



REPORT

Workshop on the Results of a Project to Develop a Geological Model of Polymetallic Nodule Deposits in the Clarion-Clipperton Zone International Seabed Authority, Kingston, Jamaica

14-17 DECEMBER, 2009

1. Polymetallic nodule resources contain nickel, cobalt, manganese and copper. While they occur in all oceans, deposits in the Clarion-Clipperton Zone (CCZ) in the Pacific Ocean are considered to be among the richest, containing high-grade and high-abundance nodules. Presently, seven of the eight exploration contractors with the International Seabed Authority have exploration contracts in this area. As part of its mandate to conduct resource assessments of prospective mineral deposits in the Area, the Authority met with representatives of the seven contractors to discuss ways of improving the results of resource assessments of polymetallic nodule deposits in the CCZ. In the absence of sampling data across much of this vast geographic area, participants in the meeting suggested that if the suspected relationships between high nodule grade and abundance, and factors such as sediment, bathymetry, tectonics and primary productivity could be established, they could be used as proxies for grade and abundance in poorly sampled nodulized areas. They therefore recommended that the Authority should establish a geological model of polymetallic nodule deposits in the CCZ. Between 13 and 20 May 2003, the Authority convened a workshop in Nadi, Fiji to consider the data that could be taken into account to develop such a model. It identified candidate proxy variables and devised a programme for the development of the model and a prospector's guide.

2. The success of the programme, which started in 2005, has been greatly facilitated by the generous contribution of data, information and expertise by contractor scientists and other experts in this field. Now in its final stages, the products developed by the group comprise: a Geologic Model of Polymetallic Nodule Deposits in the CCZ, which provides three independent approaches to model development; and a Prospector's Guide containing a narrative description of the key factors relevant to exploration for polymetallic nodules in the CCZ, including data and available information on known deposits. They provide the results of nine independent studies that provide extensive geophysical, geological, oceanographic and biological information relevant to deposits in the CCZ, and general guidance as to why these deposits occur, where they occur, and criteria for use in identifying such deposits in the CCZ.

3. The International Seabed Authority convened a workshop on the results of this project from 14 to 17 December 2009, at the Authority's headquarters in Kingston, Jamaica. The workshop was attended by a total of 24 participants, including the members of the Legal and Technical Commission (LTC) of the

Authority, representatives of contractors, representatives of member States and the experts who contributed to the development of the Geological Model and Prospector's Guide. The workshop was broadly divided into three segments: presentations from experts; working group deliberations; and the concluding session.

4. The workshop was formally inaugurated by Mr. Nii Allotey Odunton, Secretary-General of the International Seabed Authority. Welcoming all participants to the workshop, the Secretary-General traced the chronology of the Geological Model's development. He thanked the contractors and experts for their services to the project and their generous contribution of data. The Secretary General also informed the workshop that, for the first time, the Authority would stream the workshop live over the internet, and that this would help the Authority to reach a wide audience across the world. He invited participants to offer critical review, suggestions and improvements during the deliberations of the workshop, so that firm recommendations could be reached at its conclusion. He wished the participants a fruitful and enjoyable workshop and stay in Kingston. Mr. James A R McFarlane, Head of the Office of Resources and Environmental Monitoring of the Authority, provided a briefing about the workshop's plan and logistics. Dr. Charles Morgan of Planning Solutions Inc., Hawaii, USA, who was the Chief Consultant for the Geological Model Project, was designated as the Coordinator of the Workshop.

5. The workshop heard 11 presentations on the results obtained for selected proxy variables, how they were incorporated into the Model, the results of the resource assessment of the deposits in the CCZ, and a review of the Model's documents. The presentations commenced with a talk on Geological Model Project Implementation by Dr. Charles Morgan. During the presentation, Dr. Morgan presented the objectives of the programme, and a summary of the results of the Geological Model and the Prospector's Guide. He said the main objectives of the programme were to improve resource assessment, integrate all available exploration and environmental data and provide guidelines for future prospecting and exploration. He also traced chronologically, the project's milestones. He briefly presented the overall results of the project. Dr. Vijay Kodagali, Marine Geologist at the Authority, then presented a review of the data used for the Model. He presented the diverse and huge data set that the Authority had gathered from the generous contributions of contractors in the CCZ. He also presented the maps and figures relating to the additional data acquired for the model studies. He explained that during the project, the Authority coordinated the efforts of contractors and consultants, set up secure FTP and VPN sites for the project, carried out periodic reviews of the project, and ensured that the two products of the project – the Geological Model and Prospector's Guide were peer reviewed. An interesting discussion on data quality, distribution and normalization of the data ensued.

6. Dr. Lindsay Parson of the Southampton Oceanography Center, UK, presented the results for the proxy 'Bathymetry and Base Map'. He showed the different data sources used for preparation of the base map. In addition to the data available in the public domain, other information, including bathymetric data from satellite-derived gravity measurements, new multi-beam data provided by contractors and contractor analogue maps, were also used. The detailed maps were provided for six areas of focus in the CCZ that cover the entire nodule zone. A one minute grid interval was applied to the entire CCZ and the key areas were mapped at 0.5 minute and 0.1 minute grid intervals. He presented the maps generated from the work he undertook, and talked briefly about the tectonics of

the region. During subsequent discussions, participants complimented the contributor for the excellent assimilation of available data for the CCZ region.

7. Dr. Valery Yubko of Yuzhmorgeologiya and Dr. R Kotlinski of Interoceanmetal Joint Organization had worked on the volcanic and structural elements of the CCZ. However, as neither author was present, their work was presented by their colleague, Ms. Valcana Stoyanova. She said that the main objective of the work was to estimate the influence of factors such as bottom morphology, water depth, structural-tectonic setting, and sedimentary, volcanic and hydrothermal activity on the formation of polymetallic nodules in the entire CCZ. The data used for the study included: the structural setting of the CCZ; volcanic and hydrothermal activity; types of sediment; types and distribution of nodules; and Mn/Fe ratios. She presented a tectonic sketch of the CCZ and discussed the hydrothermal and volcanic activity data for the region. She also provided paleo reconstruction maps of the region for 5, 10, 15 and 20 million years ago. Participants showed keen interest in the results of the work, especially on the new Mahi-Mahi fracture zone, which seems to have a significant influence on nodule distribution in the region.

8. Dr. Charles Morgan presented the results of the proxy work on sediments with the report 'Regional examination of sediments'. As part of the work on sediments, the consultants assembled available data from contractors and the public domain, and integrated them into a common format. They also examined the relationship between sediments and abundance and metal content. Over 4,600 sediment station data were gathered for this study. The sediments have been classified into 13 types. A map of the sediments superimposed on the bathymetry of the CCZ was also provided.

9. Deliberations on the second day continued on sediments with a presentation by Prof. H Zhou on 'Bathymetry and sedimentation in COMRA's contract area'. He presented detailed bathymetric maps of the eastern and western segments of the COMRA contract area. The COMRA area has three basic regions: abyssal hills; seamount chains; and the abyssal basin. The seamounts have an east-west strike whereas the sedimentary graben is trending north-south. The seamount chains are more prominent in the eastern segment. Dr. Zhou also analyzed about 1,600 sediment data from free fall samplers. He said that he had used a sediment classification that comprised four classes. He presented a relationship between sediment type and bathymetry. He compared deep tow data with bathymetric data to show their relationship with nodule abundance. During discussions, many participants touched on the scheme of classifications used by different presenters for different parameters and pointed out that there is no uniformity. This anomaly was attributed to different contractors using different methods of classification. The need for a uniform classification methodology for all parameters was emphasized by participants.

10. One of the key results of the work on proxy variables for the geological model – the "Biogeochemical Model" – was presented by Dr. Charles Morgan. The biogeochemical model predicts the geographical distribution of the metal content of nodules (Mn, Co, Ni, Cu and Ni concentrations) and their abundance (kilograms of ore deposits per square meter of seafloor) using as model components the values of other known variables, including chlorophyll concentrations in surface waters, distance from the East Pacific Rise, and the Carbonate Compensation Depth (CCD). The primary sources of metals for the polymetallic nodule deposits of the CCZ are terrigenous or volcanogenic sources in North and Central America, and the East Pacific Rise. The metals are adsorbed to the surfaces of fine-grained sediments which are carried westward by the North Pacific Current. The sediments are consumed by filter-feeding zooplankton en route and converted into silt- and sand-sized faecal matter that is large enough to sink to the seafloor in the deep tropical Pacific waters. These faecal pellets can then be

metabolized by benthic animal communities and bacterial processes on reaching the sea floor. These processes remove the organic materials that bind the metals and reduce them to cationic species that are readily absorbed by the anionic manganese oxide matrix that constitutes the bulk of nodule deposits. Dr. Morgan presented different maps of nodule distribution generated from the model. Participants engaged in discussions on the components of the model and the final results following Dr. Morgan's presentation.

11. Dr Valcana Stoyanova made a presentation on the relationship between nodule coverage, morphology and distribution. In order to understand nodule distribution within this study area, Dr. Stoyanova said that an analysis was undertaken to determine the correlations among nodule parameters such as coverage, abundance, morphology, size, genetic type, water depth, bottom morphology and geographic region. She said that a classification system for nodule morphology and its formation mechanism separates hydrogenetic from diagenetic nodules, and isolates different morphological types (such as discoidal and spheroidal). She also said that throughout the eastern part of the CCZ, diagenetic, discoidal and ellipsoidal nodules are the dominant types. In the areas of highest nodule abundance, nodules with multiple nuclei are the most common morphology. The highest percentages of seafloor covered by nodules are found in water depths between 4,100 and 4,200m, and the highest abundance values are found between 12° and 16° N latitude.

12. The work of Dr JK Kang and others from KORDI, Republic of Korea, on the appraisal of nodule resource potential using GIS and geo-statistics was presented by Dr Charles Morgan. A summary of Kriging techniques and the results of other geostatistical work were provided. Resource assessment was based on conventional methodology, and the data for the assessment were subdivided in simple geometries to simplify analysis. The results indicate around 20-30 billion metric tons of nodules in the study area.

13. Spatial Decision Support system (SDSS), Artificial Neural Network (ANN) and fuzzy logic techniques were also used to model resources in the CCZ. The results were presented by Dr. H Zhou of Tongji University, Beijing. SDSS modeling was employed to estimate the mineralization potential of selected areas of the CCZ where nodule abundance and metal content data are not available. The study was based on data sets that included bathymetry, topography, sediment type, CCD and surface chlorophyll. Specific techniques employed in the study included Weights of Evidence Modeling, Fuzzy Logic, Logistic Regression and Artificial Neural Network (ANN) techniques. The results of this work provide differing assessments of the spatial distribution of areas within the study area in which nodule deposits are likely to occur. The results consistently indicate that the best prospects are found in the central and northern parts of the CCZ, while the southern, southwestern and eastern parts of the CCZ are likely to be unfavorable for nodule deposit occurrence. Various maps generated from the study showing the areas of likely occurrence were presented by the author. The novel approach employed for modeling the resources was appreciated by a number of participants, who also provided many suggestions for the improvement of the results.

14. The two products of the geological model project were reviewed by two well known experts – Dr. James Hein of USGS and Dr. Peter Halbach of Freie Universität, Berlin. Dr. Halbach presented the highlights of his assessment of the Geological model and the Prospector's Guide. At the outset, he said that after his initial review of the documents, the authors incorporated his suggested changes and updated the documents. He commented in detail about each chapter of each document. Dr. Halbach spoke about the genesis of nodules and commented on the biogeochemical model presented in the documents. He said that he also wanted the authors to consider the Peru Basin nodule province in the

model development exercise. Summarizing, he stated that the optimum for high quality nodule growth is not related to maximum growth rates or maximum manganese (Mn) concentrations, but rather to intermediate biogeochemical conditions. A lively discussion followed his presentation on nodule genesis.

15. On the third day of the workshop, participants were divided into four working groups. Leaders were chosen to conduct the deliberations of each group. The groups were:

- *Working Group 1* - Extension of the model to other world oceans: Indian, Atlantic etc.
- *Working Group 2* - Exploration technology: exploration, analytical methods, mapping, visualization, ROV/AUV etc.
- *Working Group 3* - Environmental component: research plan, time series, site plan and standardized data sets
- *Working Group 4* - Education and outreach regarding the results of the Model studies

Groups 1 and 2 met separately for the entire day. The members of Groups 3 and 4 met separately and also attended the meetings of Groups 1 and 2.

16. Day four began with a plenary session on the working group deliberations. During this session, the chairs of each Working Group presented reports on their recommendations. All delegates took part in the discussions during this session. The Working Groups later met again to finalize their recommendations.

Working Group 1: Extension of Model to other world oceans

17. Working Group 1 deliberated on:

- Developing recommendations on establishing similar geological models of nodulized provinces in the Indian Ocean, Atlantic Ocean, Peru Basin, Mexico Basin and elsewhere;
- Identifying shortfalls, deficiencies and limitations of the Geological model and Prospector's Guide of the CCZ with regard to its application to other areas, and
- Suggesting improvements to the Model and the Prospector's Guide

18. The Working Group discussed the Central Indian Ocean Basin (CIOB) scenario and said that the immediate need is to extend the Geological Model to this region. In order to increase knowledge of the area, it was strongly recommended that contractors make data available to develop a model of the CIOB. Participants felt that the CCZ model needs to be tested in the CIOB, before it can be considered as a global model for polymetallic nodule deposits.

19. The Working Group also discussed the Atlantic Ocean. Participants were informed that, compared to other regions, the limited data available in the South Atlantic Ocean would make a full test of the CCZ model impractical in this region. Therefore, a two-phase project was proposed. The first phase would be an ISA-led initiative facilitating the collection of all available data (and analyses) for the

South Atlantic, from coastal and other States, to be consolidated to create an integrated database. Participants agreed that this phase could be completed under a two-year programme. The second phase would be a test of the CCZ model on suitable areas in the South Atlantic Ocean. Participants suggested that the proposal for the South Atlantic Ocean project could be a good opportunity for the application of the Prospector's Guide in this region. They also felt that the proposed project could provide the necessary framework to search for areas where factors/conditions that control CCZ nodule formation also exist in the South Atlantic Ocean

20. The Working Group recommended that the CCZ model be revisited, taking into account the results from the Mexico Basin, and particularly the importance of hydrothermal input and lateral transportation of sediments and dissolved metals of terrigenous origin. It also recommended that the analyses and results from the Peru Basin, particularly the high Mn/Fe ratios representing the type of end member composition of diagenetic nodules observed, are also considered in the CCZ model.

21. Other recommendations of Working Group I included

- a) There is potential for the application of the CCZ model to the North Atlantic Ocean.
- b) Contractors should test the Model in their areas, and the ISA should test the model in the reserved areas.
- c) Trace metals might be of high future importance considering market trends. For example, molybdenum, zinc, titanium, Rare Earth elements (REE) and others should also be used in the Model to check its applicability in defining their resource potential.
- d) The Geological Model and the Prospector's Guide have dealt with nodule morphology, size and shape and also sediments. However, during the discussions following the presentations, it was observed that there is no uniformity in the classification schemes for these parameters. Contractors are using their own methods of classification. The Working Group, therefore, recommended that a standard classification scheme for all these parameters should be developed. It also suggested that the Authority convene a workshop/meeting of experts on this issue and that the standardized schemes be adopted by the Authority and made applicable to all future publications and reports.

Working Group 2: Exploration technology

22. The working group discussed in detail the status of exploration and mining technology. With the relative maturity of components of exploration technology, the working Group suggested that there should be a focus on gaps in the data that have to be provided by the contractors. Two needs seem to have become very important: environmental data; and nodule data for specific contractor fields. Environmental data and plans are needed in order to fulfill contractual obligations (particularly with respect to the CCZ contractor areas). These needs appear to be similar for all contractors, so a collective effort should be considered to more speedily reach common or reference contract answers. Additionally, data with sufficient detail is needed to inform decisions on the order of importance of nodule fields (and perhaps suggesting whether tailored collection techniques are required) to harvest within claims. The working group also discussed biota and environmental data, micro-exploration, funding, standards, pilot harvest efforts and open architecture.

23. The Working Group recommended among other things that the ISA consider chairing a contractor committee to promote an open discussion of standards (for example, voltages, bus, communication, connectors) protocols that would openly publish agreed issues. The working group was of the opinion that proven and detailed methodologies can readily be adapted to ISA needs, drive down commercial off-the-shelf costs (COTS), force commonality and increase the possibility of multiple vendor competition.

24. The Working Group made further observations to improve the technology environment for exploration and operations in the CCZ:

- Visualizing capability: exploratory research, combined with a higher volume of increasingly sophisticated sensor data, suggests that an important baseline technology will be data fusion, which can be presented by ever improving visualization techniques.
- Technical /Programme management: the ISA should consider, as harvesting operations come closer to reality, that individual contractor advocacy within the ISA might be well served by programme managers who are able to work on issues with a more robust technical staff, to minimize losing lessons learned from previous research/operations.

Working Group 3: Environmental component

25. Working Group 3 was given the task to recommend how to interest contractors in the accomplishments of the Geological Model. It was suggested that this could facilitate the identification and definition of abyssal habitats in the CCZ, and help identify the data required to accomplish environmental assessments and determine their relevance to the future environmental protection of the seabed.

26. The Working Group made recommendations for the application of the Geological Model to future environmental monitoring and assessment, including:

- Improve understanding of the role of biological factors in the distribution and origin of nodules;
- Standardize methods, factors, resolution and other considerations;
- Encourage habitat scale studies and data gathering for future impact analysis and recovery experiments;
- Encourage contact with appropriate scientific research institutes;
- Continue promoting interaction between mining companies and relevant international scientific programs;
- Develop a training and preparation programme for environmental assessment that helps standardize the resolutions used and information delivered, and
- Integrate unpublished data that may add to the baseline understanding of the environment.

Working Group 4: Education and outreach

27. Working Group 4 was given the task of generating recommendations to address educational and outreach strategies. Members of the Group actively participated in the meetings of the other three working groups. This operational approach was considered more efficient, given the cross-cutting nature of the tasks of Working Group 4. The Working Group's main suggestion, after two days of deliberation, was that the ISA must be charged with the responsibility of communicating the results of, and progress made on scientific, cultural and environmental work conducted at the deep seabed to all parties that would be affected by or benefit from this work. The ISA should identify the target audience and decide upon a strategy for dissemination of this information.

28. Imperative communication and education objectives to be achieved include the development of the following tools/exhibits aimed at expressing certain specific information:

- Visual Road Map of the history of the deep sea mining (exploration, prospecting) technology;
- Visual Road Map of the ISA's important achievements (including the Geological Model for Polymetallic Nodules);
- Visual Road Map of ISA regulation/policy creation and formulation processes;
- Visual Road Map of the environmental concerns related to the activities of the ISA ;
- Environmental Awareness of the Deep Sea, including a historical perspective and state-of-the-art examples.
- Deep Sea Techno-garden mining activities and technologies.

The ISA should publish the results of the workshop on its webpage and also permit use of all data used in the Model by researchers and other member States.

29. The workshop ended with a concluding session on 17 December 2009. After the chairs of the working groups presented their recommendations, the Coordinator of the workshop, Dr. Morgan, invited participants to share their views and experiences. All LTC members present gave their views. By and Large, they were appreciative of the enormous work done in connection with the Geological Model project. A few concerns regarding issues such as data validation, data inconsistency and non-standard classification of parameters were again highlighted. The representatives of the contractors and member States also spoke during the session. In his concluding remarks, the Secretary-General thanked all participants for being a part of the workshop. He recalled the words of Dr. H. Beiersdorf, late member of the LTC, who strongly advocated the geological model, saying that it is the only way the world can learn more about these resources. The Secretary-General said that it is always important to take the first step, and the Authority is happy to have done so in modeling the resources of the CCZ. He said there is always room for improvement and the Authority will strive to develop this work. He said that the workshop recommendations would be presented to the LTC and Council, and that the Authority will move forward based on the Council's advice. He said the work involved a very broad community of eminent international scientists and that the Authority is proud of their contributions. The Secretary-General thanked everyone for their contributions during the workshop.