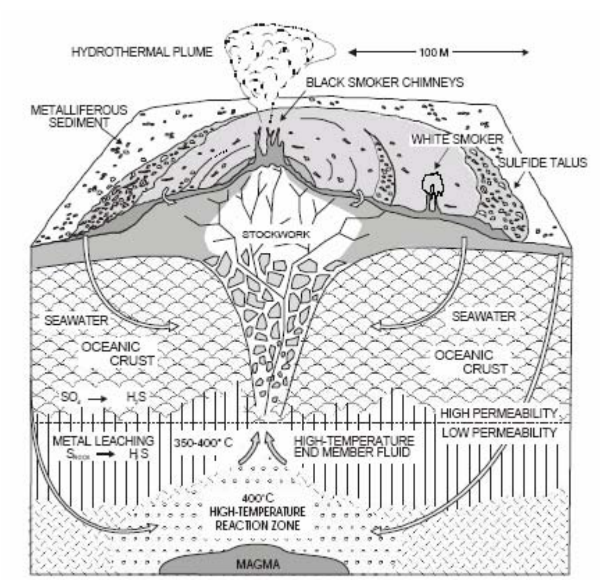


Figure 3: A cross-section of a polymetallic sulphides mound showing the principal components of seafloor hydrothermal system.

"Out of the more than 100 sites of hydrothermal mineralization currently known at the modern seafloor, only about 10 deposits may have sufficient size and grade to be considered for future mining, although information on the thickness of most of those sulphides deposits is not yet available. 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 south-western Pacific. All of these sites except two (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. Scientific drilling has been carried out by the Ocean Drilling Program to a depth of 125 m at the TAG hydrothermal field and to about 200 m 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."

Table 1: Possible Sites for Mining of Seafloor Massive Sulphides Deposits

Deposit	Ocean Area	Water Depth (m)	Jurisdiction	Country
Atlantis II Deep	Red Sea	2,000 - 2,200	EEZ	Saudi Arabia
Middle Valley	Northeast Pacific	2,400 - 2,500	EEZ	Canada
Explorer Ridge	Northeast Pacific	1,750 - 2,600	EEZ	Canada
Pacific	Southwest Pacific	1,700 - 2,000	EEZ	Tonga
North Fiji Basin	Southwest Pacific	1,900 - 2,000	EEZ	Fiji
Eastern Manus Basin	Southwest Pacific	1,450 - 1,650	EEZ	Papua New Guinea
Central Manus Basin	Southwest Pacific	2,450 - 2.500	EEZ	Papua New Guinea
Conical Seamount	Southwest Pacific	1,050 - 1,650	EEZ	Papua New Guinea
Okinawa Trough	West Pacific	1,250 - 1,610	EEZ	Japan
Galapagos Rift	East Pacific	2,600 - 2,850	EEZ	Ecuador
EPR 13oN	East Pacific	2,500 - 2,600	International	ISA
TAG	Central Atlantic	3,650 - 3,700	International	ISA

"Preussag has also performed active exploration for massive sulphides deposits in the Galapagos Spreading Center 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 sulphides deposits along the East, Northeast and Southeast Pacific Rises."

"Hydrothermal sulphides mineralization of the Atlantic – Results of Russian investigations" – G. Cherkashev. A. Ahsadze; Institute of Geology and Mineral Resources of the Ocean; and I. Glumov, Ministry of Natural resources, Russian Federation,

41. "Some of the investigations that were begun in 1985 in the Mid-Atlantic Ridge are still in progress. Nearly 20 cruises have been organized in this region. Geological and geophysical studies at scales between 1: 1 000 000 and 1: 200 000 were conducted in the course of this period in a 50-100 km band of the axial zone of the Mid-Atlantic Ridge from 12^0 N to 19° N and from 21° N to 29° N. These studies included bathymetric, magnetic, physical and chemical oceanographic studies, side-scan sonar surveys using frequencies of 30 or 100 kHz, as well as video- and photo-profiling and geological sampling. Ten (10) areas showing promise for new hydrothermal fields that are located at 28°40′°– 28°48′°N, 27°05′-27°10′°N, 25°25′-25°33′°N and 16°07′-16°09′°N were the most significant discoveries by Russian researchers during this period."

"Intensive investigations resulted in the discovery of new hydrothermal sulphides fields; the Logachev - 1 and Logachev – 2 fields, the high-cuprous and high gold content sulphides mineralization at 24° 30'N that was photographed and dredged, the MIR hydrothermal mound of the TAG field that was subsequently sampled and studied in detail, as well as the previously known Snake Pit field."

"Based on the potential resources contained in Logachev deposits, they are considered to be medium – large, with tonnage estimates between 5 to 50 million tonnes, and with the highest potential in the eastern flanges of the slope of the valley."

Metallogenesis of marine minerals *– Peter Rona, Professor Marine Geology and Geophysics Institute of Marine and Coastal Sciences Rutgers University*

42. "In 1979, on the East Pacific Rise at 21 degrees north latitude off Baja California (Mexico), scientists exploring the ocean floor discovered chimney-like formations of dark rock atop sulphide mounds, spewing hot water and surrounded by animal species different from any previously known. Since then, studies have shown that these black-smoker complexes are an outgrowth of the formation of new oceanic crust through seafloor spreading as the tectonic plates underlying the earth's surface converge or move apart. This activity is intimately associated with the generation of metallic mineral deposits at the seafloor."

"At water depths up to 3,700 metres, hydrothermal fluids, having seeped from the ocean into subterranean chambers where they are heated by the molten rock (magma) beneath the crust, are discharged from the black smokers at temperatures up to 400° Celsius. As these fluids mix with the cold surrounding seawater, metal sulphides in the water are precipitated onto the chimneys and nearby seabed. These sulphides, including galena (lead), sphalerite (zinc) and chalcopyrite (copper), accumulate at and just below the seafloor, where they form massive deposits that can range from several thousand to about 100 million tonnes. High concentrations of base metals (copper, zinc, lead) and especially precious metals (gold, silver) in some of these massive sulphide deposits have recently attracted the interest of the international mining industry. Many polymetallic sulphides deposits are also found at sites that are no longer volcanically active."

"Most sites have been located in mid-ocean at the East Pacific Rise, the Southeast Pacific Rise and the Northeast Pacific Rise. Several deposits are also known at the Mid- Atlantic Ridge but only one has so far been located at the ridge system of the Indian Ocean. The paucity of known sulphide deposits at the Mid-Atlantic Ridge and the Central Indian Ridge is largely explained by the fact that exploration in these areas has been limited. Only some 5 percent of the 60,000 kilometres of oceanic ridges worldwide have been surveyed in any detail."

"In the mid-1980s, additional sulphides deposits were discovered in the south-western Pacific, at ocean margins where basins and ridges occur on the seafloor between the continent and volcanic island arcs. In these so-called back-arc spreading centres, magma rises close to the surface at convergent plate margins where one tectonic plate slips beneath another in a process called subduction. Further deposits have been discovered in the western and south western Pacific (Lau Basin and North Fiji Basin), Okinawa Trough southwest of Japan, Manus Basin, North of New Caledonia, Woodlark basin, Papua New Guinea etc. Today more than 100 sites of hydrothermal mineralization are known and around 25 of them are high temperature black smoker venting."

Economic and financial issues in commercializing polymetallic sulphides of the Area

"Seafloor Massive Sulphides deposits and their resource potential" *- Prof. Herzig and S. Petersen, Institute for Mineralogy, Freiberg/Sachsen, Germany and Dr. Mark Hannington, Geological survey of Canada*

43. The Mineralogy of the seafloor sulphides is tabulated below.

Table 2 Mineralogy of seafloor polymetallic sulphides

	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	

Metal contents:

"Despite moderate tonnages in several seafloor deposits, recovered samples from about 50 deposits worldwide represent no more than a few hundred tonnes of material. Based on existing data and lacking 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."

Bulk Chemical composition of seafloor polymetallic sulphides

The bulk composition of some of the known seafloor polymetallic sulphides occurrences is presented in Table 3 below.

Table 3 Bulk chemical composition of seafloor polymetallic sulphides occurrences

Element	Intraoceanic Back-Arc Ridges	Intracontinental Back-Arc Ridges	Mid-Ocean Ridges
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

"Comparison of nearly 1,300 chemical analyses of seafloor sulphides reveals that deposits in different volcanic and tectonic settings have different proportions of metals. Relative to samples from sediment-starved mid-ocean ridges, massive sulphides formed in basaltic to andesitic environments of back-arc spreading centres (573 samples) are characterized by high average concentrations of zinc (17%), lead (0.4%) and barium (13%), but little iron. Polymetallic sulphides at back-arc rifts in continental crust (40 samples) also have low iron content but are commonly rich in zinc (20%) and lead (12%), and have high concentrations of silver (1.1%, or 2,304 grams/t). In general, the bulk composition of seafloor sulphides deposits in various tectonic settings is a consequence of the nature of the volcanic source rocks from which the metals are leached. Recently another dimension is added to the PMS with the report of high concentration of gold. The Mid oceanic ridges have average 1.2 gm/ton but back arc sulphides the gold concentration can be as high as 28g/ton (Lau Basin) to around 55 gm/ton at Manus Basin. The conical seamount in the EEZ of Papua New guinea has a high 230 gm/ton of gold concentration. Polymetallic sulphides have the advantage in that more than one metal can be mined simultaneously, the extraction of metals from the sulphides is a proven technology and efficient."

"Financing exploration for seafloor massive sulphides deposits" *– Julian Malnic, CEO, Direct Nickel Pty Ltd, Sydney*

44. "With exploration for Seafloor Massive Sulphides (SMS)* deposits barely half a decade old, there are not statistically sound generalizations that can be drawn from the financing experience so far. Furthermore, because of the normal confidentiality that surrounds corporate activity, knowledge of industry experience does not extend far beyond our own group. However, it is evident that the capital raising process will be similar to either terrestrial mineral exploration, or maybe even to dot.com style, companies."

"SMS mining offers scope for a highly compressed development cycle. The time between first identifying a plume and tracking down a deposit, and the time of mining the deposit can be very short, a factor that will also carry considerable economic advantage. 'With the mobility of the production vessel, test mining can be conducted within a matter of weeks of a discovery. On land, the definition drilling required to justify the cost of a test shaft will typically take two years and then test shaft will take additional time. By lowering such development threshold, the feasibility costs are also expected to be significantly lower than for terrestrial mines.”

“Using very basic assumptions and calculations about the most likely system we will use, Nautilus has performed some very useful spreadsheet models for a proposed Manus Basin mining operation. We regard these models as proprietary assets so I do not intend to present them here. But for the sake of illustration, one base case involved an arbitrary mine size of 1.5Mt and at the rate of 1000tpd, the mine life will be 4.5 years. The following chart shows the summary of net cash flow and cumulative net cash flow for this scenario. Capex costs include the acquisition of a ship for USD$50m.”

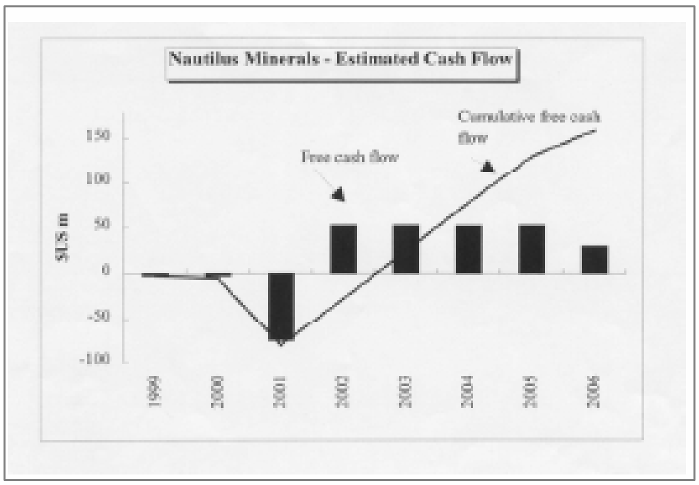


Figure 4: Summary of net cash flow for a seafloor polymetallic sulphides mine

3. Technological issues in commercializing polymetallic sulphides in the Area

Metallogenesis of marine minerals – *Peter Rona, Professor Marine Geology and Geophysics Institute of Marine and Coastal Sciences Rutgers University*

45. “Exploration for a seafloor mineral deposit involves many variations to achieve two basic objectives: to determine where the mineral deposit is located, and to determine physical, chemical and, in many cases, the biological properties of the deposit and its seafloor setting”.

(i) **Finding the deposit**: The first objective, determination of where a seafloor mineral deposit is located, involves starting the exploration within the seafloor province where that type of mineral deposit is known to occur, but at unknown distances from deposits that may be present within that province. Then apply complementary exploration methods that will sense diagnostic properties of that type of deposit and its specific setting starting at some distance from a potential deposit and gradually coming closer, that is, closing range to the deposit. The systematic exploration strategy to find a deposit on the seafloor is to progressively close range from far to near according to the sensitivity to detection of physical and chemical properties of the deposit.

(ii) Let us consider this approach of closing range to a potential mineral deposit using as an example an actively forming massive sulphides deposit in the seafloor province of a submerged volcanic mountain range at a divergent plate boundary. This strategy was successfully used to discover the TAG hydrothermal field on the Mid-Atlantic Ridge, the first hot springs and massive sulphide deposits found anywhere in the deep Atlantic Ocean (16). Hot springs associated with an active massive sulphide deposit will discharge certain metals in dissolved and particulate form (iron and manganese) and dissolved gases (helium) that can be carried by deep ocean currents for distances of hundreds of kilometres from a source. These components can be detected in water samples recovered from appropriate depths by standard shipboard water sampling methods. Certain of these metallic mineral particles from black smokers will settle through the water column to the seafloor where the metallic mineral component can be detected in cores of seafloor sediments. The general location of seafloor hot springs can be found by following concentration gradients of these metallic signals in the water column and in seafloor sediments. At ranges of tens to several kilometres (thickness of the water column in the deep ocean), shipboard bathymetric and magnetic methods and near-surface towed side-scan sonar can be employed to determine the seafloor setting and detect a characteristic magnetic signature of either an active or inactive massive sulphide deposit. When within kilometres of the hot springs, various *in situ* sampling (water, particles, seafloor sediment) and imaging (photos, video, and side-scan sonar) methods can be used on various types of unmanned deep submergence vehicles at altitudes up to tens of meters above the seafloor to locate the massive sulphides deposit. These unmanned deep submergence vehicles comprise Remotely Operated Vehicles (ROV) which are tethered to the ship and controlled though an electrical or electro-fibre optic cable with a real-time video link to the operators, and Autonomous Underwater Vehicles (AUV) which are free-swimming and are programmed to perform imaging, sampling and other measurement procedures. Manned submersibles, also known as Human Occupied Vehicles (HOV), may be used for direct observation, sampling and measurements after the massive sulphide deposit has been targeted.

(iii) Characterizing the deposit: Having found the marine mineral deposit, the next objective is to accurately determine the detailed physical, chemical and, in cases, biological properties of the deposit and its seafloor setting. This may be accomplished using the "nested survey" strategy, which starts with surveying the seafloor setting of the deposit and progressively obtains more detailed information of the deposit itself employing many of the same exploration methods used to find the deposit. Following through with the case of the deep ocean massive sulphide deposit, the exploration methods described so far provide direct information on that part of the massive sulphide deposit exposed on the seafloor and only indirect information on the portion beneath the seafloor. Recall that in describing the active sulphide mound in the TAG hydrothermal field, the surface expression is only the "tip of the iceberg" (*Figure 3*). Drilling is required to directly determine the third dimension including grade and tonnage of a massive sulphide deposit on the seafloor just as for such as deposit on land. For massive sulphides bodies on land hundreds of holes each tens to hundreds of meters long spaced meters apart may be drilled to recover almost continuous cores of the material penetrated. These cores are used to determine the shape, grade and tonnage of the massive sulphide mound and underlying feeder/stockwork zone (Figure 3). Present capability to drill a massive sulphide body at a water depth of several kilometres in the deep ocean is far more limited. For example, the active sulphides mound in the TAG hydrothermal field is one of only two such mounds that have been drilled to date by the Ocean Drilling Program (ODP). ODP Leg 158 spent two months at sea in 1994 and with formidable technical difficulty drilled 17 holes up to 125 meters long with overall core recovery of 12 percent. Drilling methods for massive sulphides deposits and associated volcanic rocks in the deep ocean are being improved but will fall far short of land standards for the foreseeable future."

"Hydrothermal sulphides mineralization of the Atlantic – Results of Russian investigations"
- G. Cherkashev. A. Ahsadze; Institute of Geology and Mineral Resources of the Ocean;
I. Glumov, Ministry of Natural resources, Russian Federation,

46. "The technologies used by Russian researchers for studying seafloor sulphides deposits included, in addition to conventional methods, a towed geophysical system called RIFT (which was applied during the discovery of the Logachev hydrothermal fields) and a submersible drill to assess the thickness of the sulphides deposits."

"Proposed exploration and mining technologies for polymetallic sulphides" *-Steven D. Scott, Director Scotiabank Marine Geology Research laboratory, Department of Geology, University of Toronto, Canada*

Exploration methodologies

47. "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 transmissometres, 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. 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 km 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 most successful method for locating actively forming PMS deposits is to find their particulate plume and tracing it to its source. This is typically done using a transmissometre that measures absorption of light by the particles within the water column. 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 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 are dredged, photographed or inspected by submersible."

"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 meters apart. Coring can be accomplished either using a bottom-deployed autonomous drill or a drill operated from a remotely operated vehicle (ROV)."

"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 and Noranda is spending about $200 million to develop 30 million metric tons of ore between 2000 and 3000 meters 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."

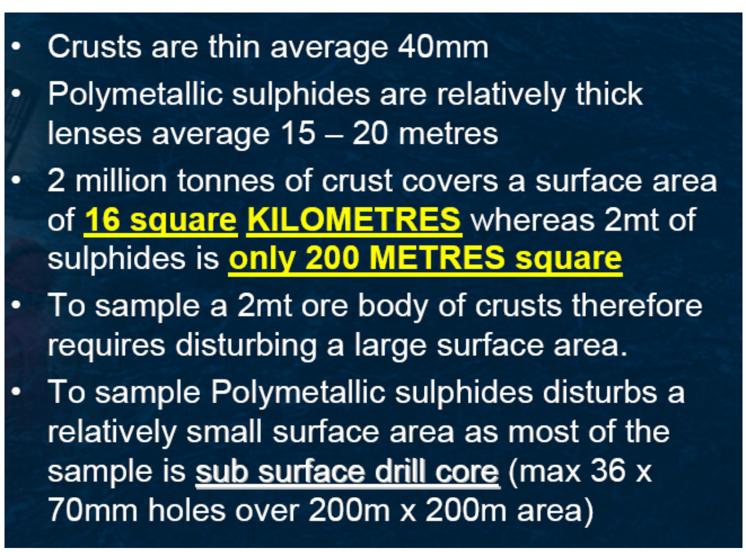
"Although the technology does not exist for recovering seafloor PMS, some schemes that were developed by Namco for recovering diamonds in the relatively shallow offshore of Namibia and by the Lockheed Corporation for recovering manganese nodules in deep ocean basins, such as robotic bottom mining vehicles 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 with a cutting blade, much as is used in coal and potash mines, that would extract, grind and pre-concentrate the desired minerals, lift these to surface in a slurry (air lift or pump) and leave the waste minerals on the sea floor."

"Exploration for and pre-feasibility of mining polymetallic sulphides - a commercial case study" *- Mr. David Heydon, Chief Executive Officer of Nautilus Minerals Ltd.*

48. "Nautilus Minerals Ltd. is a company which has an exploration licence for Polymetallic sulphides in the territorial sea of Papua New Guinea (PNG) to commercialise sulphides deposits in that area. The company is in technical alliance with six other companies that have expertise in different aspects of the integrated operations. The Nautilus has performed major exploration programme in PNG. The exploration included water column testing (to locate active plumes or vent smokers). This covered a large prospective regional area. The sea water samples from up to 10 km away can lead to locating the active metal vents. During the geophysical studies methods like resistivity measurements, self potential, magnetics, induced polarisation, video camera and gravity were employed. This helps in finding the aerial extent of the ore-body to estimate the mass or tonnage of deposit. The geophysical anomalies were 'ground truthed' during the sampling phase. The samplers used for the purpose were the dredges and the sophisticated grabs. Unlike the crusts or the polymetallic nodules which lay on the seabed surface, the PMS required drilling to test the vertical or depth extent of mineralization and to test any buried body. Drilling thus assists in determining the average grade of the body and it was carried out by Nautilus using remote operated drill rig lowered to the seafloor. Drilling in deeper waters is not so common and only a couple of ship based operators have the capability to drill in 2000 m water. Even the Ocean Drilling Program (ODP) has not successfully recovered continuous core from the top 20 m of the seabed where these sulphides may first be mined."

"The exploration drilling during the first phase should start with about 9 holes at approximately 60 m spacing drilled to 20 m depth with 70 mm core diameter. It may be necessary to include one or two 300 mm (12") holes reamed for larger sample for first phase metallurgy testing. During the pre-mining phase, for detailed grade and pre-mine planning, an additional 27 holes (30 m spacing) depending on whether local variability of geology and grades are consistent. During this phase, larger reamed holes for metallurgical studies may be required."

Exploration crusts Vs Sulphides



“If trial mining of crusts and sulphides is undertaken, it will entail mining 1 million tonnes trailing a 2mtpa mining system. 1 MT of crust covers a surface area of 8 square kilometres whereas 1 million tonnes of PMS to 20 m deep disturbs only 140 square meters of surface area.”

“Nautilus has also done a pre-feasibility engineering study of mining polymetallic sulphides at 2000 m. to mine 2 MT per annum with mine life plus 10 years needs 20 MT of sulphides. 2 MT is 200mX200m@20 m thick. A mine may stay in one spot anchored for a year or more over a field containing several deposits and it will relocate to another area to aggregate 20 mt required.”

“Nautilus has also conceptualised the ROV required for the mining operation. The Remotely Operated Vehicles (ROVs) are already being used for cable and pipe lay trenching but they are not ‘mining’. Nautilus’ study is based on 5000 hr operation and 2 million tonnes giving 400 tons per hour. Two mining vehicles per platform powered by electric umbilical each mining 200 tons per hour may be required. As the PMS have the strength of coal, it is proposed to use drum cutters. A drum cutter miner is 5 m wide and cuts a 2 m high ‘face’ with each mine r advancing only 7 meters per hour. Siemag, the world leader in hoisting ore from deep underground is associated with Nautilus in helping the lifting of ore. Siemag have proposed a system to hoist at a rate of 400 tonnes per hour from 2000 m depth. They propose to hoist 100 ton kibbles at 1.8 m/sec rate. Nautilus has considered both slurry pump and positive displacement pump option which may be assisted by airlift.”

“Technical requirements for exploration and mining seafloor massive sulphides deposits and cobalt-rich ferromanganese crusts” *– Professor Herzig and S. Petersen*, *Prof. Herzig and S. Petersen, Institute for Mineralogy, Freiberg/Sachsen, Germany and Dr Mark Hannington, Geological survey of Canada*

49. “Since the discovery of black smokers, massive sulphides and vent biota in 1979, numerous academic and government institutions carry out exploration for seafloor massive sulphides deposits at oceanic spreading centres worldwide. Leading countries in this field are the United States, France, Germany, the United Kingdom, Japan, Canada, Russia, and Australia. In some countries, such as Portugal and Italy, marine exploration programmes for massive sulphides have been newly developed over the past few years.”

“Table 4 below shows the major international efforts during the past decade in PMS studies.”

Table 4 International efforts in PMS studies

Program	Countries	Ocean Area
FAMOUS	France/USA	Mid-Atlantic
TAG	USA/France	Mid-Atlantic Ridge, 26°N
FARA	France/USA	Mid-Atlantic Ridge, Azores
DIVA	France/USA	Mid-Atlantic Ridge, Azores
BRIDGE	United Kingdom	Mid-Atlantic Ridge
CYAMEX	France/USA	East Pacific Rise, 21°N
GEOMETEP	Germany	East Pacific Rise, South
GARIMAS	Germany	Galapagos Rift, 86°W
HYDROTRACE	Germany/Canada	Juan de Fuca Ridge, Axial Seamount
VENTS	USA/Canada	Juan de Fuca Ridge
GEMINO	Germany	Central Indian Ridge
HIFIFLUX	Germany	Southwest Pacific, North Fiji Basin
STARMER	France/Japan	Southwest Pacific, North Fiji Basin
PACMANUS	Australia/Canada	Southwest Pacific, Manus Basin
PACLARK	Australia/Canada	Southwest Pacific, Woodlark Basin
NAUTILAU	France/Germany	Southwest Pacific, Lau Basin
EDISON	Germany/Canada	Southwest Pacific, Tabar-Feni Arc

"For research and resource assessment of polymetallic massive sulphides deposits, technological advances are a critical factor. In the present state of research and commercialization, information on the depth extent and therefore the size of the deposit, and the type of mineralization and alteration are extremely important. Drilling by the Ocean Drilling Program Leg 158 at the active TAG hydrothermal mound at the Mid-Atlantic Ridge4 has indicated a total tonnage of 2.7 million tonnes of sulphides above, and 1.2 million tonnes below the seafloor 5. It was also found that high concentrations of base and precious metals are confined to the upper few meters of the mound. The mound itself consists of breccias with varying proportions of pyrites, silica, and anhydrites that would not be economically recoverable. Initially, it was thought that the entire mound consists of polymetallic massive sulphides. Except for the TAG mound, the Middle Valley site at the Juan de Fuca Ridge and the Atlantis II Deep in the Red Sea, depth information is not available for any of the known seafloor sulphides deposits. Research and resource assessments of these deposits rely on surface samples only. As drilling of hydrothermal systems by the Ocean Drilling Program will be the exception rather than the rule, reliable portable drilling and coring devices are required for research and industry. It has to be demonstrated that these systems are actually capable of supporting drilling and coring several tens of meters of massive sulphides and rock at the seafloor. The available technology is an encouraging start but needs to be further developed in order for drilling at the seafloor to depths of 50-100 m a routine operation by any research vessel, and to reveal reliable information on the depth extent of mound and chimney complexes."

"After the resource potential of a massive sulphides deposit has been adequately established by grid drilling similar to land-based operations, exploitation and recovery will be the next challenges. Selective mining using large TV-controlled grabs similar to those used for exploration are an option; however, continuous mining appears to be the only economic alternative. It appears that the continuous mining systems used by De Beers Marine, offshore Namibia, for the recovery of diamonds from water depths of about 100-150 m could be converted for massive sulphides mining. These systems consist of large (7 m diameter) rotating cutter heads that are attached to a flexible drill string through which the diamond-bearing sediment is airlifted onto the ship for further processing."

"Seafloor Massive Sulphides deposits and their resource potential" *– Prof. Herzig and S. Petersen, Institute for Mineralogy, Freiberg/Sachsen, Germany and Dr Mark Hannington, Geological survey of Canada*

Size and Tonnage:

50. "Considering that estimates of the continuity of sulphide 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 1-100 million tonnes, although the depth extend of mineralization is difficult to assess. The largest deposits 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 8-9 million tonnes of sulphide ore."

"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 largely consists of metalliferous muds, instead of massive sulphides, which is a consequence of the high salinity acquired by the hydrothermal fluids from circulation through thick Miocene evaporates at the flanks of the Red Sea rift. A detailed evaluation of the 40 km^2 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 m depth has shown that this deposit can be successfully mined."

"Estimates of sizes between 1-100 million tonnes for individual massive sulphide deposits on the seafloor are well within the range of typical volcanic-associated massive sulphide 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 sulphide. More than 60 individual occurrences have been mapped along an 8 km segment of Southern Explorer Ridge, but most of the observed mineralization occurs in two large deposits with dimensions of 250 m x 200 m67. The 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 sulphide per year. Thus, a local vent field with a few black smokers can easily account for a small size sulphide deposit, depending on the duration of activity."

"Out of the more than 200 sites of hydrothermal mineralization currently known at the modern seafloor, only about 10 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 5*). 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 south-western Pacific. All of these sites except two (East Pacific Rise 13°N and TAG hydrothermal field) are located in the Exclusive Economic Zones of coastal states including Saudi Arabia, Canada, Ecuador, Papua New Guinea, Tonga, Japan, and Fiji."

Table 5 Possible sites for seafloor sulphides mining

Deposit	Ocean Area	Water Depth (m)	Jurisdiction	Country
Atlantis II Deep	Red Sea	2,000 - 2,200	EEZ	Saudi Arabia
Middle Valley	Northeast Pacific	2,400 - 2,500	EEZ	Canada
Explorer Ridge	Northeast Pacific	1,750 - 2,600	EEZ	Canada
Lau Basin	Southwest Pacific	2,700 - 2,000	EEZ	Tonga
North Fiji Basin	Southwest Pacific	1,900 - 2,000	EEZ	Fiji
Eastern Manus Basin	Southwest Pacific	2,450 - 2,650	EEZ	Papua New Guinea
Central Manus Basin	Southwest Pacific	2,450 - 2.600	EEZ	Papua New Guinea
Conical Seamount	Southwest Pacific	1,050 - 2,650	EEZ	Papua New Guinea
Okinawa Trough	West Pacific	2,600 - 2,850	EEZ	Japan
Galapagos Rift East Pacific Rise	East Pacific	2,500 - 2,600	EEZ	Ecuador
TAG	Mid Atlantic Ridge	3,650 - 3,700	-	International

"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:

(1) High gold and base metal grades,

(2) Site location close to land, i.e., commonly within the territorial waters (200 nm Exclusive Economic Zone or even 12 nm zone) of a coastal state,

(3) Shallow water depth not significantly exceeding 2,000 m (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$350-500 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 at 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."

"Proposed Exploration and Mining Technologies for Polymetallic Sulphides" -*Steven D. Scott, Director Scotiabank Marine Geology Research laboratory, Department of Geology, University of Toronto, Canada*

51. There are seafloor deposits of apparent size and grade that, 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 that contains 94 million metric tons (Mustafa et al., 1984). It 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, 1197 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 a metal content."

"The *in situ* value of the metals in the Sunrise deposit could be about $US770 per metric ton at September 3, 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 if an accumulation of sulphides is an "ore". Whether or not Sunrise is an "ore" will depend on its true grade and tonnage but also on how much can actually be recovered, mining costs, metallurgical recoveries and costs and a host of other considerations."

"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 meters per minute and the water depth at the main PACMANUS site is about 1800m. Assuming, optimistically, ½ 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 sea floor instead of lifting them to surface and concentrating them there would reduce recovery costs substantially."

"Mining on Land vs. the Seafloor- a case study"
Dr David Heydon, CEO, Nautilus Minerals Limited.

52. "The Antamina mine located at more than 4300 m above sea level in the Andes Mountains, 385 km north of Lima in Peru, is one of the largest zinc and copper producers in the world. This mine cut about 110mt. of mountain and had the lake drained. The mine generated around 112 mt waste in 2003, 1400 workers worked and has a total of 550 mt tailings slime produced in 20 years. The overview shows the nautilus project has higher copper %- (5.5% compared to 1.23% for Antamina) and Zinc (12% compared to 1.03%). The ocean mine is likely to produce 190 m pounds copper on an average. If you compare the costs, the Antamina had lot of pre-strip expense for 4 years while Nautilus the returns are immediate. The Sea mine can be moved everywhere there is no overburden and can mine around 1,000 tons/hour. No drilling and blasting will be required for ocean mining. The Antamina land mine required 2000 m tunnel to mill, 300 km pipeline and generates lot of waste. Even environmentally the ocean mining is advantageous as there are no waste

dumps. Compared to 95 mt slimes/tails for ocean mining, the Antamina has about 550 mt of slimes/tails. The land mine needs around 1400 staff, 100 MW of electricity while the Nautilus project will require less than 500 staff and 40 MW of electricity. In effect the ocean mining needs less capital, has higher grade ores, generates less waste is environmentally friendly and has higher exploration success."

3. Environmental issues

"Impact of the development of seafloor massive sulphides on deep-sea hydrothermal ecosystems"
Dr S. Kim Juniper, GEOTOP Centre, University of Quebec, Montreal, Canada

53. "Some large, seafloor polymetallic sulphides deposits are hydrothermally inactive and provide no habitat for a specialized vent fauna. There are some observations of the colonization of inactive deposits by 'normal' deep-sea organisms. This would suggest that mining would pose little threat to the survival of individual species since its fauna is drawn from the surrounding deep sea. However, inactive sites have received little attention from biologists and more extensive sampling is required to establish that the nature of their fauna. Mining will effectively eliminate the habitat formed by extinct deposits, so it is important to confirm that they host only background deep-sea species."

"Any guidelines aimed at protection of vent species will require provision for site-specific issues such as whether mining will occur on active or inactive hydrothermal sites and the geographic range of the affected vent species. Standard criteria used in environmental assessment in other marine habitats will also have to be taken into account."

VI. Supply and Demand for the Metals of Economic Interest in Cobalt-Rich Ferromanganese Crusts and Polymetallic Sulphides Deposits.

54. Based on the documentation available to the ISA, the metals of interest in cobalt-rich ferromanganese crusts are cobalt, nickel, copper and manganese, with cobalt being by far the metal of primary interest. The metals of interest in polymetallic sulphides are copper, zinc, lead and in some cases gold, silver and platinum.

55. In 2002, the ISA commissioned the services of a consultant[1] to provide it with an outlook for the metals to be found in polymetallic nodules. The metals of interest in these mineral resources are copper, nickel, cobalt and manganese. While cobalt-rich ferromanganese crusts contain the same metals, polymetallic sulphides differ in that they contain zinc, lead and in some cases gold, silver and platinum.

56. Since the submission of the consultant's report, the metal markets have shown tremendous buoyancy with the prices of all the metals indicated above increasing significantly. The major findings by the consultant at the time with respect to copper, nickel, manganese and cobalt were as follows:

- Estimates of market behaviour made in the late 1970's proved to be overoptimistic (from a producer's perspective) for both consumption levels and prices. In hindsight, the actual market behaviour is understandable but it could not have been predicted at the time of the forecasts. In spite of the

[1] Outlook for metals from polymetallic nodules – Caitlyn L. Antrim, August 2002.

difficulty, effective management of the mineral resources of the deep seabed requires the best understanding possible of how markets may behave over the next decade and beyond.

- Looking back to the metals forecasts of the late 1970's, the markets have shown lower growth and lower prices than anticipated. This is due to several factors:

  (i) Tight markets and rising prices in the early 1980's and extreme price variability that led to slow growth in demand beyond unique and essential applications;

  (ii) Improvements in steelmaking technology that resulted in a 20% reduction in the use of manganese in steel production;

  (iii) Development of improved processing technologies, expansion of existing mines and development of nickel laterite resources in Australia;

  (iv) Financial attractiveness of investment in Chile rose sufficiently to significantly increase copper production capacity, more than compensating for reduction of copper production from the Democratic Republic of the Congo due to its political instability;

  (v) Delays in anticipated growth of developing country economies and reduced growth of demand for metals in industrialized economies as service industries increased their share of the industrial economy;

  (vi) The 1991 breakup of the former Soviet Union and the subsequent decline of industrial activity in the successor states that resulted in a significant reduction in domestic metal demand and corresponding increase in the availability of Russian nickel to the world market.

- Production capacity developed under the expectations of earlier forecasts resulted in production capacity to force prices for metals gradually downward.

- Development of improved processing technologies allowed mines and processors to continue to operate even when metals prices measured in constant terms dropped below prices of the late 1970's.

The outlook for the metal markets in the coming decade will be affected by:

- Continued growth of stainless steel and copper consumption in developing countries, undergoing industrialization, particularly in China and India;

- Low cost nickel and cobalt production in Australia and New Caledonia and application of PAL technology to reduce operating costs;

- Development of Voisey Bay's nickel-cobalt deposits in Canada; and,

- Continued low growth of steel demand and further implementation of improved steel-making technology that reduces need for manganese.

57. The conditions that ensured availability of sufficient quantities of low cost nickel, copper, cobalt and manganese will not continue indefinitely. Changing patterns of

economic growth, new demands in response to growth of the electronics sector and developments in automotive technology, and long lead times for the development of new mines and processing facilities all contribute to a long term outlook for tighter supplies and rising prices. As if these factors didn't make market forecasting complex enough, there are a number of uncertainties that could have a significant effect on the metals markets, particularly for nickel and cobalt, but whose timing is uncertain. These are:

- Recovery of the economies of the Russian Federation and other former Soviet republics accompanied by significant reduction of exports of metals needed by the domestic industries;

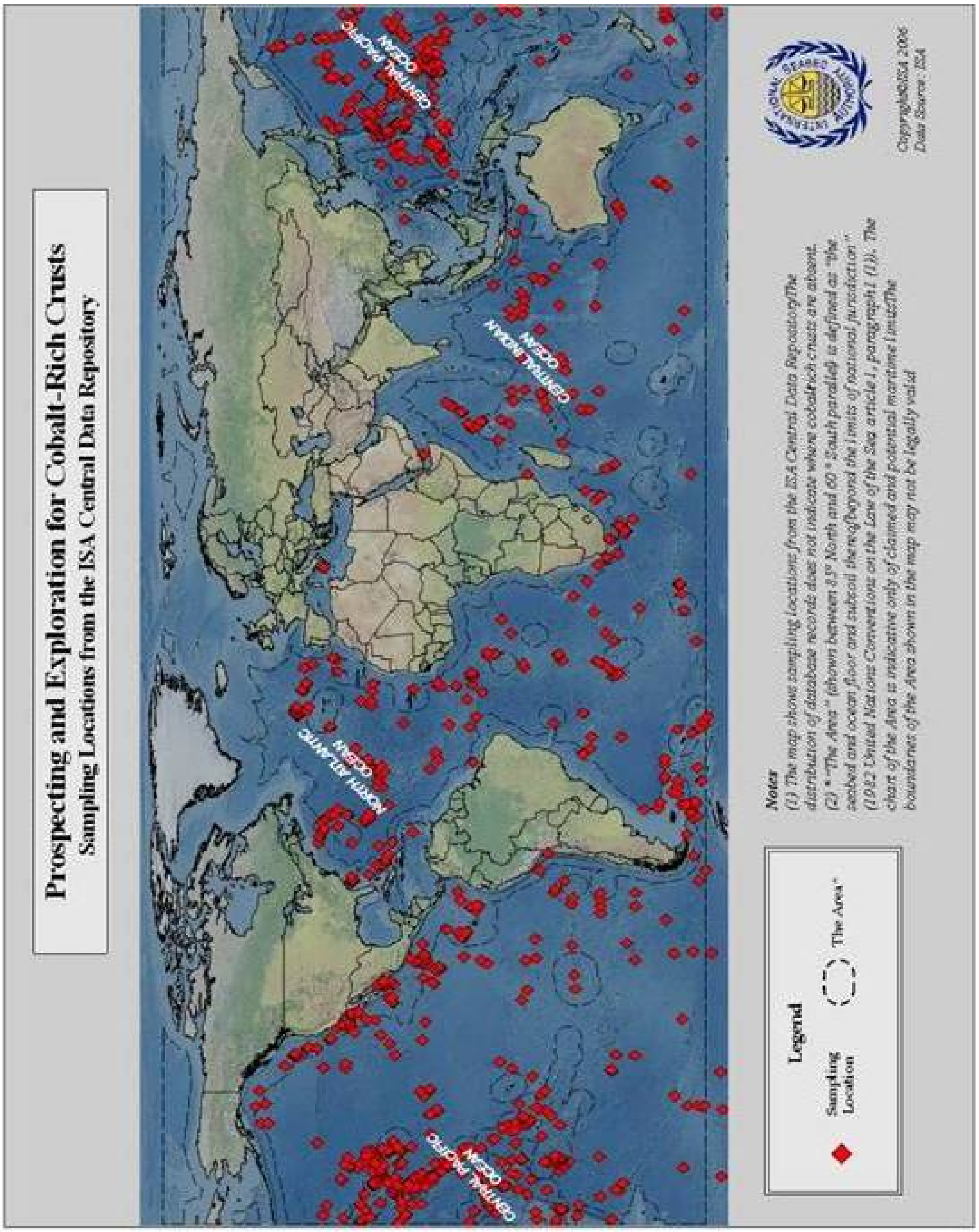
- Return of stability to the Democratic Republic of the Congo and return to production of the copper and cobalt mines;

- Rate of acceptance of hybrid and electric vehicles that require rechargeable batteries, and,

- Competition between nickel and cobalt in the market for rechargeable batteries.

58. Overall, the outlook is good for availability of nickel, copper, cobalt and manganese to support the global economy in quantities and at prices that encourage development and industrialization. It is likely, however, that major events affecting supply and demand will continue to drive the nickel and cobalt markets between periods of over- and under-supply with accompanying cycles of low and high prices. The range of prices, however, should be less pronounced than in the past due to improved production technology that makes it possible to process nickel and cobalt ores at low cost.

59. At this time, the greatest uncertainty appears to lie with the development of electric and hybrid automobiles and the choice of battery technology adopted in support of the vehicles. The size of the market and the division between nickel, cobalt and substitute materials is beyond prediction at this time, and yet it could be a major factor in the nickel market or the dominant use of cobalt within a decade.



Prospecting and Exploration for Cobalt-Rich Crusts
Sampling Locations from the ISA Central Data Repository
NORTH ATLANTIC OCEAN
CENTRAL PACIFIC OCEAN
CENTRAL INDIAN OCEAN
CENTRAL PACIFIC OCEAN
Legend
Sampling Location
The Area*
Notes
(1) The map shows sampling locations from the ISA Central Data RepositoryThe distribution of database records does not indicate where cobaltrich crusts are absent.
(2) * "The Area" (shown between 85° North and 60 ° South parallel) is defined as "the seabed and ocean floor and subsoil thereofbeyond the limits of national jurisdiction" (1982 United Nations Conventions on the Law of the Sea article 1, paragraph1 (1)). The chart of the Area is indicative only of claimed and potential maritime limitsThe boundaries of the Area shown in the map may not be legally valid
INTERNATIONAL SEABED AUTHORITY
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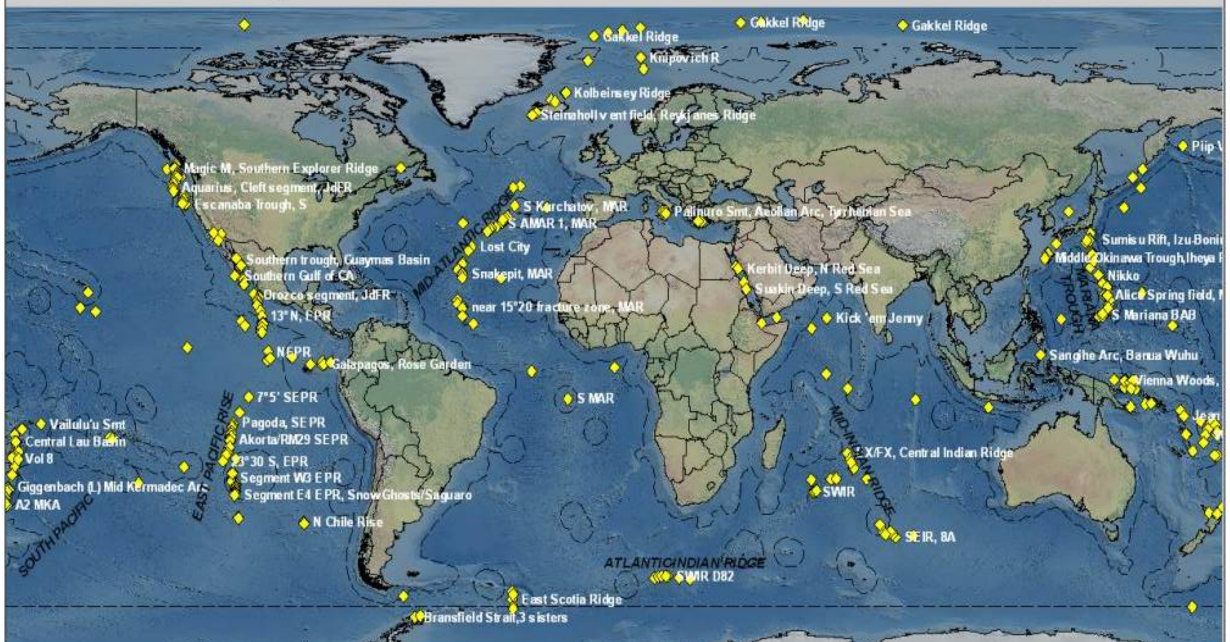
Data Source: ISA

Prospecting and Exploration for Polymetallic Sulphides
Sampling Locations and Hydrothermal Vents



Legend

Hydrothermal Vent / Sulphides Sampling Location

The Area*

Notes

(1) The map shows hydrothermal vents and sampling locations from the ISA Central Data Repository and the Interridge Hydrothermal Vent Database The distribution of database records does not indicate where vents and polymetallic sulphide deposits are absent

*(2) * "The Area" (shown between 85° North and 60° South parallel) is defined as "the seabed and ocean floor and subsoil thereof beyond the limits of national jurisdiction" (1982 United Nations Conventions on the Law of the Sea article 1, paragraph 1 (1)). The chart of the Area is indicative only of claimed and potential maritime limits The boundaries of the Area shown in the map may not be legally valid*

Annex 2

Draft regulations on prospecting and exploration for *polymetallic sulphides* and *cobalt-rich ferromanganese crusts* in the rea** (ISBA/C/WP/1/Rev.1*)

Preamble

In accordance with the United Nations Convention on the Law of the Sea ("the Convention"), the seabed and ocean floor and the subsoil thereof beyond the limits of national jurisdiction, as well as its resources, are the common heritage of mankind, the exploration and exploitation of which shall be carried out for the benefit of mankind as a whole, on whose behalf the International Seabed Authority acts. The objective of this set of Regulations is to provide for prospecting and exploration for polymetallic sulphides and cobalt-rich ferromanganese crusts.

Part I Introduction

Regulation 1
Use of terms and scope

1. Terms used in the Convention shall have the same meaning in these Regulations.

2. In accordance with the 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"), the provisions of the Agreement and Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982 shall be interpreted and applied together as a single instrument. These Regulations and references in these Regulations to the Convention are to be interpreted and applied accordingly.

3. For the purposes of these Regulations:

(a) "block" means a cell of a grid as provided by the Authority, which shall be approximately 10 kilometres by 10 kilometres and no greater than 100 square kilometres;

(b) "cobalt crusts" means hydroxide/oxide deposits of cobalt-rich iron/manganese (ferromanganese) crust formed from direct precipitation of minerals from seawater onto hard substrates containing minor but significant concentrations of cobalt, titanium, nickel, platinum, molybdenum, tellurium, cerium, other metallic and rare earth elements;

(c) "exploitation" means the recovery for commercial purposes of polymetallic sulphides or cobalt crusts in the Area and the extraction of minerals therefrom, including the construction and operation of mining, processing and transportation systems, for the production and marketing of metals;

(d) "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;

(e) "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

(f) "polymetallic sulphides" means hydrothermally formed deposits of sulphide minerals which contain concentrations of metals including, inter alia, copper, lead, zinc, gold and silver;

(g) "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;

(h) "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.

4. These Regulations shall not in any way affect the freedom of scientific research, pursuant to article 87 of the Convention, or the right to conduct marine scientific research in the Area pursuant to articles 143 and 256 of the Convention. Nothing in these Regulations shall be construed in such a way as to restrict the exercise by States of the freedom of the high seas as reflected in article 87 of the Convention.

5. These Regulations may be supplemented by further rules, regulations and procedures, in particular on the protection and preservation of the marine environment. These Regulations shall be subject to the provisions of the Convention and the Agreement and other rules of international law not incompatible with the Convention.

Part II Prospecting

Regulation 2
Prospecting

1. Prospecting shall be conducted in accordance with the Convention and these Regulations and may commence only after the prospector has been informed by the Secretary-General that its notification has been recorded pursuant to regulation 4, paragraph 2.

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

3. Prospecting shall not be undertaken in an area covered by an approved plan of work for exploration for polymetallic sulphides or cobalt crusts or in a reserved area; nor may there be prospecting in an area which the Council has disapproved for exploitation because of the risk of serious harm to the marine environment.

4. Prospecting shall not confer on the prospector any rights with respect to resources. A prospector may, however, recover a reasonable quantity of minerals, being the quantity necessary for testing, and not for commercial use.

5. There shall be no time limit on prospecting except that prospecting in a particular area shall cease upon written notification to the prospector by the Secretary-General that a plan of work for exploration has been approved with regard to that area.

6. Prospecting may be conducted simultaneously by more than one prospector in the same area or areas.

Regulation 3
Notification of prospecting

1. A proposed prospector shall notify the Authority of its intention to engage in prospecting.

2. Each notification of prospecting shall be in the form prescribed in annex 1 to these Regulations, addressed to the Secretary-General, and shall conform to the requirements of these Regulations.

3. Each notification shall be submitted:

(a) in the case of a State, by the authority designated for that purpose by it;

(b) in the case of an entity, by its designated representative;

(c) in the case of the Enterprise, by its competent authority.

4. Each notification shall be in one of the languages of the Authority and shall contain:

(a) the name, nationality and address of the proposed prospector and its designated representative;

(b) the coordinates of the broad area or areas within which prospecting is to be conducted, in accordance with the most recent generally accepted international standard used by the Authority;

(c) a general description of the prospecting programme, including the proposed date of commencement and its approximate duration;

(d) a satisfactory written undertaking that the proposed prospector will:

(i) comply with the Convention and the relevant rules, regulations and procedures of the Authority concerning:

a. cooperation in the training programmes in connection with marine scientific research and transfer of technology referred to in articles 143 and 144 of the Convention; and

b. protection and preservation of the marine environment;

(ii) accept verification by the Authority of compliance therewith; and

(iii) make available to the Authority, as far as practicable, such data as may be relevant to the protection and preservation of the marine environment.

Regulation 4
Consideration of notifications

1. The Secretary-General shall acknowledge in writing receipt of each notification submitted under regulation 3, specifying the date of receipt.

2. The Secretary-General shall review and act on the notification within 45 days of its receipt. If the notification conforms with the requirements of the Convention and these Regulations, the Secretary-General shall record the particulars of the notification in a register maintained for that purpose and shall inform the prospector in writing that the notification has been so recorded.

3. The Secretary-General shall, within 45 days of receipt of the notification, inform the proposed prospector in writing if the notification includes any part of an area included in an approved plan of work for exploration or exploitation of any category of resources, or any part of a reserved area, or any part of an area which has been disapproved by the Council for exploitation because of the risk of serious harm to the marine environment, or if the written undertaking is not satisfactory, and shall provide the proposed prospector with a written statement of reasons. In such cases, the proposed prospector may, within 90 days, submit an amended notification. The Secretary-General shall, within 45 days, review and act upon such amended notification.

4. A prospector shall inform the Secretary-General in writing of any change in the information contained in the notification.

5. The Secretary-General shall not release any particulars contained in the notification except with the written consent of the prospector. The Secretary-General shall, however, from time to time inform all members of the Authority of the identity of prospectors and the general areas in which prospecting is being conducted.

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:

(a) adverse environmental impacts from prospecting; and

(b) 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.

Regulation 6
Annual report

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:

(a) a general description of the status of prospecting and of the results obtained;

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

(c) information on compliance with the relevant future guidelines in this regard.

2. If the prospector intends to claim expenditures for prospecting as part of the development costs incurred prior to the commencement of commercial production, the prospector shall submit an annual statement, in conformity with internationally accepted accounting principles and certified by a duly qualified firm of public accountants, of the actual and direct expenditures incurred by the prospector in carrying out prospecting.

Regulation 7
Confidentiality of data and information from prospecting contained in the annual report

1. The Secretary-General shall ensure the confidentiality of all data and information contained in the reports submitted under regulation 6 applying mutatis mutandis the provisions of regulations 38 and 39, provided that data and information relating exclusively to environmental monitoring programmes shall not be considered confidential.

2. The Secretary-General may, at any time, with the consent of the prospector concerned, release data and information relating to prospecting in an area in respect of which a notification has been submitted. If the Secretary-General determines that the prospector no longer exists or cannot be located, the Secretary-General may release such data and information.

Regulation 8
Objects of an archaeological or historical nature

3. A prospector shall immediately notify the Secretary-General in writing of any finding in the Area of an object of an archaeological or historical nature and its location. The Secretary-General shall transmit such information to the Director-General of the United Nations Educational, Scientific and Cultural Organization.

Part III Applications for approval of plans of work for Exploration in the form of contracts

Section 1 General provisions

Regulation 9
General

Subject to the provisions of the Convention, the following may apply to the Authority for approval of plans of work for exploration:

(a) the Enterprise, on its own behalf or in a joint arrangement;

(b) States Parties, state enterprises or natural or juridical persons which possess the nationality of States or are effectively controlled by them or their nationals, when sponsored by such States, or any group of the foregoing which meets the requirements of these Regulations.

Section 2 Content of applications

Regulation 10
Form of applications

1. Each application for approval of a plan of work for exploration shall be in the form prescribed in annex 2 to these Regulations, shall be addressed to the Secretary-General, and shall conform to the requirements of these Regulations.

2. Each application shall be submitted:

(a) in the case of a State, by the authority designated for that purpose by it;

(b) in the case of an entity, by its designated representative or the authority designated for that purpose by the sponsoring State or States; and

(c) in the case of the Enterprise, by its competent authority.

3. Each application by a state enterprise or one of the entities referred to in subparagraph (b) of regulation 9 shall also contain:

(a) sufficient information to determine the nationality of the applicant or the identity of the State or States by which, or by whose nationals, the applicant is effectively controlled; and

(b) the principal place of business or domicile and, if applicable, place of registration of the applicant.

4. Each application submitted by a partnership or consortium of entities shall contain the required information in respect of each member of the partnership or consortium.

Regulation 11
Certificate of sponsorship

1. Each application by a state enterprise or one of the entities referred to in subparagraph (b) of regulation 9 shall be accompanied by a certificate of sponsorship issued by the State of which it is a national or by which or by whose nationals it is effectively controlled. If the applicant has more than one nationality, as in the case of a partnership or consortium of entities from more than one State, each State involved shall issue a certificate of sponsorship.

2. Where the applicant has the nationality of one State but is effectively controlled by another State or its nationals, each State involved shall issue a certificate of sponsorship.

3. Each certificate of sponsorship shall be duly signed on behalf of the State by which it is submitted, and shall contain:

(a) the name of the applicant;

(b) the name of the sponsoring State;

(c) a statement that the applicant is:

(i) a national of the sponsoring State; or
(ii) subject to the effective control of the sponsoring State or its nationals;

(d) a statement by the sponsoring State that it sponsors the applicant;

(e) the date of deposit by the sponsoring State of its instrument of ratification of, or accession or succession to, the Convention;

(f) a declaration that the sponsoring State assumes responsibility in accordance with article 139, article 153, paragraph 4, and annex III, article 4, paragraph 4, of the Convention.

4. States or entities in a joint arrangement with the Enterprise shall also comply with this regulation.

Regulation 12
Total area covered by the application

1. The area covered by each application for approval of a plan of work for exploration shall be comprised of not more than 100 blocks.

2. For polymetallic sulphides or cobalt crusts the exploration area shall consist of contiguous blocks. For the purposes of this regulation two blocks that touch at any point shall be considered to be contiguous.

3. Notwithstanding the provisions in paragraph 1 above, where a contractor has elected to contribute a reserved area to carry out activities pursuant to annex III, article 9, of the Convention, in accordance with regulation 17, the total area covered by an application shall not exceed 200 blocks.

Regulation 13
Financial and technical capabilities

1. Each application for approval of a plan of work for exploration shall contain specific and sufficient information to enable the Council to determine whether the applicant is financially and technically capable of carrying out the proposed plan of work for exploration and of fulfilling its financial obligations to the Authority.

2. An application for approval of a plan of work for exploration by the Enterprise shall include a statement by its competent authority certifying that the Enterprise has the necessary financial resources to meet the estimated costs of the proposed plan of work for exploration.

3. An application for approval of a plan of work for exploration by a State or a state enterprise shall include a statement by the State or the sponsoring State certifying that the applicant has the necessary financial resources to meet the estimated costs of the proposed plan of work for exploration.

4. An application for approval of a plan of work for exploration by an entity shall include copies of its audited financial statements, including balance sheets and profit-and-loss statements, for the most recent three years, in conformity with internationally accepted accounting principles and certified by a duly qualified firm of public accountants; and

(a) if the applicant is a newly organized entity and a certified balance sheet is not available, a pro forma balance sheet certified by an appropriate official of the applicant;

(b) if the applicant is a subsidiary of another entity, copies of such financial statements of that entity and a statement from that entity, in conformity with internationally accepted accounting principles and certified by a duly qualified firm of public accountants, that the applicant will have the financial resources to carry out the plan of work for exploration;

(c) if the applicant is controlled by a State or a state enterprise, a statement from the State or state enterprise certifying that the applicant will have the financial resources to carry out the plan of work for exploration.

5. Where an applicant referred to in paragraph 4 intends to finance the proposed plan of work for exploration by borrowings, its application shall include the amount of such borrowings, the repayment period and the interest rate.

6. Each application shall include:

(a) a general description of the applicant’s previous experience, knowledge, skills, technical qualifications and expertise relevant to the proposed plan of work for exploration;

(b) a general description of the equipment and methods expected to be used in carrying out the proposed plan of work for exploration and other relevant non-proprietary information about the characteristics of such technology;

(c) a general description of the applicant's financial and technical capability to respond to any incident or activity which causes serious harm to the marine environment.

7. Where the applicant is a partnership or consortium of entities in a joint arrangement, each member of the partnership or consortium shall provide the information required by this regulation.

Regulation 14
Previous contracts with the Authority

Where the applicant or, in the case of an application by a partnership or consortium of entities in a joint arrangement, any member of the partnership or consortium, has previously been awarded any contract with the Authority, the application shall include:

(a) the date of the previous contract or contracts;

(b) the dates, reference numbers and titles of each report submitted to the Authority in connection with the contract or contracts; and

(c) the date of termination of the contract or contracts, if applicable.

Regulation 15
Undertakings

Each applicant, including the Enterprise, shall, as part of its application for approval of a plan of work for exploration, provide a written undertaking to the Authority that it will:

(a) accept as enforceable and comply with the applicable obligations created by the provisions of the Convention and the rules, regulations and procedures of the Authority, the decisions of the organs of the Authority and the terms of its contracts with the Authority;

(b) accept control by the Authority of activities in the Area, as authorized by the Convention; and

(c) provide the Authority with a written assurance that its obligations under the contract will be fulfilled in good faith.

Regulation 16

Applicant's election of a reserved area contribution or equity interest or joint venture or production sharing participation

Each applicant shall, in the application, elect either to:

(a) contribute a reserved area to carry out activities pursuant to Annex III, article 9, of the Convention, in accordance with regulation 17; or

(b) offer an equity interest in accordance with regulation 19; or

(c) enter into a joint venture arrangement in accordance with regulation 19; or

(d) enter into a production-sharing contract in accordance with regulation 19.

Regulation 17
Data and information to be submitted before the designation of a reserved area

1. Where the applicant elects to contribute a reserved area, the area covered by the application shall be sufficiently large and of sufficient estimated commercial value to allow two mining operations. The applicant shall divide the blocks comprising the application into two groups of equal estimated commercial value and composed of contiguous blocks. The area to be allocated to the applicant shall be subject to the provisions of regulation 27.

2. Each such application shall contain sufficient data and information, as prescribed in section III of annex 2 to these Regulations, with respect to the area under application to enable the Council, on the recommendation of the Legal and Technical Commission, to designate a reserved area based on the estimated commercial value of each part. Such data and information shall consist of data available to the applicant with respect to both parts of the area under application, including the data used to determine their commercial value.

3. The Council, on the basis of the data and information submitted by the applicant pursuant to section III of annex 2 to these Regulations, if found satisfactory, and taking into account the recommendation of the Legal and Technical Commission, shall designate the part of the area under application which is to be a reserved area. The area so designated shall become a reserved area as soon as the plan of work for exploration for the non-reserved area is approved and the contract is signed. If the Council determines that additional information, consistent with these Regulations and annex 2, is needed to designate the reserved area, it shall refer the matter back to the Commission for further consideration, specifying the additional information required.

4. Once the plan of work for exploration is approved and a contract has been issued, the data and information transferred to the Authority by the applicant in respect of the reserved area may be disclosed by the Authority in accordance with article 14, paragraph 3, of annex III to the Convention.

Regulation 18
Applications for approval of plans of work with respect to a reserved area

1. Any State which is a developing State or any natural or juridical person sponsored by it and effectively controlled by it or by any other developing State, or any group of the foregoing, may notify the Authority that it wishes to submit a plan of work for exploration with respect to a reserved area. The Secretary-General shall forward such notification to the Enterprise, which shall inform the Secretary-General in writing within six months whether or not it intends to carry out activities in that area. If the Enterprise intends to carry out activities in that area, it shall, pursuant to paragraph 4, also inform in

writing the contractor whose application for approval of a plan of work for exploration originally included that area.

2. An application for approval of a plan of work for exploration in respect of a reserved area may be submitted at any time after such an area becomes available following a decision by the Enterprise that it does not intend to carry out activities in that area or where the Enterprise has not, within six months of the notification by the Secretary-General, either taken a decision on whether it intends to carry out activities in that area or notified the Secretary-General in writing that it is engaged in discussions regarding a potential joint venture. In the latter instance, the Enterprise shall have one year from the date of such notification in which to decide whether to conduct activities in that area.

3. If the Enterprise or a developing State or one of the entities referred to in paragraph 1 does not submit an application for approval of a plan of work for exploration for activities in a reserved area within 15 years of the commencement by the Enterprise of its functions independent of the Secretariat of the Authority or within 15 years of the date on which that area is reserved for the Authority, whichever is the later, the contractor whose application for approval of a plan of work for exploration originally included that area shall be entitled to apply for a plan of work for exploration for that area provided it offers in good faith to include the Enterprise as a joint-venture partner.

4. A contractor has the right of first refusal to enter into a joint venture arrangement with the Enterprise for exploration of the area which was included in its application for approval of a plan of work for exploration and which was designated by the Council as a reserved area.

Regulation 19
Equity interest, joint venture or production sharing participation

1. Where the applicant elects to offer an equity interest, joint venture or a production sharing, it shall submit data and information in accordance with regulation 20. The area to be allocated to the applicant shall be subject to the provisions of regulation 27.

2. Equity interest: the Equity interest, which shall take effect at the time the applicant applies for a contract for exploitation, shall include the following:

The Enterprise shall obtain a minimum of 20 per cent of the equity participation in the venture arrangement on the following basis:

(a) Half of such equity participation shall be obtained without payment, directly or indirectly, to the applicant and shall be treated *pari passu* for all purposes with the equity participation of the applicant;

(b) The remainder of such equity participation shall be treated *pari passu* for all purposes with the equity participation of the applicant except that the Enterprise shall not receive any profit distribution with respect to such participation until the applicant has recovered its total equity participation in the venture.

3. Joint venture: notwithstanding paragraph (2) above, the applicant shall nevertheless offer the Enterprise the opportunity to obtain up to 50 per cent participation in a joint venture on the basis of *pari passu* treatment with the applicant for all purposes:

(a) In the event the Enterprise elects not to accept 50 per cent of such equity participation, the Enterprise may obtain a lesser per cent on the basis of pari passu treatment with the applicant for all purposes for such lesser participation;

(b) Except as specifically provided in the agreement between the applicant and the Enterprise, the Enterprise shall not by reason of its participation be otherwise obligated to provide funds or credits or issue guarantees or otherwise accept any financial liability whatsoever for, or on behalf of, the joint venture arrangement, nor shall the Enterprise be required to subscribe for additional participation so as to maintain its proportionate participation in the joint venture arrangement.

4. Production sharing: A production sharing contract shall include a requirement that the applicant will be responsible for all the management and execution of the operations during the exploration phase with its own capital, manpower, technology and equipment at its sole risk and cost. During the exploitation phase, the applicant is entitled to recover these costs. Thereafter, profits will be split on a 50:50 basis between the applicant and the Enterprise.

Regulation 20
Data and information to be submitted for approval of the plan of 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:

(a) a general description and a schedule of the proposed exploration programme, including the programme of activities 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 description of the programme for oceanographic and environmental baseline 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;

(c) a preliminary assessment of the possible impact of the proposed exploration activities on the marine environment;

(d) 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;

(e) data necessary for the Council to make the determination it is required to make in accordance with regulation 13, paragraph 1; and

(f) a schedule of anticipated yearly expenditures in respect of the programme of activities for the immediate five-year period.

2. Where the applicant elects to contribute a reserved area, the data and information relating to such area shall be transferred by the applicant after the Council has designated the reserved area in accordance with regulation 17, paragraph 3.

3. Where the applicant elects to offer an equity interest or joint venture arrangement or enter into a production sharing contract, the data and information relating to such area shall be transferred by the applicant at the time of the election.

<u>Section 3 Fees</u>

Regulation 21
Fee for applications

1. The fee for processing applications for approval of a plan of work for exploration shall be 250,000 United States dollars or its equivalent in a freely convertible currency. The fee shall be paid to the Authority by the applicant at the time of submitting an application.

2. The amount of the fee shall be reviewed from time to time by the Council in order to ensure that it covers the administrative costs incurred by the Authority in processing the application.

<u>Section 4 Processing of applications</u>

Regulation 22
Receipt, acknowledgement and safe custody of applications

The Secretary-General shall:

(a) acknowledge in writing receipt of every application for approval of a plan of work for exploration submitted under this Part, specifying the date of receipt;

(b) place the application together with the attachments and annexes thereto in safe custody and ensure the confidentiality of all confidential data and information contained in the application; and

(c) notify the members of the Authority of the receipt of such application and circulate to them information of a general nature which is not confidential regarding the application.

Regulation 23
Consideration by the Legal and Technical Commission

1. 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.

2. The Commission shall examine applications in the order in which they are received.

3. The Commission shall determine if the applicant:

(a) has complied with the provisions of these Regulations;

(b) has given the undertakings and assurances specified in regulation 15;

(c) possesses the financial and technical capability to carry out the proposed plan of work for exploration; and

(d) has satisfactorily discharged its obligations in relation to any previous contract with the Authority.

4. 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:

(a) provide for effective protection of human health and safety;

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

(c) ensure that installations are not established where interference may be caused to the use of recognized sea lanes essential to international navigation or in areas of intense fishing activity.

5. If the Commission makes the determinations specified in paragraph 3 and determines that the proposed plan of work for exploration meets the requirements of paragraph 4, the Commission shall recommend approval of the plan of work for exploration to the Council.

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:

(a) a plan of work for exploration approved by the Council for polymetallic sulphides or cobalt crusts; or

(b) a plan of work approved by the Council for exploration for or exploitation of other resources if such proposed plan of work for exploration for polymetallic sulphides or cobalt crusts might cause undue interference with activities under such an approved plan of work for such other resources; or

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

7. Except in the case of applications by the Enterprise, on its own behalf or in a joint venture, and applications under regulation 18, 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 a reserved area or an area designated by the Council to be a reserved area.

8. If the Commission finds that an application does not comply with these Regulations, it shall notify the applicant in writing, through the Secretary-General, indicating the reasons. The applicant may, within 45 days of such notification, amend its application. If the Commission after further consideration is of the view that it should not recommend approval of the plan of work for exploration, it shall so inform the applicant and provide the applicant with a further opportunity to make representations within 30 days of such information. The Commission shall consider any such representations made by the applicant in preparing its report and recommendation to the Council.

9. In considering a proposed plan of work for exploration, the Commission shall have regard to the principles, policies and objectives relating to activities in the Area as provided for in part XI and annex III of the Convention and the Agreement.

10. The Commission shall consider applications expeditiously and shall submit its report and recommendations to the Council on the designation of the areas and on the plan of work for exploration at the first possible opportunity, taking into account the schedule of meetings of the Authority.

11. In discharging its duties, the Commission shall apply these Regulations and the rules, regulations and procedures of the Authority in a uniform and non-discriminatory manner.

Regulation 24
Consideration and approval of plans of work for exploration by the Council

1. The Council shall consider the reports and recommendations of the Commission relating to approval of plans of work for exploration in accordance with paragraphs 11 and 12 of section 3 of the annex to the Agreement.

2. If the Commission has made recommendations for the approval of applications in the same area or areas by more than one applicant, the Secretary-General shall so notify such applicants, who may, within 45 days of such notification, amend their applications so as to resolve conflicts with respect to such applications. If such conflicts are not resolved within the said period, the Council shall determine the area or areas to be allocated to each applicant on an equitable and non-discriminatory basis.

Part IV Contracts for exploration

Regulation 25
The contract

1. After a plan of work for exploration has been approved by the Council, it shall be prepared in the form of a contract between the Authority and the applicant as prescribed in annex 3 to these Regulations. Each contract shall incorporate the standard clauses set out in annex 4 in effect at the date of entry into force of the contract.

2. The contract shall be signed by the Secretary-General on behalf of the Authority and by the applicant. The Secretary-General shall notify all members of the Authority in writing of the conclusion of each contract.

Regulation 26
Rights of the contractor

1. The contractor shall have the exclusive right to explore an area covered by a plan of work for exploration in respect of polymetallic sulphides or cobalt crusts. The Authority shall ensure that no other entity operates in the same area for resources other than polymetallic sulphides or cobalt crusts in a manner that might interfere with the operations of the contractor.

2. A contractor who has an approved plan of work for exploration only shall have a preference and a priority among applicants submitting plans of work for exploitation of the same area and resources. Such preference or priority may be withdrawn by the Council if the contractor has failed to comply with the requirements of its approved plan of work for exploration within the time period specified in a written notice or notices from the Council to the contractor indicating which requirements have not been complied with by the contractor. The time period specified in any such notice shall not be unreasonable. The contractor shall be accorded a reasonable opportunity to be heard before the withdrawal of such preference or priority becomes final. The Council shall provide the reasons for its proposed withdrawal of preference or priority and shall consider any contractor's response. The decision of the Council shall take account of that response and shall be based on substantial evidence.

3. A withdrawal of preference or priority shall not become effective until the contractor has been accorded a reasonable opportunity to exhaust the judicial remedies available to it pursuant to part XI, section 5, of the Convention.

Regulation 27
Size of area and relinquishment

1. The contractor shall relinquish the blocks allocated to it in accordance with paragraphs 2, 3 and 4 of this regulation.

2. By the end of the fifth year from the date of the contract, the contractor shall have relinquished:

(a) at least 50 per cent of the number of blocks allocated to it; or

(b) if 50 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

3. By the end of the tenth year from the date of the contract, the contractor shall have relinquished:

(a) at least 75 per cent of the number of blocks allocated to it; or

(b) if 75 per cent of that number of blocks is a whole number and a fraction, the next higher whole number of the blocks.

4. At the end of the fifteenth year from the date of the contract, or when the contractor applies for exploitation rights, whichever is the earlier, the contractor shall

nominate up to 25 blocks from the remaining number of blocks allocated to it, which shall be retained by the contractor.

5. Relinquished blocks shall revert to the Area.

6. The Council may, at the request of the contractor, and on the recommendation of the Commission, in exceptional circumstances, defer the schedule of relinquishment. Such exceptional circumstances shall be determined by the Council and shall include, inter alia, consideration of prevailing economic circumstances or other unforeseen exceptional circumstances arising in connection with the operational activities of the Contractor.

Regulation 28
Duration of contracts

1. A plan of work for exploration shall be approved for a period of 15 years. Upon expiration of a plan of work for exploration, the contractor shall apply for a plan of work for exploitation unless the contractor has already done so, has obtained an extension for the plan of work for exploration or decides to renounce its rights in the area covered by the plan of work for exploration.

2. Not later than six months before the expiration of a plan of work for exploration, a contractor may apply for extensions for the plan of work for exploration for periods of not more than five years each. Such extensions shall be approved by the Council, on the recommendation of the Commission, if the contractor has made efforts in good faith to comply with the requirements of the plan of work but for reasons beyond the contractor's control has been unable to complete the necessary preparatory work for proceeding to the exploitation stage or if the prevailing economic circumstances do not justify proceeding to the exploitation stage.

Regulation 29
Training

Pursuant to article 15 of annex III to the Convention, each contract shall include as a schedule a practical programme for the training of personnel of the Authority and developing States and drawn up by the contractor in cooperation with the Authority and the sponsoring State or States. Training programmes shall focus on training in the conduct of exploration, and shall provide for full participation by such personnel in all activities covered by the contract. Such training programmes may be revised and developed from time to time as necessary by mutual agreement.

Regulation 30
Periodic review of the implementation of the plan of work for exploration

1. The contractor and the Secretary-General shall jointly undertake a periodic review of the implementation of the plan of work for exploration at intervals of five years. The Secretary-General may request the contractor to submit such additional data and information as may be necessary for the purposes of the review.

2. In the light of the review, the contractor shall indicate its programme of activities for the following five-year period, making such adjustments to its previous programme of activities as are necessary.

3. The Secretary-General shall report on the review to the Commission and to the Council. The Secretary-General shall indicate in the report whether any observations transmitted to him by States Parties to the Convention concerning the manner in which the contractor has discharged its obligations under these Regulations relating to the protection and preservation of the marine environment were taken into account in the review.

Regulation 31
Termination of sponsorship

1. Each contractor shall have the required sponsorship throughout the period of the contract.

2. If a State terminates its sponsorship it shall promptly notify the Secretary-General in writing. The sponsoring State should also inform the Secretary-General of the reasons for terminating its sponsorship. Termination of sponsorship shall take effect six months after the date of receipt of the notification by the Secretary-General, unless the notification specifies a later date.

3. In the event of termination of sponsorship the contractor shall, within the period referred to in paragraph 2, obtain another sponsor. Such sponsor shall submit a certificate of sponsorship in accordance with regulation 11. Failure to obtain a sponsor within the required period shall result in the termination of the contract.

4. A sponsoring State shall not be discharged by reason of the termination of its sponsorship from any obligations accrued while it was a sponsoring State, nor shall such termination affect any legal rights and obligations created during such sponsorship.

5. The Secretary-General shall notify the members of the Authority of the termination or change of sponsorship.

Regulation 32
Responsibility and liability

Responsibility and liability of the contractor and of the Authority shall be in accordance with the Convention. The contractor shall continue to have responsibility for any damage arising out of wrongful acts in the conduct of its operations, in particular damage to the marine environment, after the completion of the exploration phase.

Part V Protection and preservation of the marine environment

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 for 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,1 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 as far as reasonably possible using the best technology available to it.

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.

Regulation 34
Environmental baselines and monitoring

1. Each contract shall require the contractor to gather environmental baseline data and to establish environmental baselines, taking into account any recommendations issued by the Legal and Technical Commission pursuant to regulation 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. The Secretary-General shall transmit such reports to the Commission for its consideration pursuant to article 165 of the Convention.

Regulation 35
Emergency orders

1. When the Secretary-General has been notified by a contractor or otherwise becomes aware 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, the Secretary-General shall cause a general notification of the incident to be issued, shall notify in writing the contractor and the sponsoring State or States, and shall report immediately to the Legal and Technical Commission and to the Council. A copy of the report shall be circulated to all members of the Authority, to competent international organizations and to

concerned subregional, regional and global organizations and bodies. The Secretary-General shall monitor developments with respect to all such incidents and shall report on them as appropriate to the Commission and to the Council.

2. Pending any action by the Council, the Secretary-General shall take such immediate measures of a temporary nature as are practical and reasonable in the circumstances to prevent, contain and minimize the threat of serious or irreversible damage to the marine environment. Such temporary measures shall remain in effect for no longer than 90 days, or until the Council decides what measures, if any, to take pursuant to paragraph 5 of this regulation, whichever is the earlier.

3. After having received the report of the Secretary-General, the Commission shall determine, based on the evidence provided to it and taking into account the measures already taken by the contractor, which measures are necessary to respond effectively to the incident in order to prevent, contain and minimize the threat of serious or irreversible damage to the marine environment, and shall make its recommendations to the Council.

4. The Council shall consider the recommendations of the Commission.

5. The Council, taking into account the recommendations of the Commission and any information provided by the Contractor, may issue emergency orders, which may include orders for the suspension or adjustment of operations, as may be reasonably necessary to prevent, contain and minimize the threat of serious harm to the marine environment arising out of activities in the Area.

6. If a contractor does not promptly comply with an emergency order to prevent a threat of serious harm to the marine environment arising out of its activities in the Area, the Council shall take by itself or through arrangements with others on its behalf, such practical measures as are necessary to prevent, contain and minimize any such serious harm to the marine environment.

7. In order to enable the Council, when necessary, to take immediately the practical measures to prevent, contain and minimize the threat of serious harm to the marine environment referred to in paragraph 6, the contractor, prior to the commencement of testing of collecting systems and processing operations, will provide the Council with a guarantee of its financial and technical capability to comply promptly with emergency orders or to assure that the Council can take such emergency measures. If the contractor does not provide the Council with such a guarantee, the sponsoring State or States shall, in response to a request by the Secretary-General and pursuant to articles 139 and 235 of the Convention, take necessary measures to ensure that the contractor provides such a guarantee or shall take measures to ensure that assistance is provided to the Authority in the discharge of its responsibilities under paragraph 6.

Regulation 36
Rights of coastal States

1. Nothing in these Regulations shall affect the rights of coastal States in accordance with article 142 and other relevant provisions of the Convention.

2. Any coastal State which has 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 may notify the Secretary-General in writing of the grounds upon

which such belief is based. The Secretary-General shall provide the Contractor and its sponsoring State or States with a reasonable opportunity to examine the evidence, if any, provided by the coastal State as the basis for its belief. The contractor and its sponsoring State or States may submit their observations thereon to the Secretary-General within a reasonable time.

3. If there are clear grounds for believing that serious harm to the marine environment is likely to occur, the Secretary-General shall act in accordance with regulation 35 and, if necessary, shall take immediate measures of a temporary nature as provided for in paragraph 2 of regulation 35.

4. Contractors shall take all measures necessary to ensure that their activities are conducted so as not to cause damage by pollution to the marine environment under the jurisdiction or sovereignty of other States, and that pollution arising from incidents or activities in its exploration area does not spread beyond such area.

Regulation 37
Objects of an archaeological or historical nature

The contractor shall immediately notify the Secretary-General in writing of any finding in the exploration area of an object of an archaeological or historical nature and its location. The Secretary-General shall transmit such information to the Director-General of the United Nations Educational, Scientific and Cultural Organization. Following the finding of any such object of an archaeological or historical nature in the exploration area, the contractor shall take all reasonable measures to avoid disturbing such object.

Part VI Confidentiality

Regulation 38
Proprietary data and information and confidentiality

1. Data and information submitted or transferred to the Authority or to any person participating in any activity or programme of the Authority pursuant to these Regulations or a contract issued under these Regulations, and designated by the contractor, in consultation with the Secretary-General, as being of a confidential nature, shall be considered confidential unless it is data and information which:

(a) is generally known or publicly available from other sources;

(b) has been previously made available by the owner to others without an obligation concerning its confidentiality; or

(c) is already in the possession of the Authority with no obligation concerning its confidentiality.

2. Data and information that is necessary for the formulation by the Authority of rules, regulations and procedures concerning protection of the marine environment and safety, other than equipment design data, shall not be deemed proprietary.

3. Confidential data and information may only be used by the Secretary-General and staff of the Secretariat, as authorized by the Secretary-General, and by the members of the Legal and Technical Commission as necessary for and relevant to the effective

exercise of their powers and functions. The Secretary-General shall authorize access to such data and information only for limited use in connection with the functions and duties of the staff of the Secretariat and the functions and duties of the Legal and Technical Commission.

4. Ten years after the date of submission of confidential data and information to the Authority or the expiration of the contract for exploration, whichever is the later, and every five years thereafter, the Secretary-General and the contractor shall review such data and information to determine whether they should remain confidential. Such data and information shall remain confidential if the contractor establishes that there would be a substantial risk of serious and unfair economic prejudice if the data and information were to be released. No such data and information shall be released until the contractor has been accorded a reasonable opportunity to exhaust the judicial remedies available to it pursuant to Part XI, section 5, of the Convention.

5. If, at any time following the expiration of the contract for exploration, the contractor enters into a contract for exploitation in respect of any part of the exploration area, confidential data and information relating to that part of the area shall remain confidential in accordance with the contract for exploitation.

6. The contractor may at any time waive confidentiality of data and information.

Regulation 39
Procedures to ensure confidentiality

1. The Secretary-General shall be responsible for maintaining the confidentiality of all confidential data and information and shall not, except with the prior written consent of the contractor, release such data and information to any person external to the Authority. To ensure the confidentiality of such data and information, the Secretary-General shall establish procedures, consistent with the provisions of the Convention, governing the handling of confidential information by members of the Secretariat, members of the Legal and Technical Commission and any other person participating in any activity or programme of the Authority. Such procedures shall include:

(a) maintenance of confidential data and information in secure facilities and development of security procedures to prevent unauthorized access to or removal of such data and information;

(b) development and maintenance of a classification, log and inventory system of all written data and information received, including its type and source and routing from the time of receipt until final disposition.

2. A person who is authorized pursuant to these Regulations to have access to confidential data and information shall not disclose such data and information except as permitted under the Convention and these Regulations. The Secretary-General shall require any person who is authorized to have access to confidential data and information to make a written declaration witnessed by the Secretary-General or his or her authorized representative to the effect that the person so authorized:

(a) acknowledges his or her legal obligation under the Convention and these Regulations with respect to the non-disclosure of confidential data and information;

(b) agrees to comply with the applicable regulations and procedures established to ensure the confidentiality of such data and information.

3. The Legal and Technical Commission shall protect the confidentiality of confidential data and information submitted to it pursuant to these Regulations or a contract issued under these Regulations. In accordance with the provisions of article 163, paragraph 8, of the Convention, members of the Commission shall not disclose, even after the termination of their functions, any industrial secret, proprietary data which are transferred to the Authority in accordance with Annex III, article 14, of the Convention, or any other confidential information coming to their knowledge by reason of their duties for the Authority.

4. The Secretary-General and staff of the Authority shall not disclose, even after the termination of their functions with the Authority, any industrial secret, proprietary data which are transferred to the Authority in accordance with Annex III, article 14, of the Convention, or any other confidential information coming to their knowledge by reason of their employment with the Authority.

5. Taking into account the responsibility and liability of the Authority pursuant to Annex III, article 22, of the Convention, the Authority may take such action as may be appropriate against any person who, by reason of his or her duties for the Authority, has access to any confidential data and information and who is in breach of the obligations relating to confidentiality contained in the Convention and these Regulations.

Part VII General procedures

Regulation 40
Notice and general procedures

1. Any application, request, notice, report, consent, approval, waiver, direction or instruction hereunder shall be made by the Secretary-General or by the designated representative of the prospector, applicant or contractor, as the case may be, in writing. The requirement to provide any information in writing under these Regulations is satisfied by the provision of the information in an electronic document containing a digital signature. Service shall be by hand, or by telex, facsimile or registered airmail to the Secretary-General at the headquarters of the Authority or to the designated representative.

2. Delivery by hand shall be effective when made. Delivery by telex shall be deemed to be effective on the business day following the day when the “answer back” appears on the sender’s telex machine. Delivery by facsimile shall be effective when the “transmit confirmation report” confirming the transmission to the recipient’s published facsimile number is received by the transmitter. Delivery by registered airmail shall be deemed to be effective 21 days after posting. An electronic document is presumed to be received by the addressee when it enters an information system designated or used by the addressee for the purpose of receiving documents of the type sent and it is capable of being retrieved and processed by the addressee.

3. Notice to the designated representative of the prospector, applicant or contractor shall constitute effective notice to the prospector, applicant or contractor for all purposes

under these Regulations, and the designated representative shall be the agent of the prospector, applicant or contractor for the service of process or notification in any proceeding of any court or tribunal having jurisdiction.

4. Notice to the Secretary-General shall constitute effective notice to the Authority for all purposes under these Regulations, and the Secretary-General shall be the Authority's agent for the service of process or notification in any proceeding of any court or tribunal having jurisdiction.

Regulation 41
Recommendations for the guidance of contractors

1. The Legal and Technical Commission may from time to time 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.

2. The full text of such recommendations shall be reported to the Council. Should the Council find that a recommendation is inconsistent with the intent and purpose of these Regulations, it may request that the recommendation be modified or withdrawn.

Part VIII Settlement of disputes

Regulation 42
Disputes

1. Disputes concerning the interpretation or application of these Regulations shall be settled in accordance with Part XI, section 5, of the Convention.

2. Any final decision rendered by a court or tribunal having jurisdiction under the Convention relating to the rights and obligations of the Authority and of the Contractor shall be enforceable in the territory of each State Party to the Convention.

Part IX Resources other than polymetallic sulphides or cobalt crusts

Regulation 43
Resources other than polymetallic sulphides or cobalt crusts

If a prospector or contractor finds resources in the Area other than polymetallic sulphides or cobalt crusts, the prospecting and exploration for and exploitation of such resources shall be subject to the rules, regulations and procedures of the Authority relating to such resources in accordance with the Convention and the Agreement. The prospector or contractor shall notify the Authority of its find.

Notes

1 *Report of the United Nations Conference on Environment and Development, Rio de Janeiro, 3-14 June 1991* (United Nations publication, Sales No. E.91.1.8 and corrigenda), vol. 1: *Resolutions adopted by the Conference*, resolution 1, annex 1.

Attachment 1 Notification of intention to engage in prospecting

1. Name of prospector:
2. Street address of prospector:
3. Postal address (if different from above):
4. Telephone number:
5. Facsimile number:
6. Electronic mail address:
7. Nationality of prospector:
8. If prospector is a juridical person, identify prospector's

    (a) Place of registration; and

    (b) Principal place of business/domicile and attach a copy of the prospector's certificate of registration.

9. Name of prospector's designated representative:
10. Street address of prospector's designated representative (if different from above):
11. Postal address (if different from above):
12. Telephone number:
13. Facsimile number:
14. Electronic mail address:

15. Attach the coordinates of the broad area or areas in which prospecting is to be conducted, as referred to in the World Geodetic System WGS 84 or the International Terrestrial Reference Frame (ITRF) defined by the International Association of Geodesy.

16. Attach a general description of the prospecting programme, including the date of commencement and the approximate duration of the programme.

17. Attach a written undertaking that the prospector will:

(a) Comply with the Convention and the relevant rules, regulations and procedures of the Authority concerning:

(i) Cooperation in the training programmes in connection with marine scientific research and transfer of technology referred to in articles 143 and 144 of the Convention; and

(ii) Protection of the marine environment; and

(b) Accept verification by the Authority of compliance therewith.

18. List hereunder all the attachments and annexes to this notification (all data and information should be submitted in hard copy and in a digital format specified by the Authority):

Date: ____________

____
Signature of prospector's designated representative

ATTESTATION:

____
Signature of person attesting

____
Name of person attesting

____
Title of person attesting

Attachment 2 Application for approval of a plan of work for exploration to obtain a contract

Section I Information concerning the applicant

1. Name of applicant:
2. Street address of applicant:
3. Postal address (if different from above):
4. Telephone number:
5. Facsimile number:
6. Electronic mail address:
7. Name of applicant's designated representative:
8. Street address of applicant's designated representative (if different from above):
9. Postal address (if different from above):
10. Telephone number:
11. Facsimile number:
12. Electronic mail address:
13. If the applicant is a juridical person, identify applicant's

(a) Place of registration; and

(b) Principal place of business/domicile and attach a copy of the applicant's certificate of registration.

14. Identify the sponsoring State or States.

15. In respect of each sponsoring State, provide the date of deposit of its instrument of ratification of, or accession or succession to, the 1982 United Nations Convention on the Law of the Sea and the date of its consent to be bound by the Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982.

16. A certificate of sponsorship issued by the sponsoring State must be attached with this application. If the applicant has more than one nationality, as in the case of a partnership or consortium of entities from more than one State, certificates of sponsorship issued by each of the States involved must be attached.

Section II Applicant's election with respect to a reserved area contribution, joint venture participation or production sharing contract

17. Elect either to:

(a) Contribute a reserved area to carry out activities pursuant to Annex III, article 9, of the Convention, in accordance with regulation 17; or

(b) Offer an equity interest in accordance with regulation 19;

(c) Offer a joint venture arrangement in accordance with regulation 19; or

(d) Enter into a production sharing contract in accordance with regulation 19.

Section III Information relating to the area under application

18. Define the boundaries of the area under application by attaching a list of geographical coordinates referred to in the World Geodetic System WGS 84 or the International Terrestrial Reference Frame (ITRF) defined by the International Association of Geodesy.

19. Attach a chart (on a scale and projection specified by the Authority) and, if the applicant elects to contribute a reserved area in accordance with regulation 16, a list of the coordinates identifying two parts of equal estimated commercial value.

20. If the applicant elects to contribute a reserved area in accordance with regulation 16, include in an attachment sufficient information to enable the Council to designate a reserved area based on the estimated commercial value of each part of the area under application. Such attachment must include the data available to the applicant with respect to both parts of the area under application, including:

(a) Data on the location, survey and evaluation of the polymetallic sulphides or cobalt crusts in the areas, including:

(i) A description of the technology related to the recovery and processing of polymetallic sulphides or cobalt crusts that is necessary for making the designation of a reserved area;

(ii) A map of the physical and geological characteristics, such as seabed topography, bathymetry and information on the reliability of such data;

(iii) Data and maps showing location of the ore body (or bodies), grade of polymetallic sulphides and abundance and grade of cobalt crusts (in kg/m^2);

(iv) A calculation based on standard procedures, including statistical analysis, using the data submitted and assumptions made in the calculations that the two areas could be expected to contain polymetallic sulphides or cobalt crusts of equal estimated commercial value expressed as recoverable metals in mineable areas;

(v) A description of the techniques used by the applicant;

(b) Information concerning environmental parameters (seasonal and during test period) including, inter alia, wind speed and direction, wave height, period and direction, current speed and direction, water salinity, temperature and biological communities.

21. If the area under application includes any part of a reserved area, attach a list of coordinates of the area which forms part of the reserved area and indicate the applicant's qualifications in accordance with regulation 18 of the Regulations.

Section IV Financial and technical information

22. Attach sufficient information to enable the Council to determine whether the applicant is financially capable of carrying out the proposed plan of work for exploration and of fulfilling its financial obligations to the Authority:

(a) If the application is made by the Enterprise, attach certification by its competent authority that the Enterprise has the necessary financial resources to meet the estimated costs of the proposed plan of work for exploration;

(b) If the application is made by a State or a state enterprise, attach a statement by the State or the sponsoring State certifying that the applicant has the necessary financial resources to meet the estimated costs of the proposed plan of work for exploration;

(c) If the application is made by an entity, attach copies of the applicant's audited financial statements, including balance sheets and profit-and-loss statements, for the most recent three years in conformity with internationally accepted accounting principles and certified by a duly qualified firm of public accountants; and

(i) If the applicant is a newly organized entity and a certified balance sheet is not available, a pro forma balance sheet certified by an appropriate official of the applicant;

(ii) If the applicant is a subsidiary of another entity, copies of such financial statements of that entity and a statement from that entity in conformity with internationally accepted accounting practices and certified by a duly qualified firm of public accountants that the applicant will have the financial resources to carry out the plan of work for exploration;

(iii) If the applicant is controlled by a State or a state enterprise, a statement from the State or state enterprise certifying that the applicant will have the financial resources to carry out the plan of work for exploration.

23. If it is intended to finance the proposed plan of work for exploration by borrowings, attach a statement of the amount of such borrowings, the repayment period and the interest rate.

24. Attach sufficient information to enable the Council to determine whether the applicant is technically capable of carrying out the proposed plan of work for exploration, including:

(a) A general description of the applicant's previous experience, knowledge, skills, technical qualifications and expertise relevant to the proposed plan of work for exploration;

(b) A general description of the equipment and methods expected to be used in carrying out the proposed plan of work for exploration and other relevant non-proprietary information about the characteristics of such technology; and

(c) A general description of the applicant's financial and technical capability to respond to any incident or activity which causes serious harm to the marine environment.

Section V The plan of work for exploration

25. Attach the following information relating to the plan of work for exploration:

(a) A general description and a schedule of the proposed exploration programme, including the programme of activities for the immediate five-year period, such as studies to be undertaken in respect of the environmental, technical, economic and other appropriate factors which must be taken into account in exploration;

(b) A description of a 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 of the potential environmental impact of the proposed exploration activities, taking into account any recommendations issued by the Legal and Technical Commission;

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

(d) A description of the proposed measures for the prevention, reduction and control of pollution and other hazards, as well as possible impacts, to the marine environment;

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

Section VI Undertakings

26. Attach a written undertaking that the applicant will:

(a) Accept as enforceable and comply with the applicable obligations created by the provisions of the Convention and the rules, regulations and procedures of the Authority, the decisions of the relevant organs of the Authority and the terms of its contracts with the Authority;

(b) Accept control by the Authority of activities in the Area as authorized by the Convention;

(c) Provide the Authority with a written assurance that its obligations under the contract will be fulfilled in good faith.

Section VII Previous contracts

27. Has the applicant or, in the case of an application by a partnership or consortium of entities in a joint arrangement, any member of the partnership or consortium or any affiliate previously been awarded any contract with the Authority?

28. If the answer to 27 is “yes”, the application must include:

(a) The date of the previous contract or contracts;

(b) The dates, reference numbers and titles of each report submitted to the Authority in connection with the contract or contracts; and

(c) The date of termination of the contract or contracts, if applicable.

<u>Section VIII Attachments</u>

29. List all the attachments and annexes to this application (all data and information should be submitted in hard copy and in a digital format specified by the Authority):

Date: ____________ ____
Signature of applicant’s designated representative

ATTESTATION:

____
Signature of person attesting

____
Name of person attesting

____
Title of person attesting

Attachment 3 Contract for exploration

THIS CONTRACT made the day of between the INTERNATIONAL SEABED AUTHORITY represented by its SECRETARY-GENERAL (hereinafter referred to as "the Authority") and represented by (hereinafter referred to as "the Contractor") WITNESSETH as follows:

Incorporation of clauses

A. The standard clauses set out in annex 4 to the Regulations on Prospecting and Exploration for Polymetallic Sulphides and Cobalt-rich Crusts in the Area shall be incorporated herein and shall have effect as if herein set out at length.

Exploration area

B. For the purposes of this contract, the "exploration area" means that part of the Area allocated to the Contractor for exploration, defined by the coordinates listed in schedule 1 hereto, as reduced from time to time in accordance with the standard clauses and the Regulations.

Grant of rights

C. In consideration of:

(1) Their mutual interest in the conduct of exploration activities in the exploration area pursuant to the Convention and the Agreement;

(2) The responsibility of the Authority to organize and control activities in the Area, particularly with a view to administering the resources of the Area, in accordance with the legal regime established in Part XI of the Convention and the Agreement and Part XII of the Convention respectively; and

(3) The interest and financial commitment of the Contractor in conducting activities in the exploration area and the mutual covenants made herein;

the Authority hereby grants to the Contractor the exclusive right to explore for (polymetallic sulphides) (cobalt crusts) in the exploration area in accordance with the terms and conditions of this contract.

Entry into force and contract term

D. This contract shall enter into force on signature by both parties and, subject to the standard clauses, shall remain in force for a period of fifteen years thereafter unless:

(1) The Contractor obtains a contract for exploitation in the exploration area which enters into force before the expiration of such period of fifteen years; or

(2) The contract is sooner terminated provided that the term of the contract may be extended in accordance with standard clauses 3.2 and 17.2.

Schedules

E. The schedules referred to in the standard clauses, namely section 4 and section 8, are for the purposes of this contract schedules 2 and 3 respectively.

Entire agreement

F. This contract expresses the entire agreement between the parties, and no oral understanding or prior writing shall modify the terms hereof. IN WITNESS WHEREOF the undersigned, being duly authorized thereto by the respective parties, have signed this contract at …, this … day of …

Schedule 1

[Coordinates and illustrative chart of the exploration area]

Schedule 2

[The current five-year programme of activities as revised from time to time]

Schedule 3

[The training programme shall become a schedule to the contract when approved by the Authority in accordance with section 8 of the standard clauses.]

Annex 4 Standard clauses for exploration contract

Section 1 Definitions

1.1 In the following clauses:

(a) "exploration area" means that part of the Area allocated to the Contractor for exploration, described in schedule 1 hereto, as the same may be reduced from time to time in accordance with this contract and the Regulations;

(b) "programme of activities" means the programme of activities which is set out in schedule 2 hereto as the same may be adjusted from time to time in accordance with sections 4.3 and 4.4 hereof;

(c) "regulations" means the Regulations for Prospecting and Exploration for Polymetallic Sulphides and Cobalt Crusts in the Area, adopted by the Authority.

1.2 Terms and phrases defined in the Regulations shall have the same meaning in these standard clauses.

1.3 In accordance with the Agreement relating to the Implementation of Part XI of the United Nations Convention on the Law of the Sea of 10 December 1982, its provisions and Part XI of the Convention are to be interpreted and applied together as a single instrument; this contract and references in this contract to the Convention are to be interpreted and applied accordingly.

1.4 This contract includes the schedules to this contract, which shall be an integral part hereof.

Section 2 Security of tenure

2.1 The Contractor shall have security of tenure and this contract shall not be suspended, terminated or revised except in accordance with sections 20, 21 and 24 hereof.

2.2 The Contractor shall have the exclusive right to explore for (polymetallic sulphides) (cobalt crusts) in the exploration area in accordance with the terms and conditions of this contract. The Authority shall ensure that no other entity operates in the exploration area for a different category of resources in a manner that might unreasonably interfere with the operations of the Contractor.

2.3 The Contractor, by notice to the Authority, shall have the right at any time to renounce without penalty the whole or part of its rights in the exploration area, provided that the Contractor shall remain liable for all obligations accrued prior to the date of such renunciation in respect of the area renounced.

2.4 Nothing in this contract shall be deemed to confer any right on the Contractor other than those rights expressly granted herein. The Authority reserves the right to enter into contracts with respect to resources other than (polymetallic sulphides) (cobalt crusts) with third parties in the area covered by this contract.

Section 3 Contract term

3.1 This contract shall enter into force on signature by both parties and shall remain in force for a period of fifteen years thereafter unless:

(a) the Contractor obtains a contract for exploitation in the exploration area which enters into force before the expiration of such period of fifteen years; or

(b) the contract is sooner terminated, provided that the term of the contract may be extended in accordance with sections 3.2 and 17.2 hereof.

3.2 Upon application by the Contractor, not later than six months before the expiration of this contract, this contract may be extended for periods of not more than five years each on such terms and conditions as the Authority and the Contractor may then agree in accordance with the Regulations. Such extensions shall be approved if the Contractor has made efforts in good faith to comply with the requirements of this contract but for reasons beyond the Contractor's control has been unable to complete the necessary preparatory work for proceeding to the exploitation stage or if the prevailing economic circumstances do not justify proceeding to the exploitation stage.

3.3 Notwithstanding the expiration of this contract in accordance with section 3.1 hereof, if the Contractor has, at least 90 days prior to the date of expiration, applied for a contract for exploitation, the Contractor's rights and obligations under this contract shall continue until such time as the application has been considered and a contract for exploitation has been issued or refused.

Section 4 Exploration

4.1 The Contractor shall commence exploration in accordance with the time schedule stipulated in the programme of activities set out in schedule 2 hereto and shall adhere to such time periods or any modification thereto as provided for by this contract.

4.2 The Contractor shall carry out the programme of activities set out in schedule 2 hereto. In carrying out such activities the Contractor shall spend in each contract year not less than the amount specified in such programme, or any agreed review thereof, in actual and direct exploration expenditures

.

4.3 The Contractor, with the consent of the Authority, which consent shall not be unreasonably withheld, may from time to time make such changes in the programme of activities and the expenditures specified therein as may be necessary and prudent in accordance with good mining industry practice, and taking into account the market conditions for the metals contained in (polymetallic sulphides) (cobalt crusts) and other relevant global economic conditions.

4.4 Not later than 90 days prior to the expiration of each five-year period from the date on which this contract enters into force in accordance with section 3 hereof, the Contractor and the Secretary-General shall jointly undertake a review of the implementation of the plan of work for exploration under this contract. The Secretary-General may require the Contractor to submit such additional data and information as may be necessary for the purposes of the review. In the light of the review, the Contractor shall make such adjustments to its plan of work as are necessary and shall indicate its programme of activities for the following five-year period, including a revised schedule of anticipated yearly expenditures. Schedule 2 hereto shall be adjusted accordingly.

Section 5 Environmental monitoring

5.1 The 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 as far as reasonably possible using for this purpose the best technology available to it.

5.2 Prior to the commencement of exploration activities, the Contractor shall submit to the Authority:

(a) an impact assessment of the potential effects on the marine environment of the proposed activities;

(b) a proposal for a monitoring programme to determine the potential effect on the marine environment of the proposed activities; and

(c) data that could be used to establish an environmental baseline against which to assess the effect of the proposed activities.

5.3 The Contractor shall, in accordance with the Regulations, gather environmental baseline data as exploration activities progress and develop and shall establish environmental baselines against which to assess the likely effects of the Contractor's activities on the marine environment.

5.4 The Contractor shall, in accordance with the Regulations, establish and carry out a programme to monitor and report on such effects on the marine environment. The Contractor shall cooperate with the Authority in the implementation of such monitoring.

5.5 The Contractor shall, within 90 days of the end of each calendar year, report to the Secretary-General on the implementation and results of the monitoring programme referred to in section 5.4 hereof and shall submit data and information in accordance with the Regulations.

Section 6 Contingency plans and emergencies

6.1 The Contractor shall, prior to the commencement of its programme of activities under this contract, submit to the Secretary-General a contingency plan to respond effectively to incidents that are likely to cause serious harm to the marine environment arising from the Contractor's activities at sea in the exploration area. Such contingency plan shall establish special procedures and provide for adequate and appropriate equipment to deal with such incidents and, in particular, shall include arrangements for:

(a) the immediate raising of a general alarm in the area of the exploration activities;

(b) immediate notification to the Secretary-General;

(c) the warning of ships which might be about to enter the immediate vicinity;

(d) a continuing flow of full information to the Secretary-General relating to particulars of the contingency measures already taken and further actions required;

(e) the removal, as appropriate, of polluting substances;

(f) the reduction and, so far as reasonably possible, prevention of serious harm to the marine environment, as well as mitigation of such effects;

(g) as appropriate, cooperation with other contractors with the Authority to respond to an emergency; and

(h) periodic emergency response exercises.

6.2 The Contractor shall promptly report to the Secretary-General any incident arising from its activities that has caused or is likely to cause serious harm to the marine environment. Each such report shall contain the details of such incident, including, inter alia:

(a) the coordinates of the area affected or which can reasonably be anticipated to be affected;

(b) the description of the action being taken by the Contractor to prevent, contain, minimize and repair the serious harm to the marine environment;

(c) a description of the action being taken by the Contractor to monitor the effects of the incident on the marine environment; and

(d) such supplementary information as may reasonably be required by the Secretary-General.

6.3 The Contractor shall comply with emergency orders issued by the Council and immediate measures of a temporary nature issued by the Secretary-General in accordance with the Regulations, to prevent, contain, minimize or repair serious harm to the marine environment, which may include orders to the Contractor to immediately suspend or adjust any activities in the exploration area.

6.4 If the Contractor does not promptly comply with such emergency orders or immediate measures of a temporary nature, the Council may take such reasonable measures as are necessary to prevent, contain, minimize or repair any such serious harm to the marine environment at the Contractor's expense. The Contractor shall promptly reimburse the Authority the amount of such expenses. Such expenses shall be in addition to any monetary penalties which may be imposed on the Contractor pursuant to the terms of this contract or the Regulations.

Section 7 Objects of an archaeological or historical nature

The Contractor shall immediately notify the Secretary-General in writing of any finding in the exploration area of an object of an archaeological or historical nature and its location. Following the finding of any such object of an archaeological or historical nature in the exploration area, the Contractor shall take all reasonable measures to avoid disturbing such object.

Section 8 Training

8.1 In accordance with the Regulations, the Contractor shall, prior to the commencement of exploration under this contract, submit to the Authority for approval proposed training programmes for the training of personnel of the Authority and developing States, including the participation of such personnel in all of the Contractor's activities under this contract.

8.2. The scope and financing of the training programme shall be subject to negotiation between the Contractor, the Authority and the sponsoring State or States.

8.3 The Contractor shall conduct training programmes in accordance with the specific programme for the training of personnel referred to in section 8.1 hereof approved by the Authority in accordance with the Regulations, which programme, as revised and developed from time to time, shall become a part of this contract as schedule 3.

Section 9 Books and records

The Contractor shall keep a complete and proper set of books, accounts and financial records, consistent with internationally accepted accounting principles. Such books, accounts and financial records shall include information which will fully disclose the actual and direct expenditures for exploration and such other information as will facilitate an effective audit of such expenditures.

Section 10 Annual reports

10.1 The Contractor shall, within 90 days of the end of each calendar year, submit a report to the Secretary-General in such format as may be recommended from time to time by the Legal and Technical Commission covering its programme of activities in the exploration area and containing, as applicable, information in sufficient detail on:

(a) the exploration work carried out during the calendar year, including maps, charts and graphs illustrating the work that has been done and the results obtained;

(b) the equipment used to carry out the exploration work, including the results of tests conducted of proposed mining technologies, but not equipment design data; and

(c) the implementation of training programmes, including any proposed revisions to or developments of such programmes.

10.2 Such reports shall also contain:

(a) the results obtained from environmental monitoring programmes, including observations, measurements, evaluations and analyses of environmental parameters;

(b) a statement of the quantity of (polymetallic sulphides) (cobalt crusts) recovered as samples or for the purpose of testing;

(c) a statement, in conformity with internationally accepted accounting principles and certified by a duly qualified firm of public accountants, or, where the Contractor is a State or a state enterprise, by the sponsoring State, of the actual and direct exploration expenditures of the Contractor in carrying out the programme of activities during the Contractor's accounting year. Such expenditures may be claimed by the contractor as part of the contractor's development costs incurred prior to the commencement of commercial production; and

(d) details of any proposed adjustments to the programme of activities and the reasons for such adjustments.

10.3 The Contractor shall also submit such additional information to supplement the reports referred to in sections 10.1 and 10.2 hereof as the Secretary-General may from time to time reasonably require in order to carry out the Authority's functions under the Convention, the Regulations and this contract.

10.4 The Contractor shall keep, in good condition, a representative portion of samples and cores of the (polymetallic sulphides) (cobalt crusts) obtained in the course of exploration until the expiration of this contract. The Authority may request the Contractor in writing to deliver to it for analysis a portion of any such sample and cores obtained during the course of exploration.

<u>Section 11 Data and information to be submitted on expiration of the contract</u>

11.1 The Contractor shall transfer to the Authority all data and information that are both necessary for and relevant to the effective exercise of the powers and functions of the Authority in respect of the exploration area in accordance with the provisions of this section.

11.2 Upon expiration or termination of this contract the Contractor, if it has not already done so, shall submit the following data and information to the Secretary-General:

(a) copies of geological, environmental, geochemical and geophysical data acquired by the Contractor in the course of carrying out the programme of activities that are necessary for and relevant to the effective exercise of the powers and functions of the Authority in respect of the exploration area;

(b) the estimation of mineable deposits, when such deposits have been identified, which shall include details of the grade and quantity of the proven, probable and possible (polymetallic sulphide) (cobalt crust) reserves and the anticipated mining conditions;

(c) copies of geological, technical, financial and economic reports made by or for the Contractor that are necessary for and relevant to the effective exercise of the powers and functions of the Authority in respect of the exploration area;

(d) information in sufficient detail on the equipment used to carry out the exploration work, including the results of tests conducted of proposed mining technologies, but not equipment design data;

(e) a statement of the quantity of (polymetallic sulphides) (cobalt crusts) recovered as samples or for the purpose of testing; and

(f) a statement on how and where samples of cores are archived and their availability to the Authority.

11.3 The data and information referred to in section 11.2 hereof shall also be submitted to the Secretary-General if, prior to the expiration of this contract, the Contractor applies for approval of a plan of work for exploitation or if the Contractor renounces its rights in the exploration area to the extent that such data and information relates to the renounced area.

Section 12 Confidentiality

Data and information transferred to the Authority in accordance with this contract shall be treated as confidential in accordance with the provisions of this section and the Regulations.

Section13 Undertakings

13.1 The Contractor shall carry out exploration in accordance with the terms and conditions of this contract, the Regulations, Part XI of the Convention, the Agreement and other rules of international law not incompatible with the Convention.

13.2 The Contractor undertakes:

(a) to accept as enforceable and comply with the terms of this contract;

(b) to comply with the applicable obligations created by the provisions of the Convention, the rules, regulations and procedures of the Authority and the decisions of the relevant organs of the Authority;

(c) to accept control by the Authority of activities in the Area as authorized by the Convention;

(d) to fulfil its obligations under this contract in good faith; and

(e) to observe, as far as reasonably practicable, any recommendations which may be issued from time to time by the Legal and Technical Commission.

13.3 The Contractor shall actively carry out the programme of activities:

(a) with due diligence, efficiency and economy;
(b) with due regard to the impact of its activities on the marine environment; and

(c) with reasonable regard for other activities in the marine environment.

13.4 The Authority undertakes to fulfil in good faith its powers and functions under the Convention and the Agreement in accordance with article 157 of the Convention.

Section 14 Inspection

14.1 The Contractor shall 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:

(a) monitor the Contractor's compliance with the terms and conditions of this contract and the Regulations; and

(b) monitor the effects of such activities on the marine environment.

14.2 The Secretary-General shall give reasonable notice to the Contractor of the projected time and duration of inspections, the name of the inspectors and any activities the inspectors are to perform that are likely to require the availability of special equipment or special assistance from personnel of the Contractor.

14.3 Such inspectors shall have the authority to inspect any vessel or installation, including its log, equipment, records, facilities, all other recorded data and any relevant documents which are necessary to monitor the Contractor's compliance.

14.4 The Contractor, its agents and employees shall assist the inspectors in the performance of their duties and shall:

(a) accept and facilitate prompt and safe boarding of vessels and installations by inspectors;

(b) cooperate with and assist in the inspection of any vessel or installation conducted pursuant to these procedures;

(c) provide access to all relevant equipment, facilities and personnel on vessels and installations at all reasonable times;

(d) not obstruct, intimidate or interfere with inspectors in the performance of their duties;

(e) provide reasonable facilities, including, where appropriate, food and accommodation, to inspectors; and

(f) facilitate safe disembarkation by inspectors.

14.5 Inspectors shall avoid interference with the safe and normal operations on board vessels and installations used by the Contractor to carry out activities in the area visited and shall act in accordance with the Regulations and the measures adopted to protect confidentiality of data and information.

14.6 The Secretary-General and any duly authorized representatives of the Secretary-General, shall have access, for purposes of audit and examination, to any books, documents, papers and records of the Contractor which are necessary and directly pertinent to verify the expenditures referred to in section 10.2 (c).

14.7 The Secretary-General shall provide relevant information contained in the reports of inspectors to the Contractor and its sponsoring State or States where action is necessary.

14.8 If for any reason the Contractor does not pursue exploration and does not request a contract for exploitation, it shall, before withdrawing from the exploration area, notify the Secretary-General in writing in order to permit the Authority, if it so decides, to carry out an inspection pursuant to this section.

Section 15 Safety, labour and health standards

15.1 The Contractor shall comply with the generally accepted international rules and standards established by competent international organizations or general diplomatic conferences concerning the safety of life at sea, and the prevention of collisions and such rules, regulations and procedures as may be adopted by the Authority relating to safety at sea. Each vessel used for carrying out activities in the Area shall possess current valid certificates required by and issued pursuant to such international rules and standards.

15.2 The Contractor shall, in carrying out exploration under this contract, observe and comply with such rules, regulations and procedures as may be adopted by the Authority relating to protection against discrimination in employment, occupational safety and health, labour relations, social security, employment security and living conditions at the work site. Such rules, regulations and procedures shall take into account conventions and recommendations of the International Labour Organization and other competent international organizations.

Section 16 Responsibility and liability

16.1 The Contractor shall be liable for the actual amount of any damage, including damage to the marine environment, arising out of its wrongful acts or omissions, and those of its employees, subcontractors, agents and all persons engaged in working or acting for them in the conduct of its operations under this contract, including the costs of reasonable measures to prevent or limit damage to the marine environment, account being taken of any contributory acts or omissions by the Authority.

16.2 The Contractor shall indemnify the Authority, its employees, subcontractors and agents against all claims and liabilities of any third party arising out of any wrongful acts or omissions of the Contractor and its employees, agents and subcontractors, and all persons engaged in working or acting for them in the conduct of its operations under this contract.

16.3 The Authority shall be liable for the actual amount of any damage to the Contractor arising out of its wrongful acts in the exercise of its powers and functions, including violations under article 168, paragraph 2, of the Convention, account being taken of contributory acts or omissions by the Contractor, its employees, agents and subcontractors, and all persons engaged in working or acting for them in the conduct of its operations under this contract.

16.4 The Authority shall indemnify the Contractor, its employees, subcontractors, agents and all persons engaged in working or acting for them in the conduct of its operations under this contract, against all claims and liabilities of any third party arising out of any wrongful acts or omissions in the exercise of its powers and functions hereunder, including violations under article 168, paragraph 2, of the Convention.

16.5 The Contractor shall maintain appropriate insurance policies with internationally recognized carriers, in accordance with generally accepted international maritime practice.

Section 17 Force majeure

17.1 The Contractor shall not be liable for an unavoidable delay or failure to perform any of its obligations under this contract due to force majeure. For the purposes of this contract, force majeure shall mean an event or condition that the Contractor could not reasonably be expected to prevent or control; provided that the event or condition was not caused by negligence or by a failure to observe good mining industry practice.

17.2 The Contractor shall, upon request, be granted a time extension equal to the period by which performance was delayed hereunder by force majeure and the term of this contract shall be extended accordingly.

17.3 In the event of force majeure, the Contractor shall take all reasonable measures to remove its inability to perform and comply with the terms and conditions of this contract with a minimum of delay; provided that the Contractor shall not be obligated to resolve or terminate any labour dispute or any other disagreement with a third party except on terms satisfactory to it or pursuant to a final decision of any agency having jurisdiction to resolve the dispute.

17.4 The Contractor shall give notice to the Authority of the occurrence of an event of force majeure as soon as reasonably possible, and similarly give notice to the Authority of the restoration of normal conditions.

Section 18 Disclaimer

Neither the Contractor nor any affiliated company or subcontractor shall in any manner claim or suggest, whether expressly or by implication, that the Authority or any official thereof has, or has expressed, any opinion with respect to (polymetallic sulphides) (cobalt crusts) in the exploration area and a statement to that effect shall not be included in or endorsed on any prospectus, notice, circular, advertisement, press release or similar document issued by the Contractor, any affiliated company or any subcontractor that refers directly or indirectly to this contract. For the purposes of this section, an “affiliated company” means any person, firm or company or State-owned entity controlling, controlled by, or under common control with, the Contractor.

Section 19 Renunciation of rights

The Contractor, by notice to the Authority, shall have the right to renounce its rights and terminate this contract without penalty, provided that the Contractor shall remain liable for all obligations accrued prior to the date of such renunciation and those obligations required to be fulfilled after termination in accordance with the Regulations.

Section 20 Termination of sponsorship

20.1 If the nationality or control of the Contractor changes or the Contractor’s sponsoring State, as defined in the Regulations, terminates its sponsorship, the Contractor shall promptly notify the Authority forthwith.

20.2 In either such event, if the Contractor does not obtain another sponsor meeting the requirements prescribed in the Regulations which submits to the Authority a certificate of sponsorship for the Contractor in the prescribed form within the time specified in the Regulations, this contract shall terminate forthwith.

Section 21 Suspension and termination of contract and penalties

21.1 The Council may suspend or terminate this contract, without prejudice to any other rights that the Authority may have, if any of the following events should occur:

(a) if, in spite of written warnings by the Authority, the Contractor has conducted its activities in such a way as to result in serious persistent and wilful violations of the fundamental terms of this contract, Part XI of the Convention, the Agreement and the rules, regulations and procedures of the Authority; or

(b) if the Contractor has failed to comply with a final binding decision of the dispute settlement body applicable to it; or

(c) if the Contractor becomes insolvent or commits an act of bankruptcy or enters into any agreement for composition with its creditors or goes into liquidation or receivership, whether compulsory or voluntary, or petitions or applies to any tribunal for the appointment of a receiver or a trustee or receiver for itself or commences any proceedings relating to itself under any bankruptcy, insolvency or readjustment of debt law, whether now or hereafter in effect, other than for the purpose of reconstruction.

21.2 Any suspension or termination shall be by notice, through the Secretary-General, which shall include a statement of the reasons for taking such action. The suspension or termination shall be effective 60 days after such notice, unless the Contractor within such period disputes the Authority's right to suspend or terminate this contract in accordance with Part XI, section 5, of the Convention.

21.3 If the Contractor takes such action, this contract shall only be suspended or terminated in accordance with a final binding decision in accordance with Part XI, section 5, of the Convention.

21.4 If the Council has suspended this contract, the Council may by notice require the Contractor to resume its operations and comply with the terms and conditions of this contract, not later than 60 days after such notice.

21.5 In the case of any violation of this contract not covered by section 21.1 (a) hereof, or in lieu of suspension or termination under section 21.1 hereof, the Council may impose upon the Contractor monetary penalties proportionate to the seriousness of the violation.

21.6 The Council may not execute a decision involving monetary penalties until the Contractor has been accorded a reasonable opportunity to exhaust the judicial remedies available to it pursuant to Part XI, section 5, of the Convention.

21.7 In the event of termination or expiration of this contract, the Contractor shall comply with the Regulations and shall remove all installations, plant, equipment and materials in the exploration area and shall make the area safe so as not to constitute a danger to persons, shipping or to the marine environment.

Section 22 Transfer of rights and obligations

22.1 The rights and obligations of the Contractor under this contract may be transferred in whole or in part only with the consent of the Authority and in accordance with the Regulations.

22.2 The Authority shall not unreasonably withhold consent to the transfer if the proposed transferee is in all respects a qualified applicant in accordance with the Regulations and assumes all of the obligations of the Contractor and if the transfer does not confer to the transferee a plan of work, the approval of which would be forbidden by Annex III, article 6, paragraph 3 (c), of the Convention.

22.3 The terms, undertakings and conditions of this contract shall inure to the benefit of and be binding upon the parties hereto and their respective successors and assigns.

Section 23 No waiver

No waiver by either party of any rights pursuant to a breach of the terms and conditions of this contract to be performed by the other party shall be construed as a waiver by the party of any succeeding breach of the same or any other term or condition to be performed by the other party.

Section 24 Revision

24.1 When circumstances have arisen or are likely to arise which, in the opinion of the Authority or the Contractor, would render this contract inequitable or make it impracticable or impossible to achieve the objectives set out in this contract or in Part XI of the Convention or the Agreement, the parties shall enter into negotiations to revise it accordingly.

24.2 This contract may also be revised by agreement between the Contractor and the Authority to facilitate the application of any rules, regulations and procedures adopted by the Authority subsequent to the entry into force of this contract.

24.3 This contract may be revised, amended or otherwise modified only with the consent of the Contractor and the Authority by an appropriate instrument signed by the authorized representatives of the parties.

Section 25 Disputes

25.1 Any dispute between the parties concerning the interpretation or application of this contract shall be settled in accordance with Part XI, section 5, of the Convention.

25.2 Any final decision rendered by a court or tribunal having jurisdiction under the Convention relating to the rights and obligations of the Authority and of the Contractor shall be enforceable in the territory of each State Party to the Convention.

Section 26 Notice

26.1 Any application, request, notice, report, consent, approval, waiver, direction or instruction hereunder shall be made by the Secretary-General or by the designated representative of the Contractor, as the case may be, in writing. Service shall be by hand, or by telex, facsimile or registered airmail to the Secretary-General at the headquarters of the Authority or to the designated representative. The requirement to provide any information in writing under these Regulations is satisfied by the provision of the information in an electronic document containing a digital signature.

26.2 Either party shall be entitled to change any such address to any other address by not less than ten days' notice to the other party.

26.3 Delivery by hand shall be effective when made. Delivery by telex shall be deemed to be effective on the business day following the day when the "answer back" appears on the sender's telex machine. Delivery by facsimile shall be effective when the "transmit confirmation report" confirming the transmission to the recipient's published facsimile number is received by the transmitter. Delivery by registered airmail shall be deemed to be effective 21 days after posting. An electronic document is presumed to have been received by the addressee when it enters an information system designated or used by the addressee for the purpose of receiving documents of the type sent and it is capable of being retrieved and processed by the addressee.

26.4 Notice to the designated representative of the Contractor shall constitute effective notice to the Contractor for all purposes under this contract, and the designated representative shall be the Contractor's agent for the service of process or notification in any proceeding of any court or tribunal having jurisdiction.

26.5 Notice to the Secretary-General shall constitute effective notice to the Authority for all purposes under this contract, and the Secretary-General shall be the Authority's agent for the service of process or notification in any proceeding of any court or tribunal having jurisdiction.

Section 27 Applicable law

27.1 This contract shall be governed by the terms of this contract, the rules, regulations and procedures of the Authority, Part XI of the Convention, the Agreement and other rules of international law not incompatible with the Convention.

27.2 The Contractor, its employees, subcontractors, agents and all persons engaged in working or acting for them in the conduct of its operations under this contract shall observe the applicable law referred to in section 27.1 hereof and shall not engage in any transaction, directly or indirectly, prohibited by the applicable law.

27.3 Nothing contained in this contract shall be deemed an exemption from the necessity of applying for and obtaining any permit or authority that may be required for any activities under this contract.

Section 28 Interpretation

The division of this contract into sections and subsections and the insertion of headings are for convenience of reference only and shall not affect the construction or interpretation hereof.

Section 29 Additional documents

Each party hereto agrees to execute and deliver all such further instruments, and to do and perform all such further acts and things as may be necessary or expedient to give effect to the provisions of this contract.

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