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Establishment of a geological model of the polymetallic nodules in the Clarion-Clipperton Zone

Summary prepared by the secretariat of the International Seabed Authority of a meeting held in Kingston from 25 to 27 May 2005

I. Introduction

A. Background

1. One of the primary responsibilities of the secretariat of the International Seabed Authority is to assess the quantities of metals present in seabed polymetallic nodules in the international seabed area under the jurisdiction of the Authority. To carry out this responsibility, the secretariat periodically undertakes an assessment of the reserved areas in the Clarion-Clipperton Zone (CCZ), the region of the North-eastern Pacific using the data submitted by contractors and maintained in the Authority POLYDAT database. The results of its most recent assessment demonstrated that the information submitted by contractors, though satisfactory for some purposes, does not permit the in situ quantities of metals in these areas to be estimated with a degree of confidence that is comparable to many land-based mineral resource estimates.[1]

2. After convening a number of workshops and meetings on the subject[2] and consulting with the Authority Legal and Technical Commission,[3] the secretariat initiated a project in the first quarter of 2005 to develop a geological model and an associated prospector's guide that will attempt to reduce the uncertainty associated with the secretariat's resource assessment for these deposits. The meeting described in the present report was the first task completed for this project.

B. Meeting objectives

3. The secretariat convened the meeting to enlist the support and participation of contractors in the project. The specific objectives of the meeting were:

(a) To describe to the representatives of the contractors the specific data that the secretariat is requesting in support of the project and to explain how these data will support the development of the model;

(b) To receive from the contractor representatives the specific descriptions of the data that can be provided to the secretariat in support of the project;

(c) To identify potential ways in which the technical staff from the contractors can participate directly in the project.

C. Meeting participants

4. The secretariat organized the meeting to include its staff, representatives of the contractors and technical experts who have been retained to support the secretariat in the development of the model. Table 1 lists the participants and their contact information.

Table 1
Meeting participants

Name	*Affiliation*	*E-mail*	*Telephone*	*Fax*
Michel Hoffert	Louis Pasteur University, Strasbourg, France/AFERNOD	mhoffert@illite.u-strasbg.fr	(33)390 240 418	(33)390 240 402
Yuri Kazmin	Yuzhmorgeologiya Gelengik, Russian Federation	yukazmin@dol.ru	(7-095)244 7069	(7-095)254 5733
Charles Morgan	Planning Solutions, Inc.	SauChai@aol.com	808-550-4539	808-550-4549
Lindsay Parsons	Southampton Oceanography Centre, United Kingdom	L.Parson@noc.soton.ac.uk	(44)02380-596541	(44)02380-596554
Craig Smith	University of Hawai'i, Manoa	csmith@soest.hawaii.edu	808-956-7776	808-956-9516
Huaiyang Zhou	Guangzhou Institute of Geochemistry	zhouhy@gig.ac.cn	0086-20-85290303	0086-20-85290303
Xiqiu Han	State Oceanic Administration, Hangzhou	xqhan@mail.hz.zj.cn	0086-571-88076924	0086-571-88071539
Ning Zhou	COMRA	zhouning@comra.org	0086-10-6804-7769	0086-10-6804-8974
Jung-Keuk Kang	KORDI	jkkang@sari.kordi.re.kr		
Valcana Stoyanova	IOM	v.stoyanova@iom.gov.pl	48-91 4539 398	48-91 4539-399

D. Report organization

5. The following sections describe the key results from the meeting. Section II describes the specific data the secretariat is requesting from the contractors and the reasons why these data may be useful in the formulation of the geological model. Section III describes the responses to the requests made at the meeting by the contractor representatives. Section IV describes the primary action items from the meeting that will contribute to the implementation of the geological model project.

II. Data requests

6. This section describes the specific data types that have been identified by the secretariat as being useful for the establishment of the geological model and that were discussed in some detail at the meeting. The general data types are listed in table 2. The following sections describe the data under consideration and outline the reasons why they may be useful for the model. The region of interest for the study is bound by 0˚-20˚ northern latitude and 110˚-160˚ western longitude.

Table 2
Summary of data requests

Bathymetry

Digitized data, particularly from multi-beam systems

Any relevant data sets that can augment coverage

Abundance and metal content

Any values within the region

Any values of elemental ratios (e.g. Mn/Fe) within this region

Sediments and nodule morphology

Nodule morphology and other characteristics

Photo surveys of deposits

Sediment characterization, especially ages and $CaCO_3$ content

Shallow seismic data (e.g. 3.5 kHz) regarding transparent layer thickness, hiatuses and other structure

Water column data

Unpublished oxygen profiles

Unpublished sediment-trap data

Ocean current measurements

Tectonic and volcanic data

Mapping of volcanic and tectonic features

Chemical, mineralogical and age data from volcanic rocks

Indications of hydrothermal activity

Gravity, magnetic and other geophysical data

Heat flow data

Biological data

Abundance and biomass of benthic fauna

Megafauna species composition

Sediment-community oxygen consumption rates

Radiochemical profiles of particle-associated radionuclides, especially ^{210}Pb and ^{14}C

A. Bathymetry

7. The May 2003 Fiji workshop and the December 2004 meeting of experts both concluded that a state of the art, digital bathymetric base map of the CCZ is a high priority requirement for the development of the geological model. The secretariat will produce such a map as part of this project, combining existing and newly released data sets. This compilation will provide a base map for analysis and a proxy variable for incorporation into the model. The compilation will also provide support for the project component that will examine the tectonic and volcanic factors that may be relevant to deposit formation that are described in section E below.

8. The secretariat will use, as appropriate, the following techniques to confirm and evaluate the secured data:

(a) Quality control: This includes crossover error analysis, assessment of and inter-comparison of gridded data sets;

(b) Co-registration and digitization: This includes, as necessary, transformation to a common geographic projection and datum and digitization of analog data;

(c) Incorporation of satellite data: This includes the investigation of the feasibility of refining the satellite-derived bathymetry model with new additional data for comparison with new marine derived bathymetry;

(d) Compilation and formatting: This includes the compilation of all datasets made available; generation of grids at appropriate grid intervals; and formatting of compiled data and grids for incorporation into the project's Geographic Information System and the Authority Central Data Repository;

(e) Error analysis: This includes the application of statistical methods to the bathymetric database to establish a value of confidence for the model base map.

B. Abundance and metal content

9. The final extent and accuracy of the resource assessment that constitutes the primary product of the geological model are directly dependent upon the extent and quality of the abundance and metal content data used in the assessment. However, because these data often have commercial value and proprietary significance for contractors, their release is usually limited.

10. The secretariat is examining ways to use abundance and metal content data of contractors in processed form that can still be useful for resource assessment, while preserving the privacy of the original data sets. If that effort is successful, the resulting assessment will be greatly enhanced and will make it possible for contractors to make available to the secretariat other available abundance and metal content data that they may have from relinquished and other areas within the region of interest for this study.

11. Additionally, the secretariat is pursuing the use of proxy variables for abundance and metal content to maximize the extent and accuracy of resource predictions.

C. Sediments and nodule morphology

1. Nodule morphology

12. Michel Hoffert explained to participants how the morphology of nodules is related to their formation processes and to their composition. Smooth surfaces often denote slow, hydrogenetic (precipitation directly from seawater) metal accumulation in relatively low abundance, low grade deposits, while botryoidal surfaces and discoid nodule shapes indicate diagenetic (within the sediments) growth in relatively high grade, high abundance nodules. Thus, information on nodule morphology, where samples have not been analysed for metal content (e.g. from bottom-camera photos) can be useful qualitative indicators of grade and abundance.

2. Sediment data

13. Oceanographic research on the CCZ nodule deposits and deposits in other deep-sea environments has established with a high degree of confidence that the formation of these deposits is dependent upon biological and sedimentary processes within the water column and the sediments just below the sea floor. These processes deliver metals to the seafloor and transform them into nodule deposits.

14. For example, work by von Stackelberg and Beiersdorf (1988) and others suggests a correlation between nodule abundance and the occurrence of a persistent surficial layer of sediments that lacks significant internal acoustic reflectivity in shallow seismic (usually 3.5 kHz) records. This layer is commonly found to be the acoustic signature of siliceous ooze deposits where high grade deposits have been found. These studies also suggest an association between nodule abundance and the presence of erosional surfaces in the sediments (termed “hiatuses”) covered by hard, non-erosive substrates (such as rocks and indurated sediments) that can serve as the initial surfaces for precipitation of the manganese nodules.

15. Work in the South Pacific (Cronan and Hodkinson 1994) has shown that the nickel and copper content of the nodules there, and sometimes their abundance, are related to the vertical distance of the deposits from the carbonate compensation depth.[4] Metals contained in Aeolian dust, fine-grained inorganic particles from continental runoff, and other sources are apparently scavenged from surface waters by plankton and then entrained within sinking plankton tests and fecal matter. As the organic matter sinks, and after it settles onto the seafloor, its decay releases reduced metals.

16. When the seafloor is above the carbonate compensation depth, the metal-bearing, labile organic matter is diluted by the calcium carbonate in the sediments to values too low to enrich nickel and copper in nodules there. Below the carbonate compensation depth, the organic matter at least partially decays in the water column as the sediments fall to the seafloor, thereby liberating metals into seawater rather than into the sediment interstitial waters, within which the best nodules form. As this phenomenon is unlikely to be area-specific, it probably occurs in the CCZ also.

17. Thus, nodule growth appears linked to the extraction processes that remove the metals from the surface waters and make them available for incorporation into nodule deposits and to the sedimentary surfaces and erosive processes on the seafloor. Data related to these processes will be useful in deriving qualitative indicators of nodule abundance and grade and may provide quantitative proxy variables.

D. Water column data

18. As noted above, one of the primary sources of metals for the CCZ deposits may be fine-grained sediments that are scavenged from surface waters by plankton and then transported to the nodule deposit sites as fecal matter. If the geographic distribution of these surface-water processes has persisted throughout most of the period when the major polymetallic nodule deposits have been forming (believed to be less than 15 million years), then deposit abundance distribution should be related to the persistence and intensity of the biological processes that remove particles from surface waters in the modern ocean. Thus, information related to primary productivity, sedimentation rates and compositions, and surface current velocities may be useful as indicators of nodule abundance.

E. Tectonic and volcanic data

19. Although the important role of volcanism in the CCZ is well recognized, proper attention has not been given to the comparative analysis of the age and nature of volcanic activity in various parts of the CCZ. For example, more intensive volcanic activity is known to occur in the remote eastern part of the CCZ (which lies within the western flank of the East Pacific Ridge and consists of rather young basement) than occurs in most of the rest of the region. This may represent volcanic structures that are typical of extinct spreading centres and that are potential sources for the metals found in the deposits. Intensive volcanic activity is also reported in the remote west, near the Line Islands volcanic chain. In this region, the type, age and origin of volcanism may be different from the volcanic activity in the east and may correspond to the processes of formation of volcanic ridges over a hot spot, leading to sources of metals and formation processes different than those that dominate farther east.

20. The secretariat will integrate and analyse available data related to the tectonic and volcanic frameworks within the CCZ, with the aim of determining the potential relationships of these variables to nodule abundance and grade. The work will include integrating the bathymetric and other geophysical data into a tectonic model of the region. It will also focus on the role of volcanism in the formation of the polymetallic nodule deposits. Thus, geological data that describe volcanic deposits

and hydrothermal processes and geophysical data that delineate the tectonic structures in the CCZ will be very useful in mapping the geological setting for the polymetallic nodule deposits.

F. Biological data

21. As described above, the abundance and ore grade of manganese nodules within the CCZ are correlated with biogeochemical conditions at the seafloor. In particular, the flux of particulate organic carbon (POC) to the seafloor may influence nodule abundance and grade because sinking POC is a likely carrier of metals from the surface ocean to abyssal sediments. Thus, seafloor POC flux is potentially a useful proxy for nodule abundance and/or grade, and a key parameter to include, directly or indirectly, in a geological model of polymetallic nodules in the CCZ.

22. Unfortunately, the flux of POC to the abyssal seafloor is very difficult to measure directly. The most direct approach is to deploy deep sediment traps near the seafloor for periods of more than one year to obtain estimates of the annual flux of POC to the sediment-water interface. Because such trap deployments are expensive and ship-time is intensive, deep sediment-trap data are available from only a few locations within the CCZ (summarized in Smith and Demopoulos, 2003; Hannides and Smith, 2003). However, because the abyssal seafloor biota is “food limited” and depends on the rain of POC from surface waters for its energy, a variety of benthic biological parameters are tightly correlated with seafloor POC in the deep sea in general, and in the CCZ in particular (Smith et al., 1997; Smith and Demopoulos, 2003). These benthic biological parameters may, in turn, serve as useful proxies for nodule grade and abundance, and provide important inputs into a predictive geological model of polymetallic nodules in the CCZ.

23. Those benthic biological parameters that have proven to be tightly correlated with POC flux to the deep-sea floor, and thus are potentially useful inputs for a geological model, include the following: (a) the abundance and biomass of organisms in various size classes, including megafauna, macrofauna, meiofauna and microbiota. This correlation is driven by the fact that the amount of biomass within a size class is a direct function of food availability, i.e. POC flux to the seafloor (Smith et al., 1992; Smith et al., 1997; Smith and Demopoulos, 2003); (b) sediment-community oxygen consumption. Sediment-community oxygen consumption is correlated with POC flux to the seafloor because in oxygenated deep-sea habitats, such as the CCZ, more than 95 per cent of the organic matter sinking to the seafloor is oxidized prior to sediment burial (Smith et al., 1997; Berelson et al., 1997); (c) depth of the bioturbated layer. The depth of the bioturbated layer is controlled by the size and abundance of deposit-feeding animals, which, in the food-limited deep sea, are controlled by the flux of food material in the form of POC to the seafloor (Smith and Rabouille, 2002). Thus, it is possible that information that can help estimate the relative abundance of benthic fauna in different areas can be used as a proxy for the flux of metals accumulating in the polymetallic nodule deposits and, ultimately, nodule abundance.

III. Contractors' response

A. General responses

24. Representatives of the contractors who were able to attend the meeting responded individually to the data requests made by the secretariat, recalled the responses that they had provided to the secretariat questionnaire and commented generally on the project.

25. The contractor representatives in attendance all concurred with the following general points:

(a) The geological model project is a worthwhile effort that is an appropriate undertaking for the secretariat;

(b) Requested data will be provided, but the specific commitments can be made only after internal reviews by contractor management;

(c) There should be direct collaboration by contractor staff in the implementation of the project to ensure that they can influence the way the work is completed and to take advantage of the extensive expertise available among the active professionals working for the contractors.

26. Each contractor representative gave a presentation responding to the data requests of the secretariat and discussing potential means for more extensive collaboration in the project. These specific responses are outlined in section B below.

B. Specific responses

27. The following sections outline the specific responses made by the contractor representatives. They do not constitute commitments by the contractors, but rather are the tentative considerations of the representatives made prior to confirmation by contractor management. They include the general conclusions of the presentations made by representatives and are consistent with the results of the secretariat questionnaire.[5] One of the contractors, the Deep Ocean Resources Development Company (DORD) of Japan, was not able to send a representative to the meeting, but did send a letter to the secretariat that supported the project and pledged to provide data, as specified in an earlier communication with the secretariat. The specific responses provided below for DORD are from the DORD response to the questionnaire.

28. In 2003 Yuzhmorgeologiya studied baseline conditions by carrying out meteorological observations during the cruise taken as part of its exploration work. Description of the various conditions were given, along with graphical analysis.

1. Institut français de recherche pour l'exploitation de la mer (France)

29. Michel Hoffert provided the response for the Institut français de recherche pour l'exploitation de la mer (IFREMER). Mr. Hoffert presented an excellent description of what is known about the formation processes of CCZ deposits and how these processes are related to several of the proxy variables under

consideration. Table 3 presents a summary of the specific responses of Mr. Hoffert on behalf of IFREMER, to the data requests.

Table 3
IFREMER tentative response to the secretariat data requests

Variable	*Y/N*	*Comments*
Bathymetry	Y	Multi-beam possible
Abundance and grade	Y	Contractor approval required
Sediments and nodule morphology	Y	Analog; likely available; need processing
Water-Column data	Y	Currents and other data
Tectonic and volcanic data	Y	Limited availability
Biological data	Y	PI approval required

2. Deep Ocean Resources Development Company (Japan)

30. As noted above, DORD was not able to send a representative to the meeting. The following responses (table 4) are derived from the DORD responses to the secretariat questionnaire.

Table 4
DORD tentative response to the secretariat data requests

Variable	*Y/N*	*Comments*
Bathymetry	Y	Multi-beam possible
Abundance and grade	Y	Fe or Mn/Fe data possible
Sediments and nodule morphology	N	Not available
Water-Column data	N	No data
Tectonic and volcanic data	N	Not available
Biological data	Y	Published BIE data

3. Yuzhmorgeologiya, Russian Federation

31. Mr. Kazmin provided the following observations related to the tentative availability of data from the Yuzhmorgeologiya organization (table 5).

Table 5
Yuzhmorgeologiya tentative response to the secretariat data requests

Variable	*Y/N*	*Comments*
Bathymetry	Y	Multi-beam possible
Abundance and grade	Y	Maybe processed data
Sediments and nodule morphology	Y	Processing required
Water-Column data	Y	Associated with BIE
Tectonic and volcanic data	Y	Some
Biological data	Y	Associated with BIE; voluntary

4. China Ocean Mineral Resources Research and Development Association

32. Mr. Zhou of China Ocean Mineral Resources Research and Development Association (COMRA) explained that COMRA management must examine the specific data requests presented at the meeting before committing any data to the project. Table 6 contains the responses of COMRA, based on the results of the secretariat questionnaire. COMRA informed the meeting that it has an active research group that is currently working on a similar project and that that group would be very interested in participating directly in the development of the geological model of the International Seabed Authority.

33. Mr. Zhou presented a description of his research on the development of a geological model for CCZ deposits. The research employs relatively new computer-based mathematical techniques for examining potential proxy variables in areas where no resource data (i.e. abundance and metal content data) are available. Those techniques include the following:

- Weights of evidence
- Logistic regression
- Fuzzy logic
- Artificial neural networks

34. Mr. Zhou's group tested the first three of the techniques with synthetic data sets (constructed from figures presented at the Fiji workshop) and found that they offered a potentially effective means of extrapolating resource data. Mr. Zhou proposed the application of these techniques to the data sets being developed for the geological model of the International Seabed Authority.

Table 6
COMRA tentative response to the secretariat data requests

Variable	*Y/N*	*Comments*
Bathymetry	Y	Multi-beam
Abundance and grade	Y	In all but contract areas
Sediments and nodule morphology	?	Need to consult with contractor management
Water-Column data	?	Need to consult with contractor management
Tectonic and volcanic data	Y	If available
Biological data	?	Need to consult with contractor management

5. Interoceanmetal Joint Organization (IOM), Bulgaria, Cuba, the Czech Republic, Poland, the Russian Federation and Slovakia

35. Valcana Stoyanova presented the response of the Interoceanmetal Joint Organization (IOM) to the secretariat request for data, which is summarized in table 7. Dr. Stoyanova informed the meeting that IOM has an active research group that is very interested in participating directly in the development of the geological model of the International Seabed Authority.

Table 7
IOM tentative response to the secretariat data requests

Variable	*Y/N*	*Comments*
Bathymetry	Y	Multi-beam possible
Abundance and grade	Y	Outside contractor area
Sediments and nodule morphology	Y	Data and photos, all analogue
Water-Column data	Y	N-S Transect; BIE traps
Tectonic and volcanic data	Y	Recently collected; may be available
Biological data	Y	BIE; in area with no nodules

6. The Government of the Republic of Korea

36. J. K. Kang of the Korea Ocean Research and Development Institute (KORDI) described the exploration programme of the Republic of Korea and its accomplishments to date. Mr. Kang detailed several data sets that the Republic of Korea could make available to the secretariat for the project. He explained that the Republic of Korea has an active professional research group that is very interested

in participating directly in the development of the geological model. Table 8 lists the general types of data that the Republic of Korea could provide for the project.

Table 8
Korea tentative response to the secretariat data requests

Variable	*Y/N*	*Comments*
Bathymetry	Y	Multi-beam
Abundance and grade	Y	Outside contractor area
Sediments and nodule morphology	Y	Processing required
Water-Column data	Y	Processing required
Tectonic and volcanic data	N	Not available
Biological data	Y	Processing required

IV. Project action items

37. In summary, the meeting participants agreed to the following actions to support implementation of the project:

(a) The secretariat will formally request from each contractor the data sets described herein for completing the geological model.

(b) The contractors will work with the secretariat to define the individual scopes of work for each contractor in support of the geological model.

(c) The secretariat will continue to work to complete establishment of a secure Internet website for exchange of data among the professionals working on the project.

38. Key project milestones are as follows:

August 2005:	The secretariat will present the project description and progress to date to the Legal and Technical Commission and to the Council of the International Seabed Authority at the eleventh session of the Authority.
May 2006:	The secretariat will convene a meeting of project participants to review the progress of the project to date and to decide on the specific methods to be employed for completion of the project.
May 2007:	Final consultant reports will be submitted to the secretariat.
July 2007:	The secretariat will convene a workshop to examine the results of the project with project participants and independent experts.

Notes

[1] See Robert de l'Etoile, "Geostatistical analysis and evaluation of the metals contained in polymetallic nodules in the reserved areas", paper presented at a workshop covered by the International Seabed Authority in May 2003.

[2] Held in Fiji from 13 to 20 May 2003 and in Kingston from 6 to 10 December 2004.

[3] See ISBA/9/C4 and ISBA/10/LTC/5.

[4] The carbonate compensation depth is defined as the depth in the water column where the rate of dissolution of calcium carbonate is balanced by its rate of supply in sediment particles.

[5] "Questionnaire on the data and information that may be provided by contractors to enhance the development of a predictive geological model of polymetallic nodules in the Clarion-Clipperton Zone (CCZ)", sent to all contractors in 2003. All contractors responded in the affirmative, with specific descriptions of the data they plan to contribute to the project.

References

Anderson, R., W. Berelson, D. Hammond, J. Dymond, D. DeMaster, R. Collier, S. Honjo, M. Leinen, J. McManus, R. Pope, C. Smith and M. Stephens (1997). Biogenic budgets of particle benthic remineralization rain, and sediment accumulation in the equatorial Pacific, *Deep-Sea Research II*, vol. 44.

Cronan, D. S., and R. A. Hodkinson (1994). Element supply to surface manganese nodules along the Aitutaki-Jarvis Transect, South Pacific. *Journal of the Geological Society, London*, vol. 151.

Hannides, A., and C. R. Smith (2003). The northeast abyssal Pacific plain. *Biogeochemistry of Marine Systems*, K. B. Black and G. B. Shimmield, eds., (CRC Press, Boca Raton, Florida).

Smith, C. R., W. Berelson, D. J. DeMaster, F. C. Dobbs, D. Hammond, D. J. Hoover, R. H. Pope, and M. Stephens (1997). Latitudinal variations in benthic processes in the abyssal equatorial Pacific: control by biogenic particle flux. *Deep-Sea Research II*, vol. 44.

Smith, C. R., and A. W. J. Demopoulos (2003). Ecology of the deep Pacific Ocean floor. *Ecosystems of the World Volume 28: Ecosystems of the Deep Ocean*, P. A. Tyler, ed. (Elsevier, Amsterdam).

Smith, C. R., and C. Rabouille (2002). What controls the mixed-layer depth in deep-sea sediments? The importance of POC flux. *Limnology and Oceanography*, vol. 47.

von Stackelberg, U., and H. Beiersdorf (1988). *Manganese nodules and sediments in the equatorial North Pacific Ocean, "Sonne" Cruise SO 25, 1982* (Geologisches Jahrbuch Reihe D, Band D 87, E. Schweizerbart'sche Verlagsbuchhandlung, Science Publishers, Stuttgart, Germany).