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Status report on the development of a geological model for the Clarion-Clipperton Zone

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1. During the ninth session of the International Seabed Authority, the Legal and Technical Commission (LTC) was updated on the outcome of the Authority's Fiji Workshop, which was held from 13 to 20 May 2003, to establish a geological model of polymetallic nodules for the Clarion-Clipperton Zone (CCZ). The present note contains a summary of subsequent activities that have been carried out by the Secretariat in part fulfilment of the workshop's recommendations. It includes: (a) a summary of the contractors' meeting, which was held in New York on November 2003 to discuss their possible contribution of data and the extent of their participation in the development of the model, (b) information on data acquired from the public domain to be used to develop a bathymetric map of the CCZ, and (c) information on a computerized basis developed to facilitate spatial data analysis, data integration, modelling and mapping of the different parameters of the geological model for the CCZ.

I. Background

2. One of the primary responsibilities of the Authority is to assess the quantities of metals to be found in seabed polymetallic nodules. For this purpose, the Authority undertook an assessment of the reserved areas in the CCZ, using the data submitted by the registered pioneer investors (RPIs) and maintained in the Authority's POLYDAT database.

3. The information submitted by the RPIs, though satisfactory for some resource assessment, was not adequate for estimations of the quantities of metals to be found in these areas with a reasonable degree of confidence. During a meeting between the Authority and the RPIs in March 2001, some of the RPIs suggested that the future work of the Secretariat on resource assessment of the reserved areas in the CCZ would be enhanced through the development of a geological model for this part of the seabed.

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4. At the ninth session of the Authority, the members of LTC recognized that if the model proved to have global application in nodule areas, in addition to the Authority, the primary beneficiaries of the model would be contractors for exploration in the CCZ and in the central Indian Ocean basin, and future nodule prospectors. Further, the report of LTC (ISBA/9/C/4) emphasized the importance of close cooperation with contractors in the establishment of such a model.

5. In order to prepare for the development of the model and to address the issue of modelling nodule resources in the CCZ, the Authority convened a workshop to consider various elements that should be included in the modelling effort. The workshop was held from 13 to 20 May 2003 in Fiji.

6. The workshop produced a number of recommendations on model components and a work programme for the establishment of a reliable geological model of polymetallic nodules in the CCZ within three to four years.

7. The geological model will be developed to facilitate future mineral prospecting for polymetallic nodule deposits in the CCZ and for resource assessments. The CCZ that includes the largest known deposits of deep seabed nodules extends approximately between 110 and 160 degrees longitude west and between 5 and 20 degrees latitude north in the northeastern Pacific Ocean.

8. The model will predict the geographical distribution of nodule grade (manganese (Mn), cobalt (Co), nickel (Ni) and copper (Cu) concentrations) and abundance (kilograms of ore per square metre of seafloor), using as model components the values of other known variables, such as seabed topography, sediment characteristics, tectonic and volcanic processes for the past 20 million years, water column processes and nodule types that are believed to be geologically related to the formation of nodule deposits. The model will be a geographic three-dimensional model.

9. Data for use in the model will be with respect to grade and abundance and the proxy data noted above that will be used to develop components of the model. Data will be obtained from at least four sources: the Authority's central data repository, the public domain (United States National Oceanic and Atmospheric Administration (NOAA), the Deep Sea Drilling Project (DSDP), the Ocean Drilling Programme (ODP), the General Bathymetric Chart of the Oceans (GEBCO) etc.), contractors for nodule exploration and potential contractors. Data have been collected using different methods and equipment. It is known from the analysis of contractor data on grade and abundance for reserved areas, for example, that there was a systematic bias in some of their data sets. There will therefore be a need to identify any systematic bias between contractor data sets and the public/private data sets, establish criteria for adjustments and adjust concerned data. All data will also need to be converted into geographic information system (GIS) files for each component of the model.

10. For each set of proxy data that represents a component of the model, it assumed that the component would be defined using algorithms (a set of rules to be followed in calculations that link this data to grade or abundance) that are independent of any computer platform or proprietary software package.

11. It is assumed that there will be a certain amount of data exchange among interested scientists and consultants on the project. In this regard, it would appear

necessary to establish the data protocols to be used. It is also assumed that there will be periodic meetings to ascertain progress in the work.

12. The programme of work proposed by the workshop is divided into three phases, starting with data acquisition and processing, moving on to analysis and culminating in the production of a geological model with the stated aim of improving resource assessment. A "prospector's guide" is expected to accompany the model, giving descriptive explanations of nodule geology to complement the quantitative approach of the model. The project would rely mainly on data already available rather than original research. The model is designed to cover the broad range of factors that affect the two measures of greatest interest to both prospectors and scientists: abundance of nodules and their metal content. Inputs to the model will come from most fields covered by oceanography that relate to the environment of nodule deposits. These include seafloor topography and geology, as well as the structure and biology of the seawater overlying nodules.

13. Therefore, the workshop recommended that information from different sources should be compiled to enhance the reliability of the model. The workshop specifically recommended that a consultation process be carried out with the Authority's contractors in order to request their assistance for the elaboration of the model by providing the Authority with additional data and information.

II. Meeting of contractors

14. In response to the workshop's recommendation regarding data acquisition, the Secretariat organized a meeting with contractors on November 2003 to discuss their possible contributions to, and the extent of their participation in, the development of the model.

15. To assist contractors in this regard, a questionnaire on available data and information was submitted to them. The questionnaire raised questions in connection with bathymetry, nodule abundance, metal content, sedimentation, nodule types, water column, tectonics and volcanic activity.

16. The questionnaire also inquired about the modalities for participation of the contractors in the development of the model and the arrangements for the collection and analysis of the data and information that they could make available.

17. During the meeting, the Secretary-General of the Authority stressed the importance of this project in facilitating better knowledge of polymetallic nodule resources in the CCZ. He assured contractors that any data provided for the development of the model would be kept confidential; only the results of the compilations would be made available as general maps.

18. Responding to the questionnaire, the six contractors, whose areas are located in the CCZ, agreed to the use of their bathymetric data, specifically the bathymetric maps they had submitted with their applications for pioneer areas and the additional bathymetric data that they acquired following the allocation of pioneer areas, whether in relinquished (as applicable) or in contractor areas.

19. With the exception of available Mn/iron (Fe) ratio data, the contractors did not agree to authorize the Authority to make use of nodule abundance and metal content data from their contractor areas.

20. Yuhzmorgeologiya stated that it could provide the results of geostatistical analysis from its abundance and metal content database on the CCZ provided that it conducted the analysis itself and that its database not be submitted to the Authority. IOM, the Government of the Republic of Korea and COMRA agreed to allow the Authority to use nodule abundance and metal-content data from their relinquished areas. However, IOM set the condition that its data should be incorporated in the model in a geo-statistically processed form (kriging) that would prevent the original dataset from being derived from any published material. IFREMER/AFERNOD and COMRA stated that they could provide the Authority with the nodule abundance and metal-content data they had available in areas of the CCZ located outside of their contract area.

21. In addition, Yuhzmorgeologiya, IFREMER/AFERNOD, IOM and the Government of the Republic of Korea agreed to provide station photographs from selected sectors and information on relationships between nodule abundance and metal content and seabed bathymetry and topography from areas located outside or within their application areas.

22. In respect of data on sedimentation, the contractors stated that they could provide all data that they had on sediment distribution (facies and thickness), on the transparent layer, hiatuses, bioturbation, erosion and re-sedimentation in any area located in the CCZ. However, IOM reported that the quality of its data on sediment distribution and hiatuses differed, and that the only high-quality data that it had was that for the eastern CCZ. The Government of the Republic of Korea and IFREMER/AFERNOD both stated that some of their data would require processing before they could be made available to the Secretariat.

23. With regard to nodule types, IFREMER/AFERNOD, the Government of the Republic of Korea, COMRA, Yuhzmorgeologiya and IOM reported that they could provide data on nodule morphology, size and metal content. Yuhzmorgeologiya also stated that it could also provide data on accumulation rates and the age of nodules.

24. With regard to water column, IFREMER/AFERNOD, the Government of the Republic of Korea, Yuhzmorgeologiya, IOM and COMRA indicated that they could provide any available related data. Furthermore, Yuhzmorgeologiya reported that it could provide data on the oxygen minimum zone, carbonate compensation depth, currents and biological productivity. In addition, IOM indicated that it could provide data on the reconstruction of the level of the carbonate compensation depth (CCD) and its variations; interrelationship of nodule formation and currents; and carbonate content of sediments.

25. Regarding tectonic and volcanic activity, while the Government of the Republic of Korea and DORD stated that they had no available data and Yuhzmorgeologiya, IOM, COMRA and IFREMER/AFERNOD agreed to provide data on these parameters, including information on faults, fractures and volcanic and hydrothermal activity.

26. In relation to modalities for participation and arrangements for the collection and analysis of available data and information, while Yuhzmorgeologiya and IOM stated that they could compile data on nodule formation, accumulation and metal concentration and on the interrelationship between nodules, tectonics and volcanism, IFREMER/AFERNOD stated that it could participate in processing and compiling information on sedimentation. Additionally, the Government of the Republic of

Korea agreed to participate in the data-collection process, if needed. COMRA and DORD stated that the matter of their participation would be discussed at a later date with the Secretariat.

27. During the meeting, it was agreed that the Secretariat and the contractors would sort out arrangements for the collection and analysis of contractor data on a case-by-case basis.

III. Acquisition of data from the public domain

28. The Secretariat has acquired the following datasets from NOAA for use in developing a bathymetric and topographic map of the CCZ, and for use as proxy data for the development of the CCZ geological model:

(a) Geophysical surveys containing 2,400,000 points concerning bathymetry, magnetics and gravimetry;

(b) A two-minute grid of bathymetry;

(c) Total sediment thickness and seafloor superficial sediment description;

(d) Core data from the Ocean Drilling Programme and the Deep Sea Drilling Project.

IV. Establishment of a computerized basis for the development of the geological model for the CCZ

29. The development of a geological model requires the analysis and integration of information from various sources. Consequently, the Secretariat carried out the primary phase of the establishment of a computerized basis in order to facilitate spatial data analysis, data integration, modelling and mapping of the different parameters of the geological model for the CCZ. The computerized basis was developed both with the geostatistical software ISATIS, acquired from the French company GEOVARIANCES, and the geographical information system MapInfo. A GEOVARIANCES consultant and a GIS specialist were engaged in this process.

30. The establishment of the computerized basis started with loading different data sets into ISATIS and organizing these data sets in such a way that they could be selected for specific studies, incorporated into new datasets and updated. In that initial phase, loading data included:

(a) Location of reserved and contractors' area blocks;

(b) A total of 3,718 sampling station data, including:

(i) 2,141 sampling from reserved areas;

(ii) 725 sampling from public domain — ISA Central Data Repository (CDR);

(iii) 613 additional sampling data provided by IFREMER;

(iv) 239 additional sampling data provided by COMRA;

(c) An additional 8,342 depth measurements made available by COMRA;

(d) Multi frequency exploration (MFE) data provided by COMRA, containing a total of 52,000 abundance measurements;

(e) Sedimentological data made available by COMRA;

(f) Bathymetric, gravimetric and magnetometric survey datasets from NOAA's national geophysical data centre, which includes 2,413,000 points.

31. Upon loading the data, a data-quality control check and statistical analysis were carried out to identify possible discrepancies. Some of the identified inconsistency problems were either corrected or masked for the effect of subsequent geostatistical evaluations and mapping. Afterwards, a kriged bathymetric map was prepared with the data from NOAA to be used as a base map for the geological model. Even if further processing will be necessary, this map can be used as proxy data in order to improve the estimation of nodule abundance and metal grades through the co-kriging process; it may also be used to derive local bathymetry gradients.

32. Kriged maps were also prepared for nodule abundance and metal grades of manganese, nickel, copper, cobalt and iron. An added result of this process was the preparation of a list of parameters for kriging methods to guide the organizations that will participate in the establishment of the model. This will help them in producing comparable kriged maps without providing their original datasets.

33. In addition, series of resource simulation maps were prepared for nodule abundance and metal grades of manganese, nickel, copper, cobalt and iron. These can be used as an input to tonnage calculations, either on the global CCZ area or locally on each block.

34. Kriged and simulated maps of the bathymetry, nodule abundance and metal grades were transferred to GIS format for the elaboration of final maps, which should be improved in the future by the integration of additional data.

35. Most of the data sets that were made available for this initial work and entered into ISATIS were provided in Excel sheets. However, data can also be provided in other formats, such as Access databases, ASCII files, Shape files (among many other GIS and tabular file formats) and PRN files (Space delimited).

36. The upshot of the establishment of this computerized basis is that the Secretariat will be able to compile all sorts of data sets and perform the necessary mapping for the CCZ geological model.

V. Future work

37. The establishment of the geological model for the CCZ, in line with the recommendations of the workshop, will form a key component of the Secretariat's work programme during the 2005-2007 period. Work will start with data acquisition, followed by data analysis, culminating in the production of the model and the prospector's guide.

38. Among the proposed tasks for the near term is the integration of kriged bathymetric maps elaborated with data from public domain, with (a) the maps provided by contractors with their application for plan of work for exploration and

(b) the additional bathymetric data from areas located outside contractors' application areas.

39. With respect to proxy data to be used in the model, these will include information on the evolutionary framework of the Pacific plate that underlies the CCZ, nodule and sediment types, species distribution and water column factors, such as the oxygen minimum zone, the carbonate compensation depth and the benthic boundary layer.

40. The Secretariat will continue its efforts to finalize arrangements on a case-by-case basis for the collection and analysis of available data with contractors.

41. A meeting of experts, who will advise on specific technical matters and carry out defined tasks of the project, will be held by September 2004 to assist in developing the different model components. It is also assumed that each model component, when finalized, will consist of one or more sets of proxy data and clearly defined mathematical algorithms that generate predictions of nodule abundance and/or grade for any location within the CCZ. Ground-truth testing of the model's predictions will then be undertaken, using subsets of nodule grade and abundance data that are different from those used in calibrating input algorithms.

42. Upon completion of the work on model components, it is proposed to convene a second workshop on the model to review and modify, as necessary, the methods proposed for integrating the input data into the geological model. After this workshop, it is expected that work can proceed to complete the development, testing and documentation of the model, incorporating the recommendations of the workshop into the final design of the model.

43. Once the optimal model has been developed, predictions of nodule grade and abundance for areas of the CCZ that do not have sufficient coverage will be undertaken. Estimates of the probable accuracy that would be expected for prediction of the grade and abundance variables will also be established. Utilizing the model, an updated resource assessment of the metals of commercial interest in polymetallic nodule deposits in reserved areas of the CCZ will be undertaken.

44. The Secretariat plans to establish and maintain a file transfer site (ftp or http) that can be used by programme participants to exchange data and draft reports, thus facilitating timely and efficient transfers during the development of the model.