GEOLOGICAL MODEL
PROJECT IMPLEMENTATION

GEOLOGICAL MODEL ITEMS FOR DISCUSSION

- **PROJECT DEFINITION**

- **RESOURCE DATA & ASSESSMENT**

- **GEOLOGICAL MODEL SUMMARY OF RESULTS**

- **PROSPECTOR'S GUIDE SUMMARY OF RESULTS**

# ISA PROJECT OBJECTIVES

1. **IMPROVE CLARION-CLIPPERTON ZONE (CCZ) RESOURCE ASSESSMENT**

2. **INTEGRATE AVAILABLE RESOURCE AND RELATED ENVIRONMENTAL DATA**

3. **PROVIDE USEFUL GUIDELINES FOR PROSPECTING AND EXPLORATION**

CLARION-CLIPPERTON ZONE
110° – 160° W; 0° – 20° N

International Seabed Authority
Geological Model Project
Final Workshop
Kingston, Jamaica, December 2009
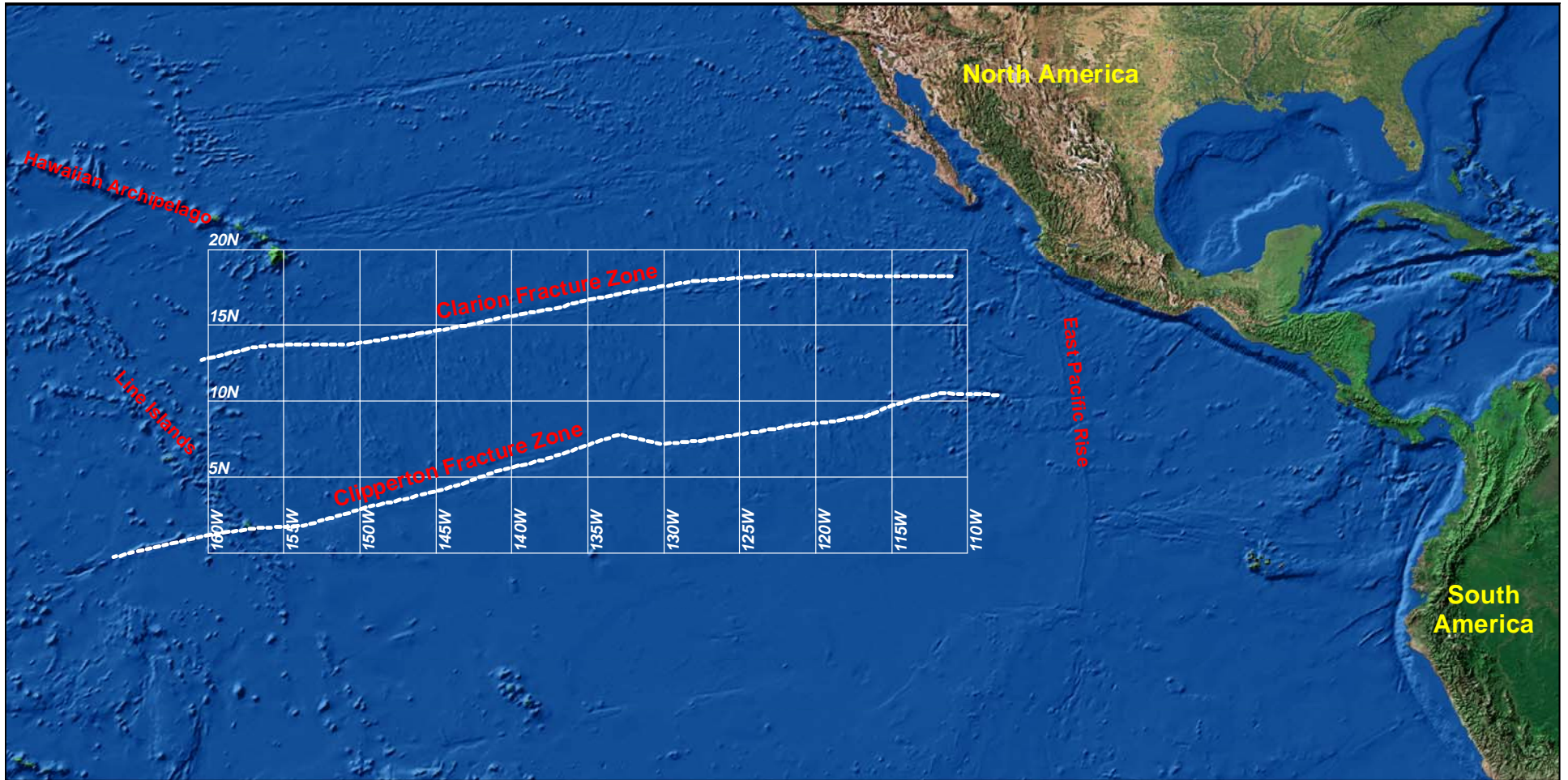
PROJECT TEAM
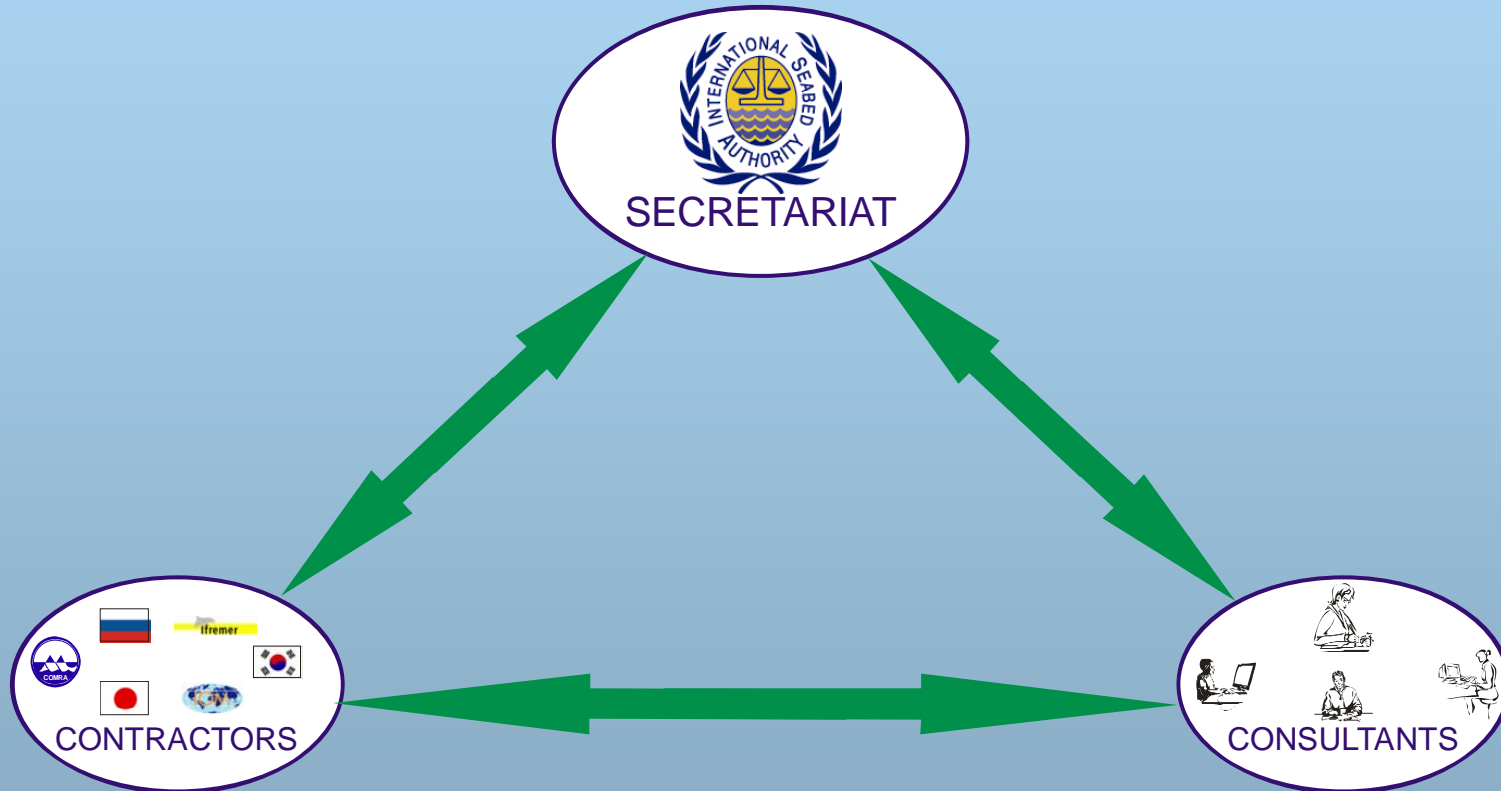
PROJECT MILESTONES

| MILESTONE	DATE
1. FIJI CONFERENCE	MAY 2003
2. PRELIMINARY REPORTS	2006 - 2007
3. MID-COURSE MTG.	NOVEMBER 2007
4. REPORTS ASSEMBLED	FEBRUARY 2009
5. FINAL REVIEW	SEPTEMBER 2009
6. FINAL WORKSHOP	DECEMBER 2009

PROJECT DELIVERED PRODUCTS

- ### *RESOURCE DATA & ASSESSMENT*

- ### *GEOLOGICAL & ENVIRONMENTAL DATA ASSEMBLY*

- ### *GEOLOGICAL MODEL*

- ### *PROSPECTOR'S GUIDE*

RESOURCE DATA

- SOURCES
- SPATIAL DISTRIBUTIONS
- ASSESSMENT SUMMARY
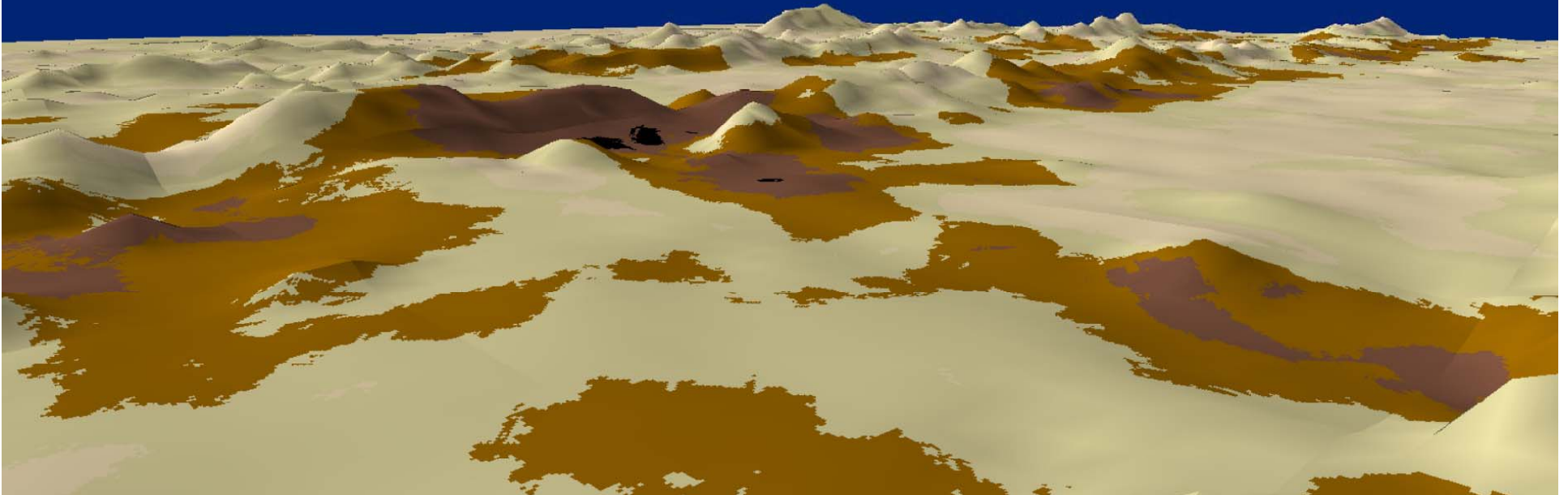
RESOURCE DATA

Data Source	CDR	KOREA	OMCO	COMRA	IOM	Totals After Screening
# Stations: Abundance	253	329	7,738	52,473	790	61,583
# Stations: Manganese	879	258	5,875	716	664	8,392
#Stations: Cobalt	711	258	5,900	716	664	8,249
#Stations: Nickel	799	258	5,923	716	664	8,360
# Stations: Copper	882	258	5,924	714	664	8,442

SAMPLE STATIONS IN RESOURCE ASSESSMENT (Abundance)
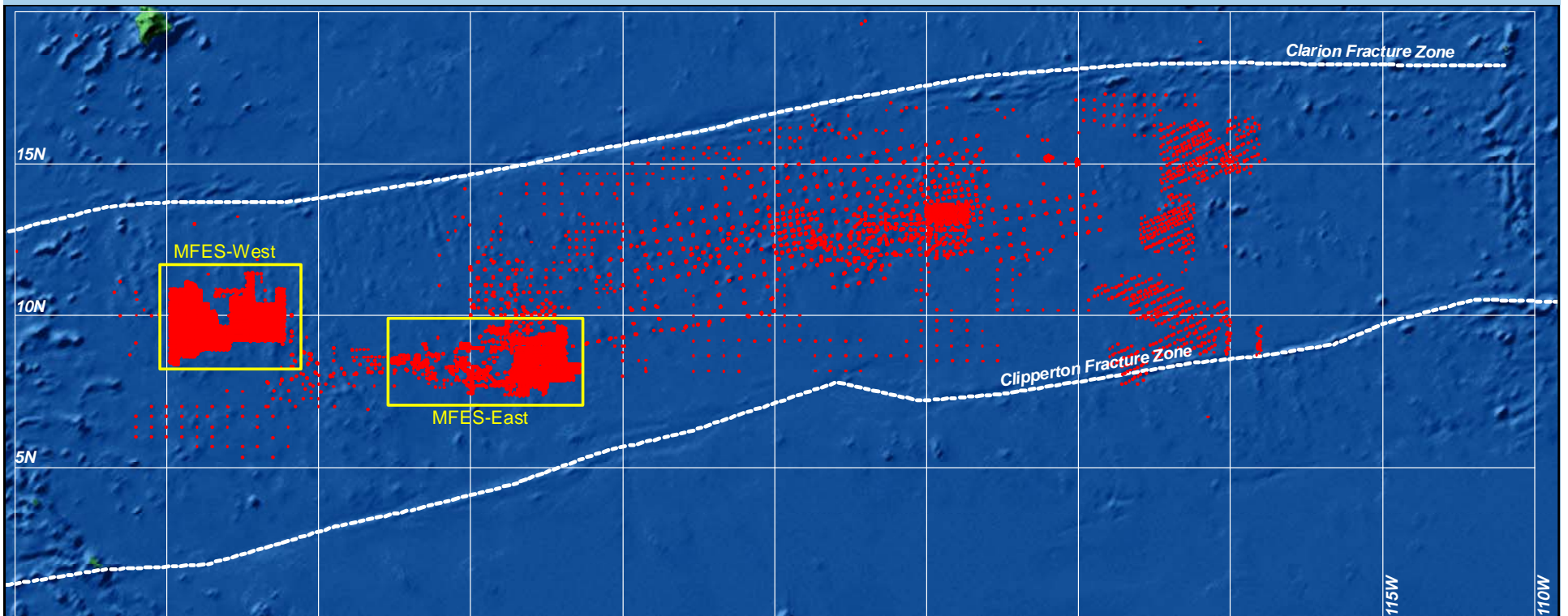
SAMPLE STATIONS IN RESOURCE ASSESSMENT
(Metal Content)

Nodule Abundance (kg/m²)

Clarion Fracture Zone

Clipperton Fracture Zone

20N
15N
10N
5N

160W 155W 150W 145W 140W 135W 130W 125W 120W 115W

Abundance (kg/m²)

0 - 2.5	7.5 - 10	15 - 17.5	22.5 - 25
2.5 - 5	10 - 12.5	17.5 - 20	25 - 27.5
5 - 7.5	12.5 - 15	20 - 22.5	> 27.5

The International Seabed Authority

PREPARED BY:
Dr. Charles L. Morgan

SOURCES:
- ISA Central Data Repository
- Lockheed-Martin Corporation
- KORDI; COMRA; IOM

Polymetallic Nodule Abundance
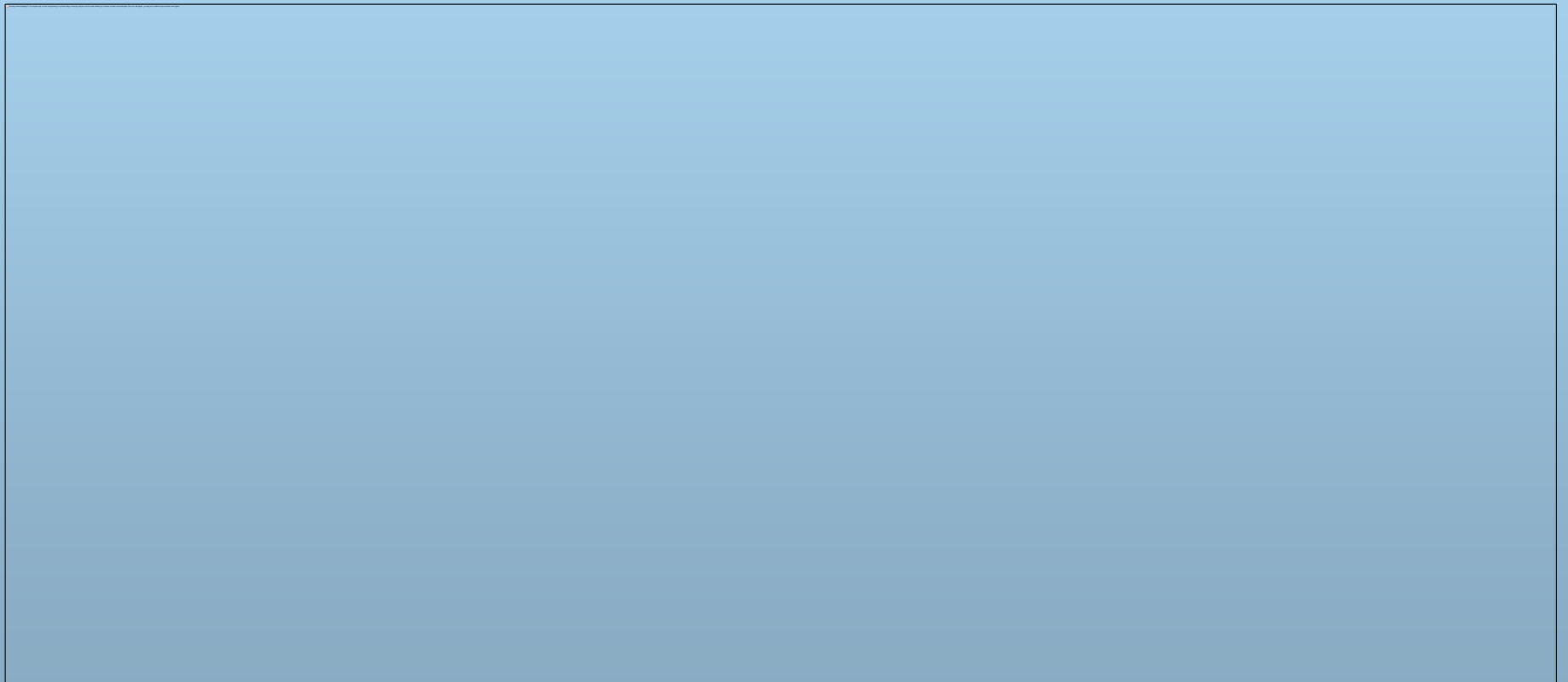
Manganese (Dry Wt. %)
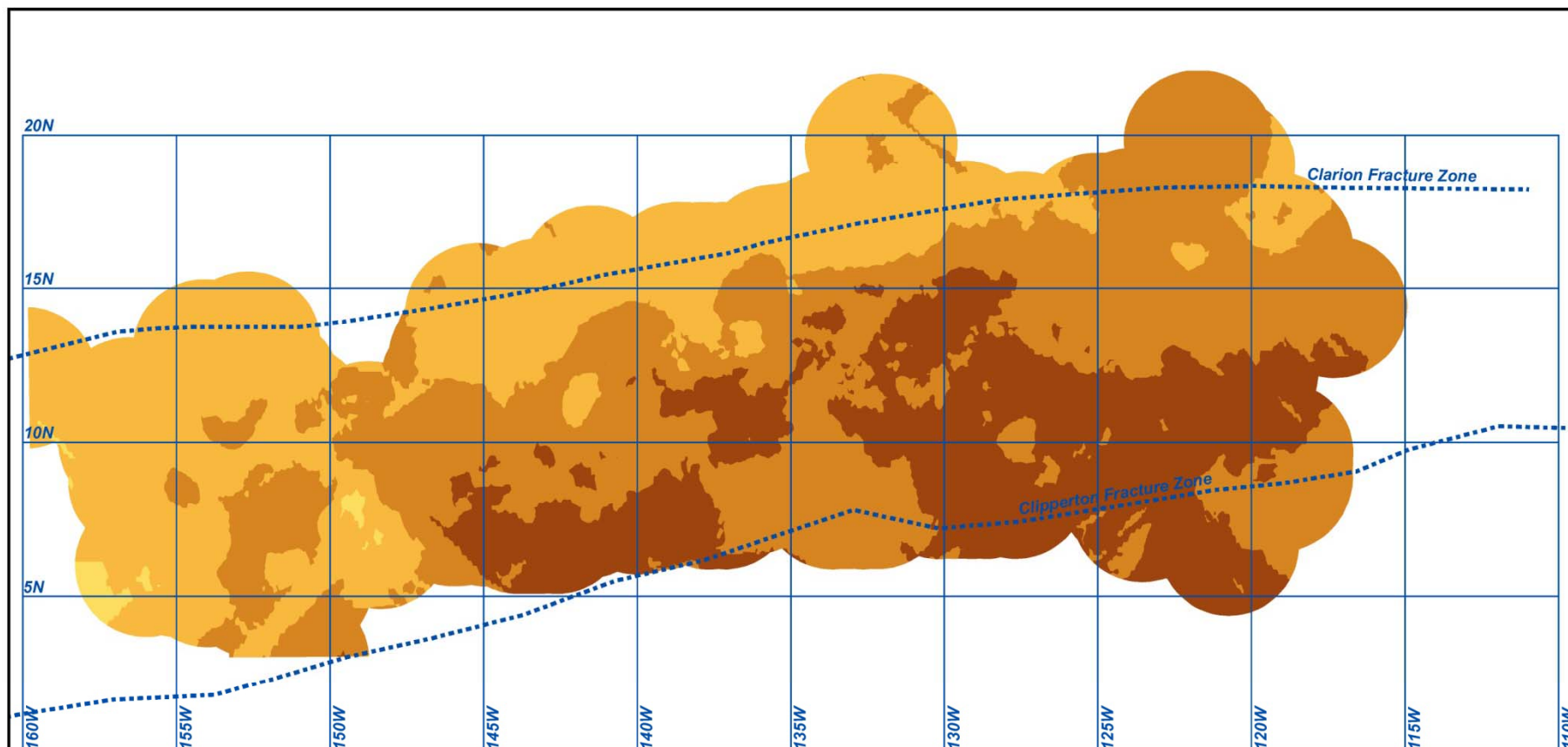
Values are plotted for the areas that
lie within the variogram range (255 km)
of the survey station locations

Clarion Fracture Zone

Clipperton Fracture Zone

The International Seabed Authority

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Manganese (Dry Wt. %)

10 - 15	25 - 30
15 - 20	30 - 35
20 - 25	35 - 40

**Manganese Content
in Polymetallic
Nodules**

Cobalt (Dry Wt. %)

Values are plotted for the areas that
lie within the variogram range (111 km)
of the survey station locations

Cobalt (Dry Wt. %)

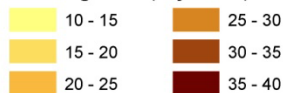|			
0.1 - 0.12	0.16 - 0.18	0.22 - 0.24	0.28 - 0.3
0.12 - 0.14	0.18 - 0.2	0.24 - 0.26	
0.14 - 0.16	0.2 - 0.22	0.26 - 0.28	

**The International
Seabed Authority**

PREPARED BY:
Dr. Charles L. Morgan

SOURCES:
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- Lockheed-Martin Corporation
- KORDI; COMRA; IOM

*Cobalt Content
in Polymetallic
Nodules*

Nickel (Dry Wt. %)

Values are plotted for the areas that lie
within the variogram range (67 km)
of the survey station locations

PREPARED FOR:
The International
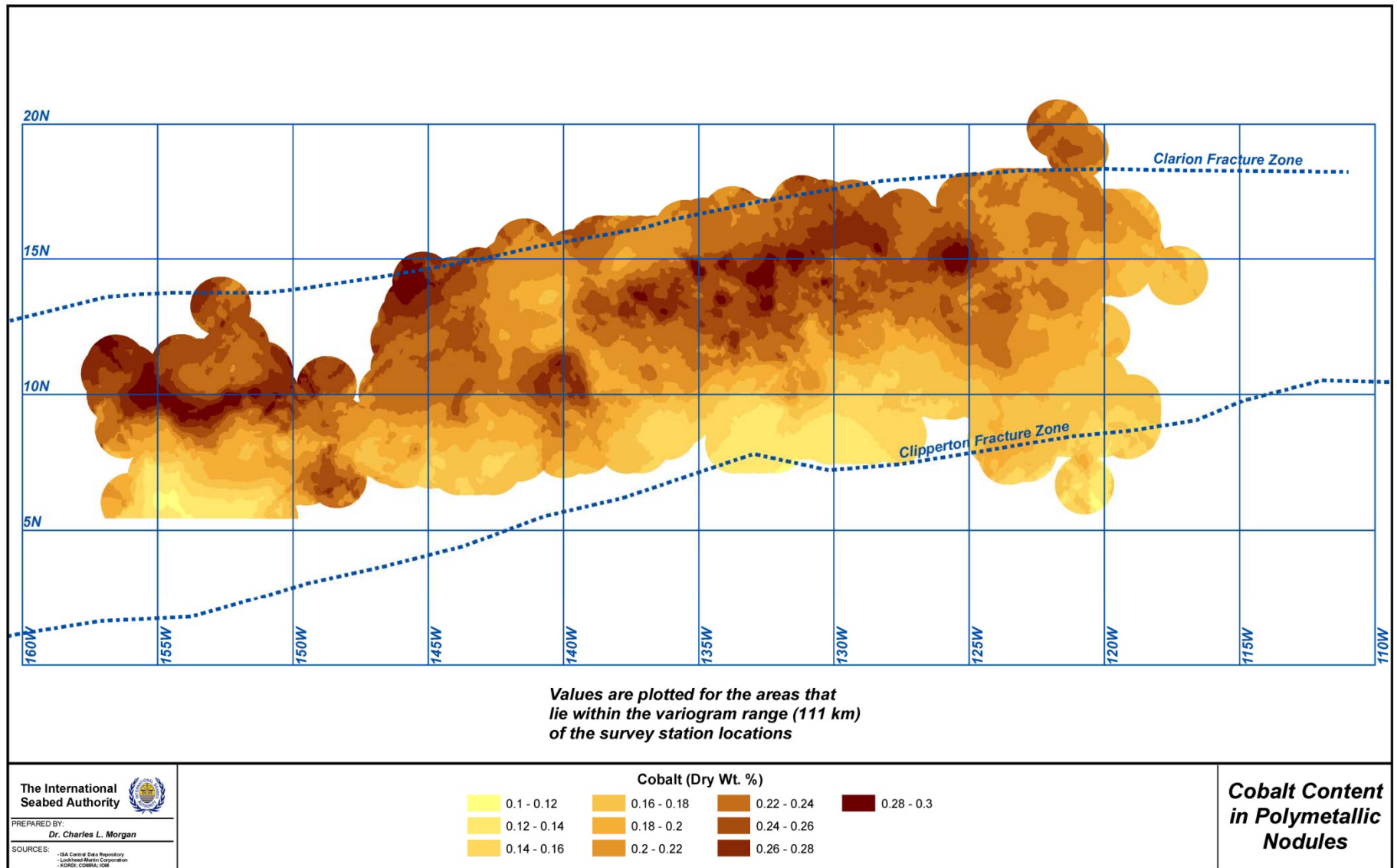Seabed Authority

PREPARED BY:
Dr. Charles L. Morgan

SOURCES:
- ISA Central Data Repository
- Lockheed-Martin Corporation
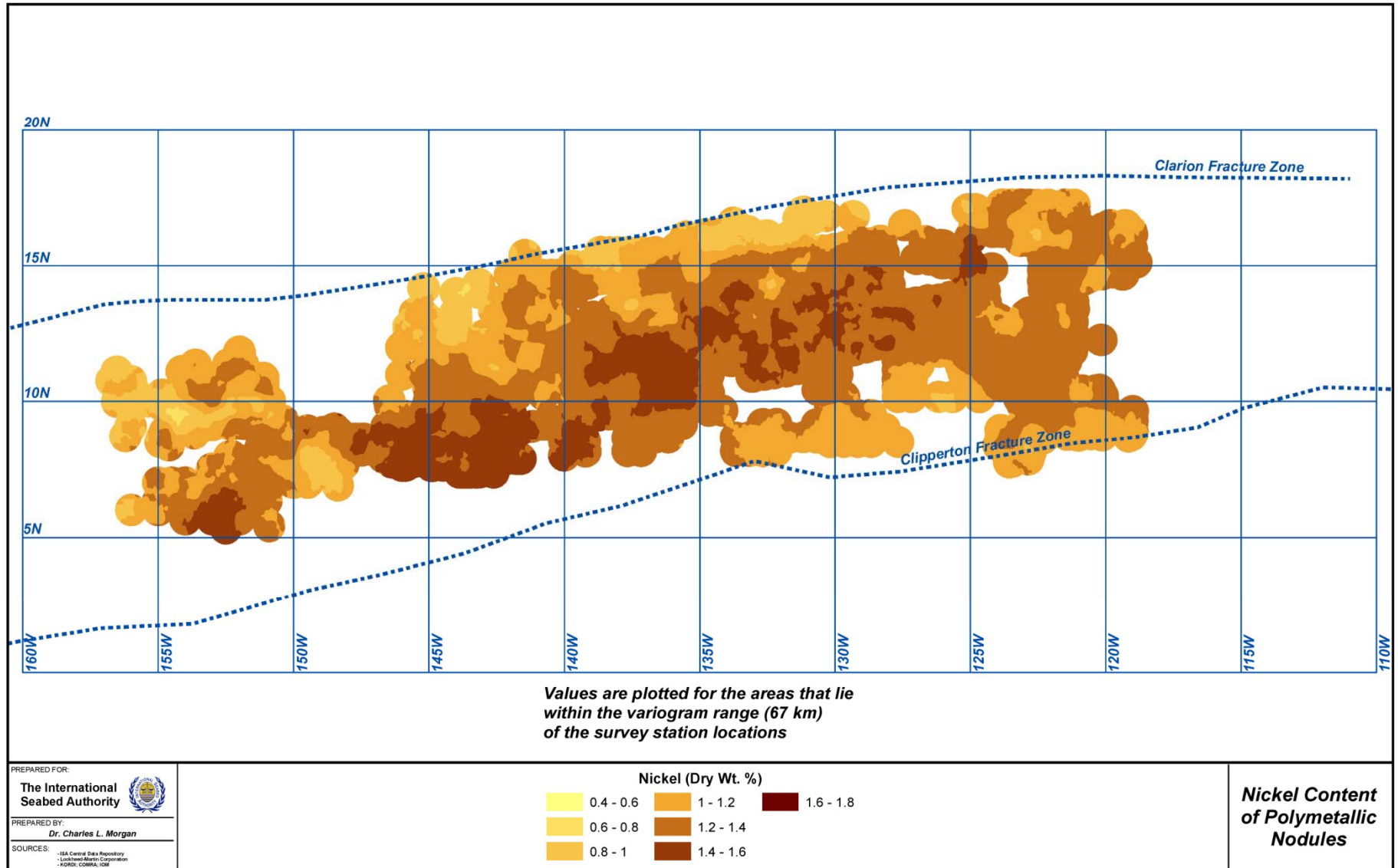- KORDI; COMRA; IOM

Nickel (Dry Wt. %)

0.4 - 0.6	1 - 1.2	1.6 - 1.8
0.6 - 0.8	1.2 - 1.4	
0.8 - 1	1.4 - 1.6	

**Nickel Content
of Polymetallic
Nodules**

Copper (Dry Wt. %)

20N

15N

10N

5N

Clarion Fracture Zone

Clipperton Fracture Zone

160W 155W 150W 145W 140W 135W 130W 125W 120W 115W

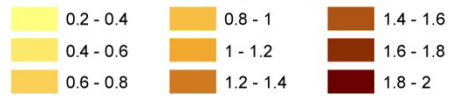*Values are plotted for the areas that lie within the variogram range (78 km) of the survey station locations*

The International Seabed Authority

PREPARED BY:
Dr. Charles L. Morgan

SOURCES:
- ISA Central Data Repository
- Lockheed-Martin Corporation
- KORDI; COMRA; IOM

Copper (Dry Wt. %)

0.2 - 0.4	0.8 - 1	1.4 - 1.6
0.4 - 0.6	1 - 1.2	1.6 - 1.8
0.6 - 0.8	1.2 - 1.4	1.8 - 2

Copper Content in Polymetallic Nodules

RESOURCE ASSESSMENT SUMMARY

Source	Included Area (km^2 X 10^6)	Estimated Tons (metric tons X 10^6)				
		Nodules	Mn	Co	Ni	Cu
Table 4.8	3.83	21,100	5,950*	46.4*	270*	234*
Table 4.7	4.19	30,700	8,657*	67.5*	393*	341*
Table 5.1	4.85	27,100	7,300	58.0	340	290

*Estimated using mean metal content values from Table 3.3

GEOLOGICAL MODEL

- FIJI CONCEPT

- BIOGEOCHEMICAL APPROACH

- SDSS APPROACH
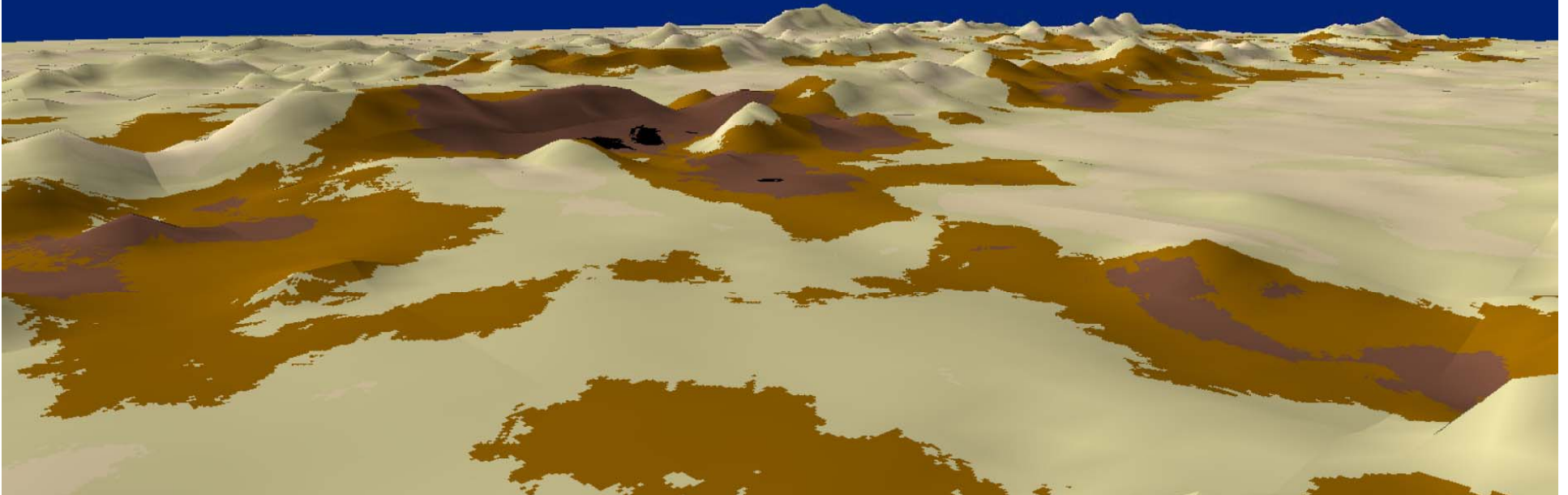
GEOLOGICAL MODEL: MAY 2003
FIJI CONFERENCE CONCEPT

1. IDENTIFY VARIABLES THAT MAY BE RELATED TO THE DEPOSITS
2. QUANTIFY RELATIONSHIP IF POSSIBLE
3. USE RELATED VARIABLES AS **PROXIES** FOR DEPOSIT OCCURRENCE
4. PREDICT WHERE UNDISCOVERED DEPOSITS MAY BE FOUND

GEOLOGICAL MODEL

- *QUANTITATIVE PREDICTIONS OF ABUNDANCE & METAL CONTENT*

- *STATISTICALLY BASED WITH CLEAR DESCRIPTIONS OF METHODS*

- *TWO APPROACHES DEVELOPED*

  ➢ *Biogeochemical Model*

  ➢ *Spatial Decision Support System Modeling*

GEOLOGICAL MODEL: AVAILABLE DATA

PROXY DATA

- *BATHYMETRY*
- *TECTONIC/VOLCANIC DATA*
- *SEDIMENT DATA*
- *NODULE MORPHOLOGY*
- *WATER COLUMN DATA*
- *BIOLOGICAL DATA*

RESOURCE DATA

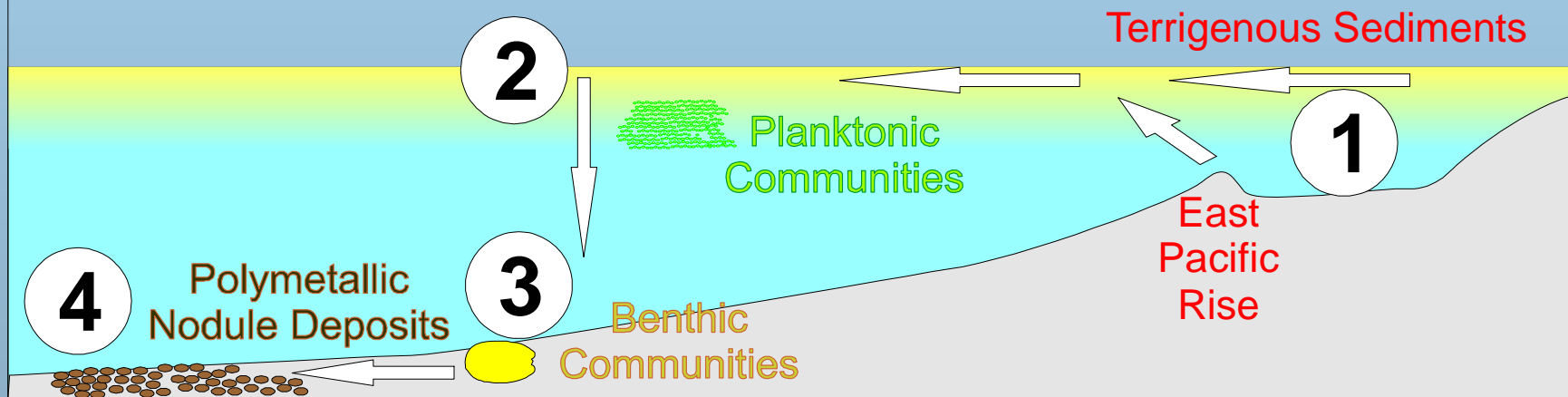- *ABUNDANCE*
- *MANGANESE*
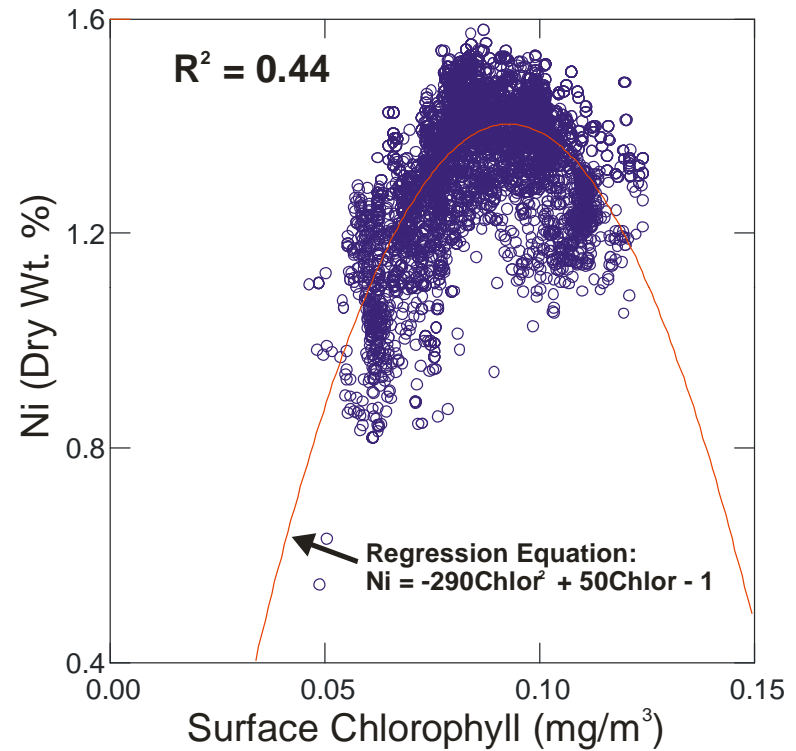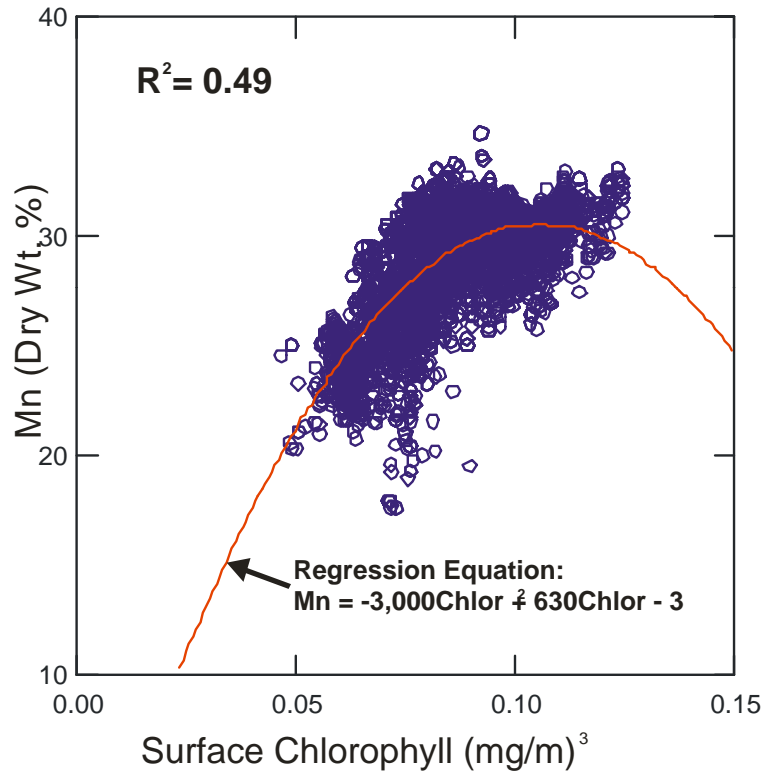- *NICKEL*
- *COPPER*
- *COBALT*

BIOGEOCHEMICAL MODEL
GENERAL HYPOTHESIS

1. **Sources of metals: Land and East Pacific Rise, carried in suspended sediments**
2. **Sediments consumed by plankton & converted to biogenic particles that sink**
3. **Biogenic particles metabolized by benthic fauna, releasing reduced metals**
4. **Reduced metals scavanged by Mn oxide surfaces**

Terrigenous Sediments

2

Planktonic Communities

1

East Pacific Rise

4 Polymetallic Nodule Deposits

3 Benthic Communities

MODEL RESULTS FOR MN & NI

$R^2 = 0.49$

$R^2 = 0.44$

Regression Equation:
Mn = -3,000Chlor^2 + 630Chlor - 3

Regression Equation:
Ni = -290Chlor^2 + 50Chlor - 1

SPATIAL DECISION SUPPORT SYSTEM MODELING (SDSS)

- USED WITH STANDARD MINING EXPLORATION METHODS

- EMPLOYS OBJECTIVE ALGORITHMS WITH POTENTIAL PROXY VARIABLES

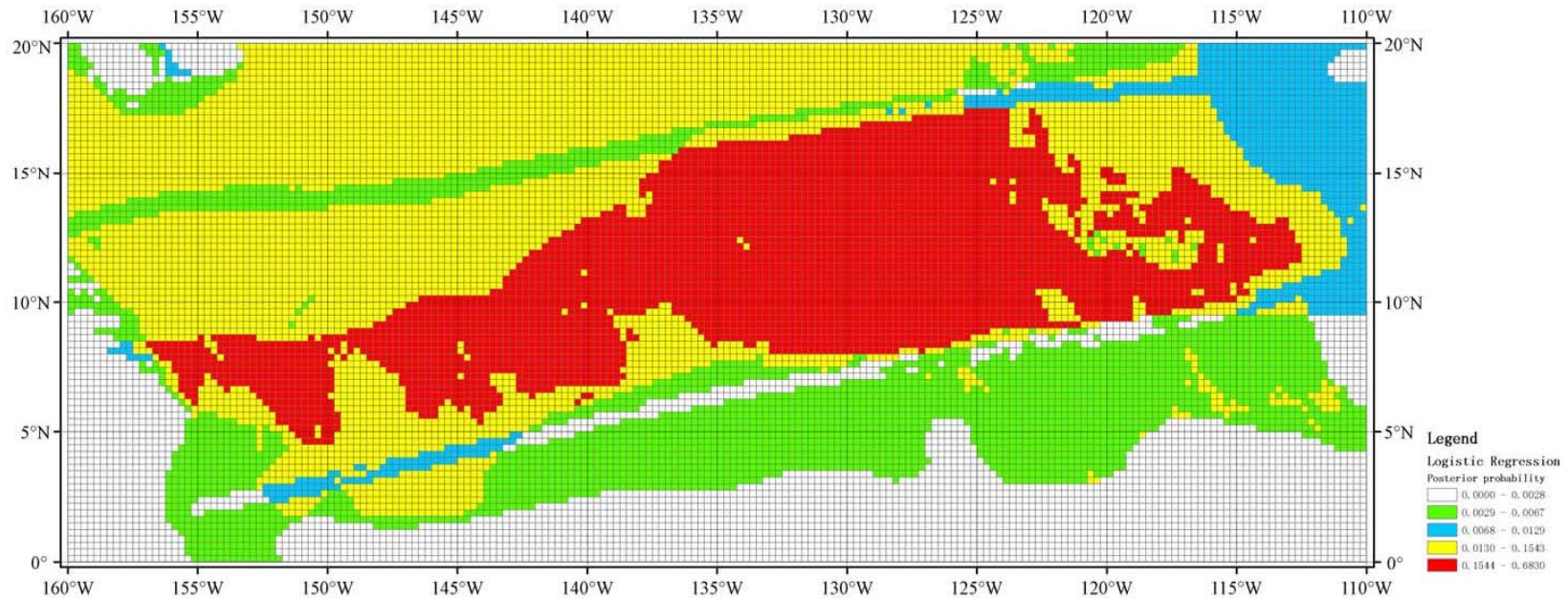- PREDICTS OPTIMAL EXPLORATION TARGETS

SDSS MODELING
PRIMARY RESULTS

## OPTIMAL EXPLORATION TARGETS:

➢ Between explored areas

➢ To the north of explored areas

LOGISTIC REGRESSION

Legend

Logistic Regression
Posterior probability

- 0.0000 – 0.0028
- 0.0029 – 0.0067
- 0.0068 – 0.0129
- 0.0130 – 0.1543
- 0.1544 – 0.6830

PROSPECTOR'S GUIDE

- GRIDDED BATHYMETRY

- VOLCANIC, TECTONIC & SEDIMENTARY FACTORS

- GROWTH MODEL

- COVERAGE, MORPHOLOGY & DISTRIBUTION IN EASTERN CCZ

- SEDIMENTS IN EASTERN CCZ

- GENESIS & SEDIMENTS IN KORDI AREA

- BATHYMETRY & SEDIMENTATON IN COMRA AREA

- REGIONAL SEDIMENTATION

- BENTHIC BIOLOGY
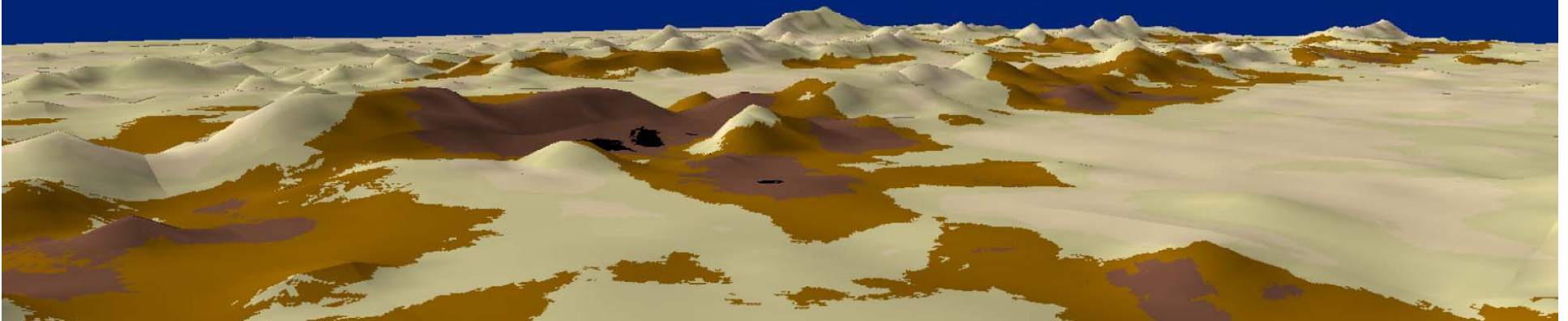
GRIDDED BATHYMETRY

- **BASE: Smith/Sandwell Predicted Bathymetry (all structures > 10-15 km)**

- **CONTRACTOR CONTRIBUTIONS:**

  - **Paper maps from Contract Applications**

  - **Multi-beam data from**
    - **France (IFREMER/AFERNOD),**
    - **Japan (DORD),**
    - **Russian Federation (Yuzhmorgeologiya),**
    - **China (COMRA),**
    - **Inter Ocean Metal Joint Organization (IOM)**

  - **Final Maps From Prof. Lindsay Parsons**
    - **1-minute (~1.8 km) data for entire region**
    - **0.5- and 0.1 minute (~900 & 200 m) data for 6 subsets of region**

VOLCANIC, TECTONIC & SEDIMENTARY FACTORS
(Authors: *Valeriy Yubko and Ryszard Kotliński*)

- **Synthesis of Regional Geology**

- **Identifies Static & Dynamic Features**

- **Relates them to Geological Processes & Nodule Formation**

NODULE GROWTH MODEL

(Authors: *Huaiyang Zhou, Wenzheng Lu, Ning Zhou, and Qunhui Yang*)

- **Links Mode of Growth to Morphology**

- **Notes the Probable Role of Bioturbation**

- **Identifies the Importance of the Semi-liquid Surface Layer**

NODULE COVERAGE, MORPHOLOGY & DISTRIBUTION IN THE EASTERN CCZ

(Authors: *V. Stoyanova and R. Kotliński*)

- **Examines Potential Correlations Between Nodule Properties & Environmental Variables**

- **Describes Distributions of Different Morphologies**

SEDIMENTS IN THE EASTERN CCZ

(Author: *R. Kotliński*)

- **Discusses General CCZ Sedimentation Patterns**

- **Describes Relevance of Miocene Hiatus**

- **Presents Data on Sediment Composition**

NODULE GENESIS & SEDIMENT DISTRIBUTION IN THE KOREA ALLOCATED AREA

Authors: Jung-Keuk Kang, et al.

- **Discusses Bathymetry & Seafloor Morphology**

- **Examines Relationships Between Nodule Morphology & Sediment**

- **Examines Relationships Between Nodule Morphology & Formation Mechanisms**

BATHYMETRY AND SEDIMENTATION IN THE COMRA CONTRACT AREA

Authors: Huaiyang Zhou, Wenzheng Lu, Ning Zhou, and Deping Li

- **Presents COMRA High Resolution Bathymetric Data Set**

- **Examines Sediment Distributions & Relationships to Bathymetry**

BENTHIC BIOLOGICAL DATA FROM THE CCZ

Authors: Sarah Mincks and Craig Smith

- **Assembles & Integrates Existing Data**

- **Shows Relationship Between Primary Productivity & Faunal Density**

SUMMARY OF PROJECT ACCOMPLISHMENTS

- *UNPRECEDENTED RESOURCE DATABASE & ASSESSMENT*

- *VALIDATION OF CLASSIC NODULE FORMATION MODEL*

- *UNIQUE INTEGRATION OF DATA AND INSIGHTS FOR CCZ DEPOSITS*