ISA Workshop December 2009

EFFECTS OF THE STRUCTURAL-TECTONIC AND VOLCANIC PROCESSES ON FORMATION OF POLYMETALLIC NODULES IN THE CCZ

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interoceanmetal
JOINT ORGANIZATION

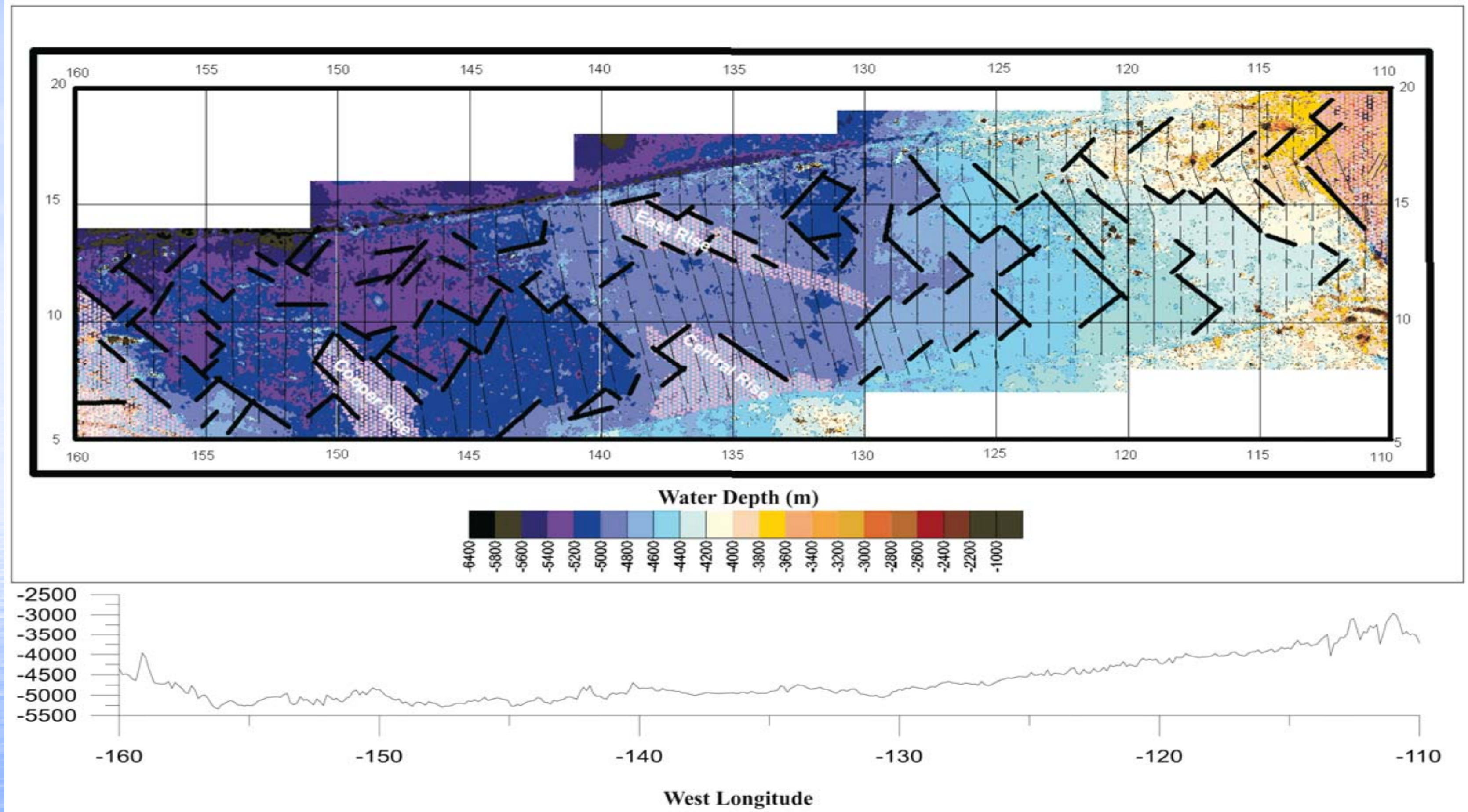
OUTLINE

- **Objective:**
  - **Estimation of the possible influence of such factors and processes as bottom morphology, water depth, structural-tectonics setting and sedimentary, volcanic and hydrothermal activity on formation of polymetallic nodules in the entire CCZ**

- **Data inputs:**
  - **Structural Setting of the CCZ;**
  - **Volcanic and Hydrothermal Activity;**
  - **Types of sediments;**
  - **Types of nodules and their distribution;**
  - **Mn/Fe ratios**

- **Establishment of a model of evolution of the CCZ ant its apparent relationship to the formation of polymetallic nodules**

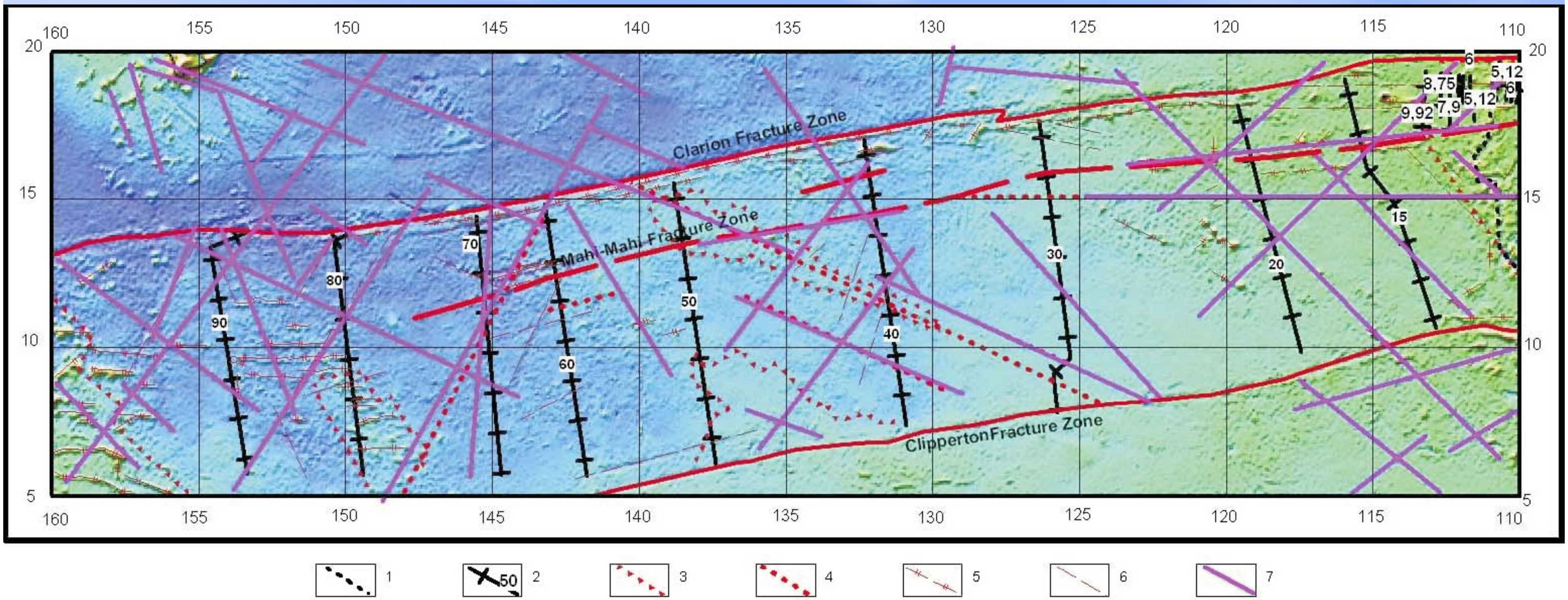
Structural Setting of the CCZ



• increasing of the water depth from East to West: from 3,800 – 4,200 m at 115ºW to 4,800-5,200 m at 130ºW, and 5,400 – 5,600 m at 145º W;

• the largest structural elements are the swell-type volcanic-tectonic Cooper Rise, Central Rise and East Rise.

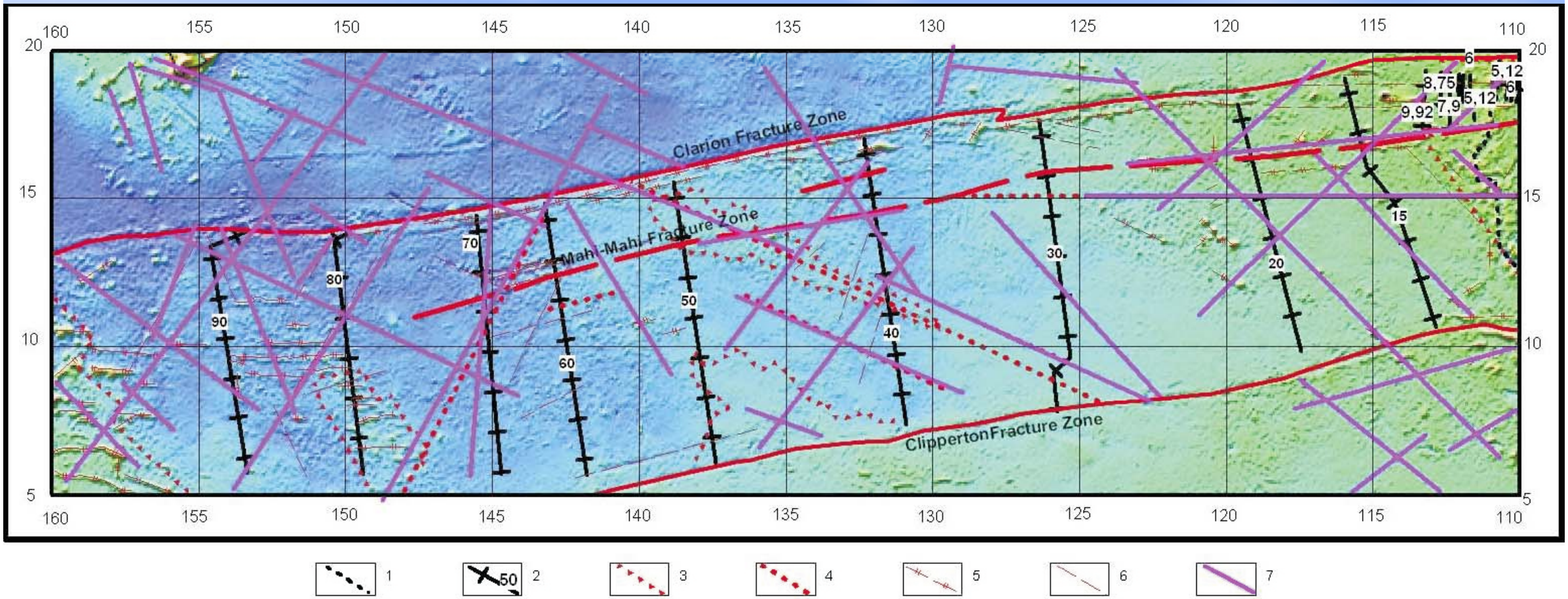
Tectonic Sketch of the CCZ



1 - Extinct Rift of the Mathematicians Ridge; 2 - Basement Age (Isochrones in MYA); 3 - Secondary level rise boundaries; 4 - Structural Lineation; 5 - Volcanic ridges and chains; 6 - Trenches or faults; 7 - Linear features indicated by seismic activity

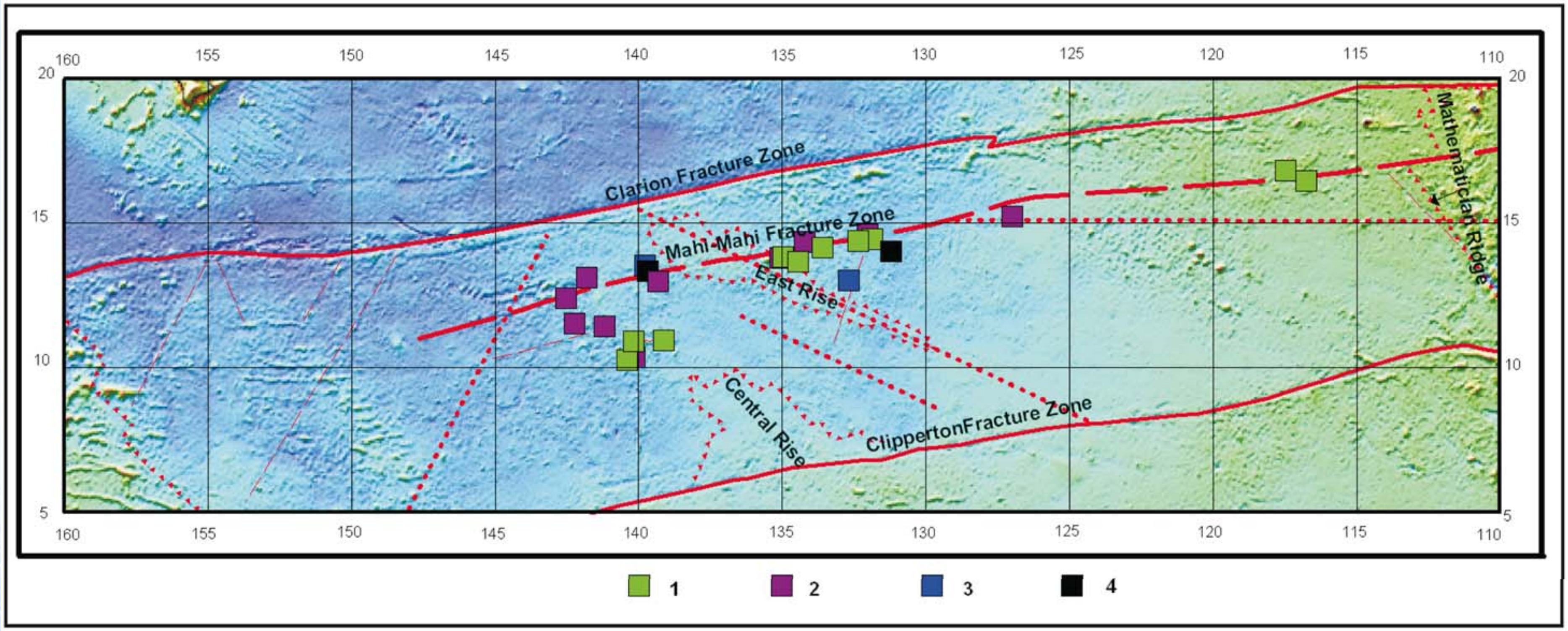
Regional variability of the seafloor morphology includes: Rises and stretched (or near-to-straight) fragments of trenches and faults which are virtually directed along one of two mutually orthogonal systems: the Hawaiian Archipelago (azimuth of ~ 300º-315º **), and** Ortho-Hawaiian trend (azimuth of ~ 30º-45º).

Tectonic Sketch of the CCZ (cont)



- The Earth's crust has total thickness of 10.6 – 10.8 km). It exhibits a two-layer: the upper part thickness of 100 – 300 m; the lower part consists primarily of basalts;
- Coring and geophysical data acquisitions have proved that the age of the basement is successively decreasing from West to East from 90 x 10^6 years at 153º W to 20 x 10^6 years at 118º W;
- Isochronous curves of the basement age are always nearly linear and oriented in sub-meridional direction, more or less parallel to the East Pacific Rise.

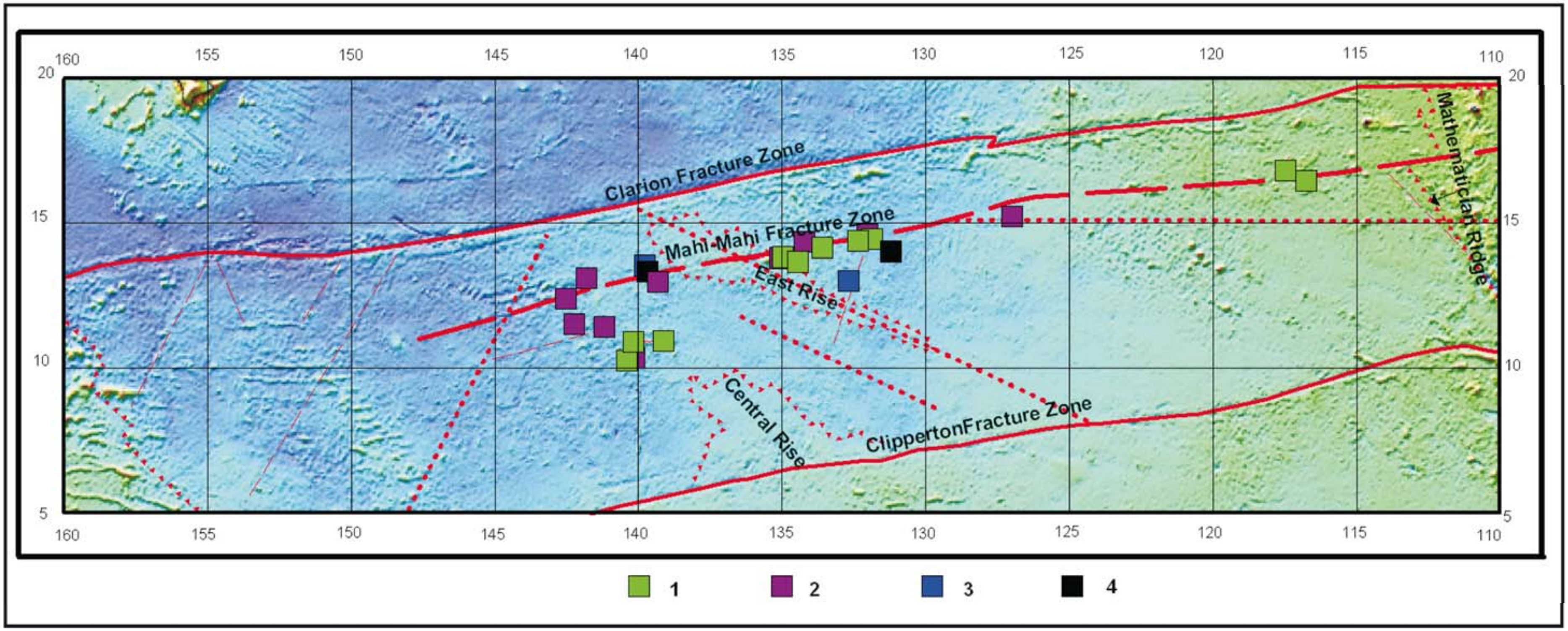
Volcanic and Hydrothermal Activity



Recent basaltic flows (1), metalliferous sediments (2), hydrothermal flints (3), and hydrothermal-metasomatic sulfides (4) in the CCZ

- The direct evidence of the resent intra-plate volcanism in the CCZ is the basalt lava of Shimada Seamount (the crustal age in the area ~ 16 - 17 million years);
- Evidence for potentially local sources of metals are found in metalliferous sediment and hydrothermal flints (YMG, SIO);
- Discovered by YMG massive hydrothermal- metasomatic sulphides (14º00'6N, 131º11'8 N)

Volcanic and Hydrothermal Activity (cont)



• Composition of the massive hydrothermal- metasomatic sulphides : Fe - 15,52 %; Cu - 17,84 %; S - 17,75 %; Ag - 0,067 %, Ni - 0,085 %; Pb - 0,31%; Zn - 0,072%; Co - 0,014 %; Mn - 0,55 %;

•the minerals (in per cent): chalcopyrite – 60-65; bornite - 5; covellite - 4; galena - 1; sphalerite – 0.5.

• It is demonstrate that the young basaltic flows, metalliferous sediments, hydrothermal and hydrothermal-metasomatic precipitations are spatially connected with Mahi-Mahi Fracture Zone.

SEDIMENTS

•The sedimentary cover consists of: carbonates (e.g. carbonate oozes), red brown clays, and siliceous sediments (siliceous oozes, and siliceous-argillaceous oozes);

• Mixtures of these end-members dominate the seabed in the CCZ and persist in nearly every setting, except where high rates of erosion, volcanic activity or other anomalous conditions occur.

• In general, the sediment lithofacies exhibit a unidirectional gradient trending from predominant carbonate sediments in the southeastern extreme to predominant red brown clays, and siliceous-argillaceous oozes in the west-northwest.

•This trend occurs despite the large differences in crustal age that occur from East to West and is believed to the culmination of two controlling factors:

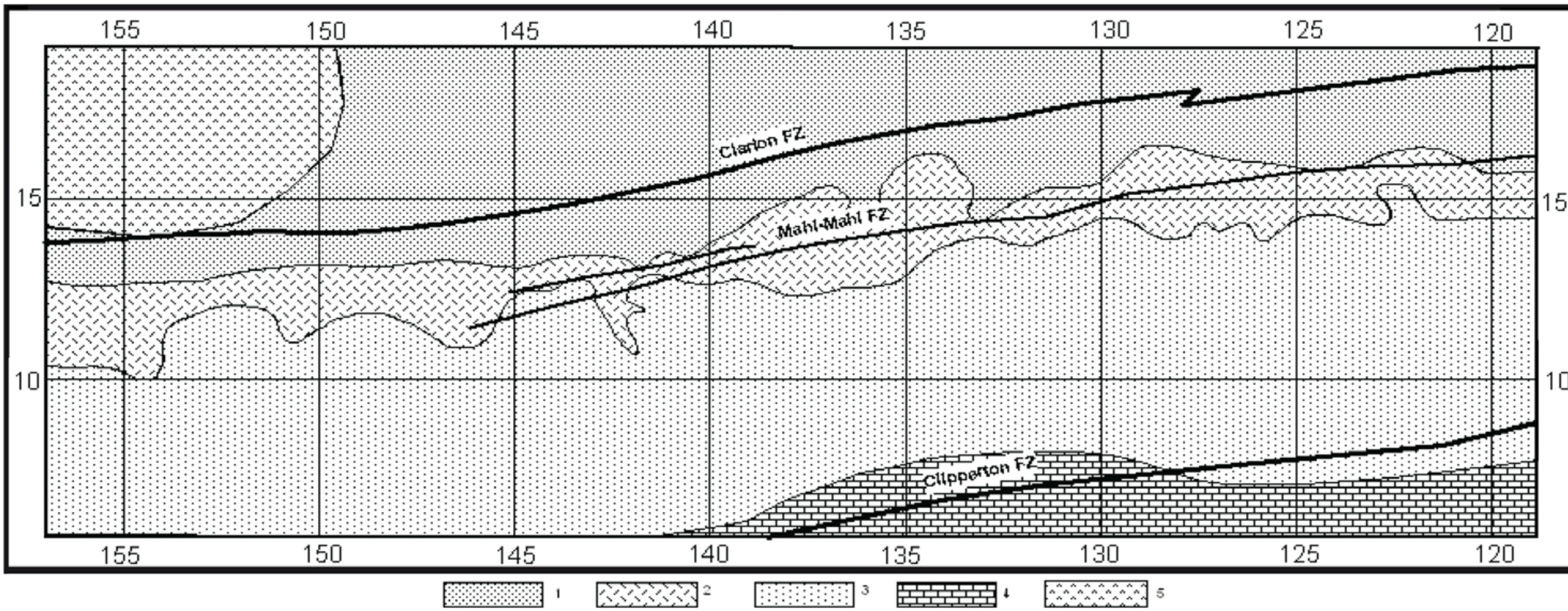
- the north-south gradient of primary productivity, decreasing to the north (Morgan, 2009),

  - and the basic, tectonically controlled increase in water depth with distance from the EPR (Sclater, Anderson, and Bell 1971)

SEDIMENTS

Distribution of the surficial sediments

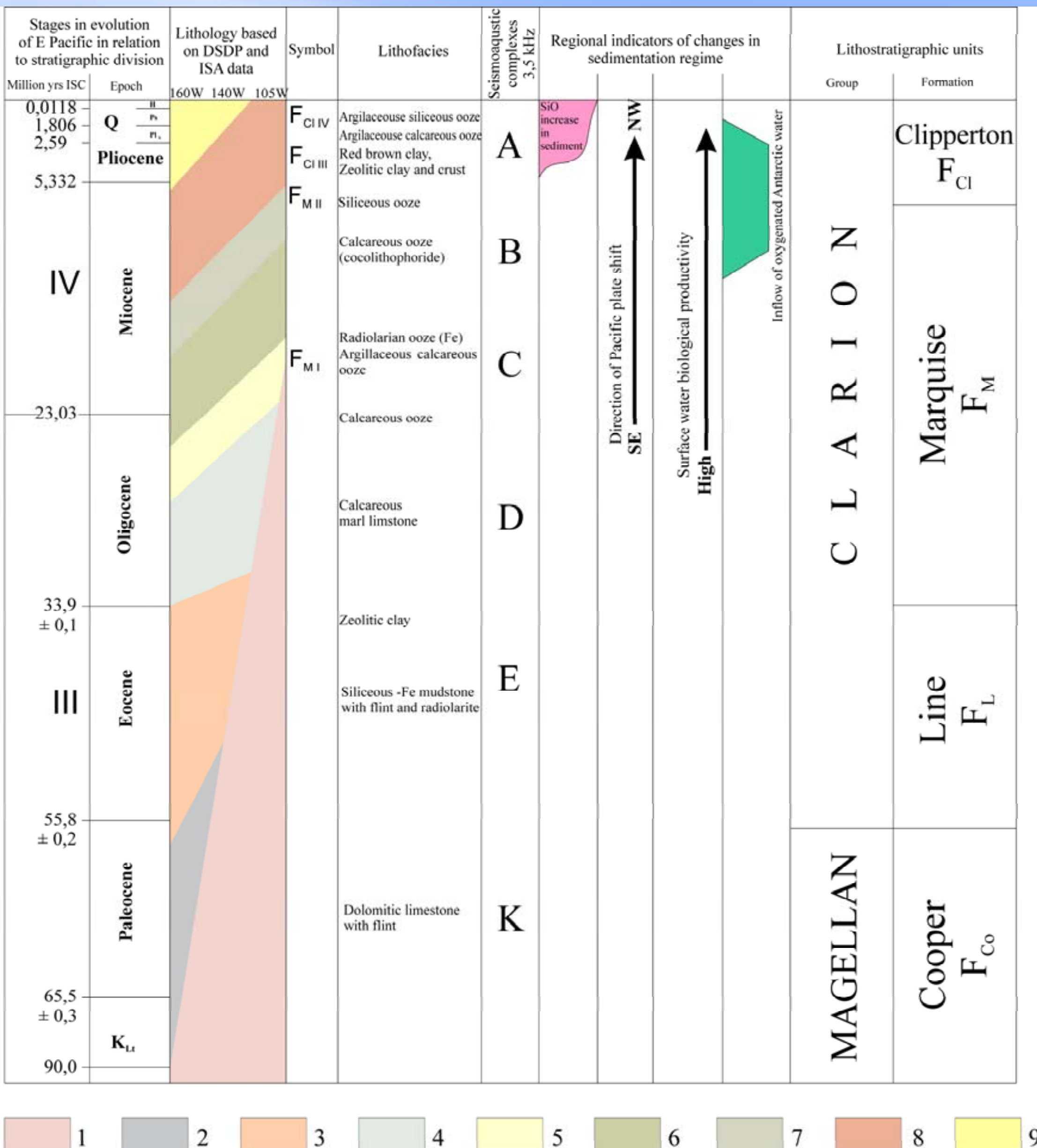
By Yubko, Kotliński, 2009



1. Red Clay; 2 - Argillaceous-Siliceous Ooze; 3 - Siliceous-Argillaceous Ooze; 4 - Calcareous Ooze; 5 - Hawaiian ash fall

The east-west increase in water depth favor the persistence of siliceous sediments, since carbonate minerals become more and more soluble with increasing hydrostatic pressure (i.e. increasing water depth). In contrast, the North-South gradient in primary productivity favors higher concentrations of carbonates, since higher sediment rates can effectively overcome the dissolution rates.

Scheme of lithostratigraphic units of CCZ



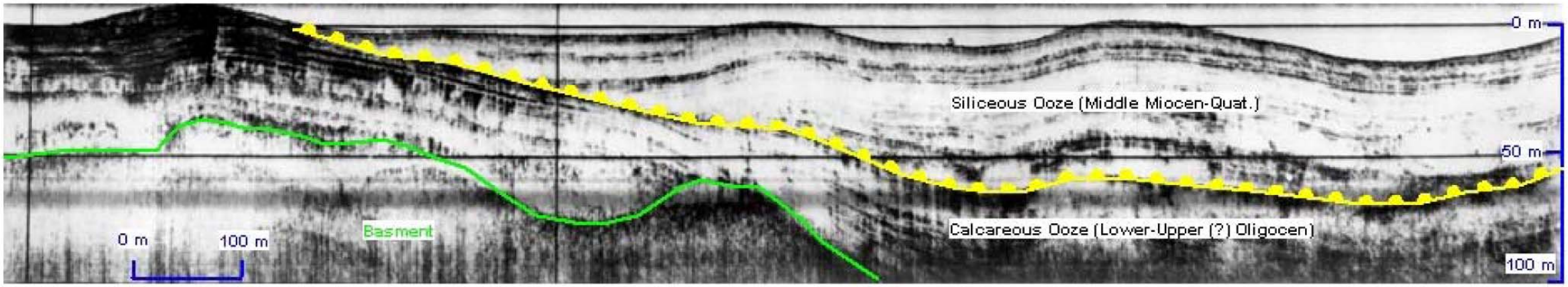
based on ISA data, Kotliński, 2009

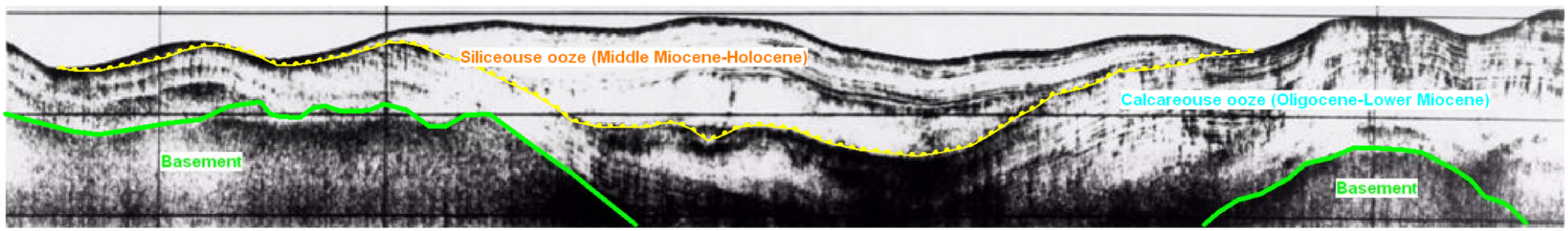
CCD – the depth and latitude where the sediment rate and dissolution rate of carbonates are equal.

In this zone facies transition from primarily siliceous sediments to primarily carbonate sediment ;

In the middle latitudes of the CCZ (10° -12.5° N) this transition occurs ~ 110° - 115° W. Moving westward at this latitude, the transition occurs in successively older sediments, i.e. Miocene at 120°-125° W and Oligocene at 135°- 140°W

Structure and lithology of sediment cover

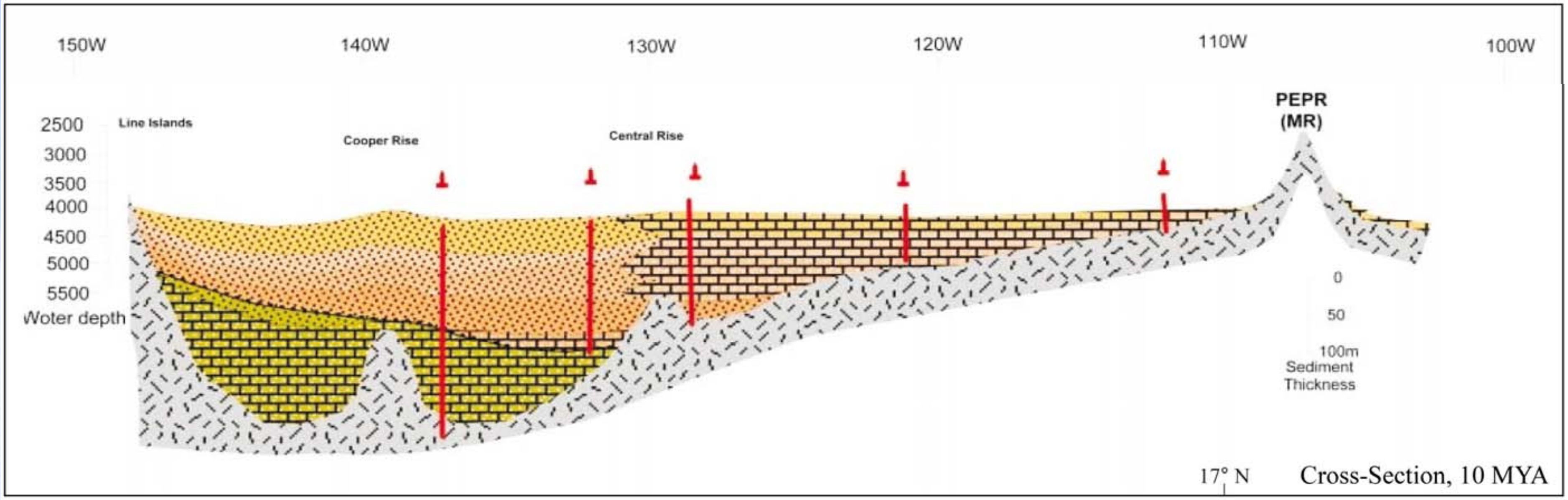


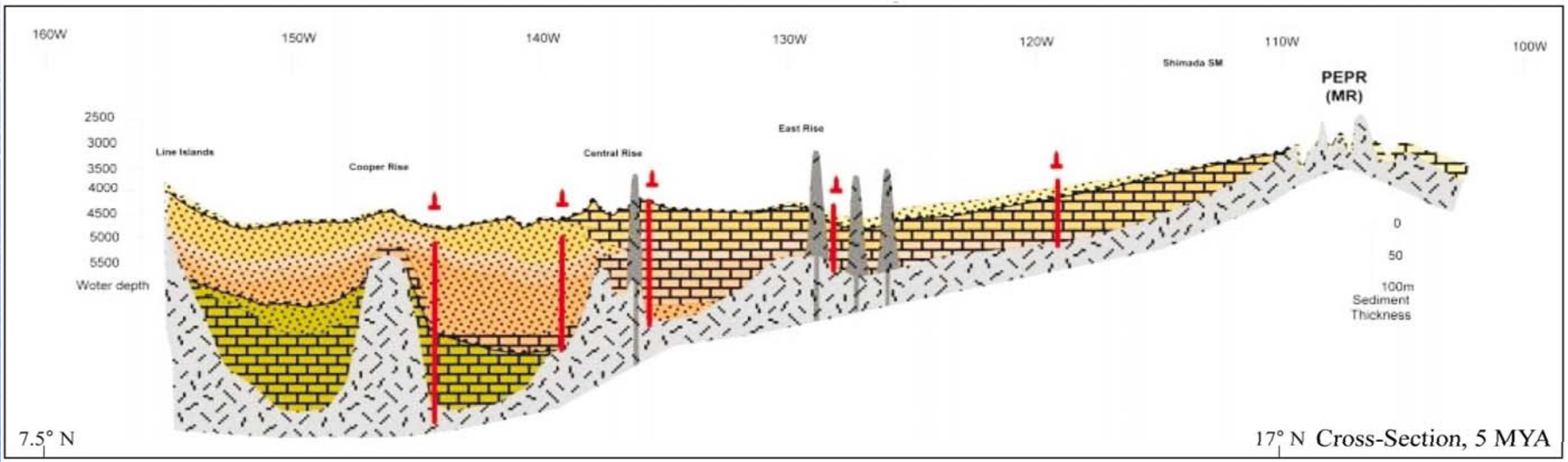


Primers of angular and stratigraphic discontinues bitewing Oligocene and Middle Miocene-Quarter sedimentary complexes (East-West acoustic profiles near 13º50' N, 131º27' W (upper picture) and 13º41' N, 131º42' W (lower picture)). Yellow line - position of Middle Miocene erosion surface. Green line - position of basement surface.

Paleo-Reconstruction of the CCZ

Yubko, Kotliński, 2009

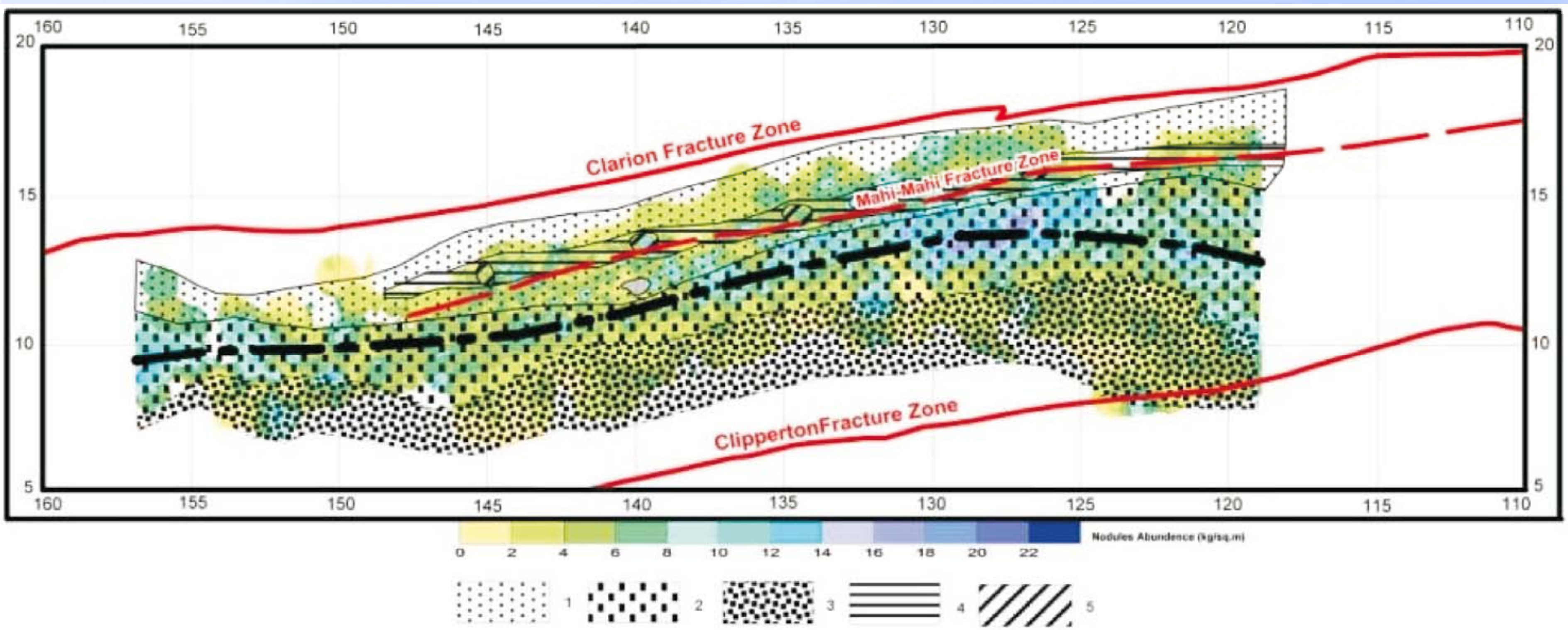




As for the aforementioned Middle Miocene unconformity, there is practically incontestable evidence of the fact that it appeared due to combination of two geological processes that took place 5 – 15 million years ago

POLYMETALLIC NODULES

Analysis of the spatial distribution of nodule abundance and metal concentration suggests an axial line of maximum abundance that is approximately parallel to and midway between the bounding fracture zones



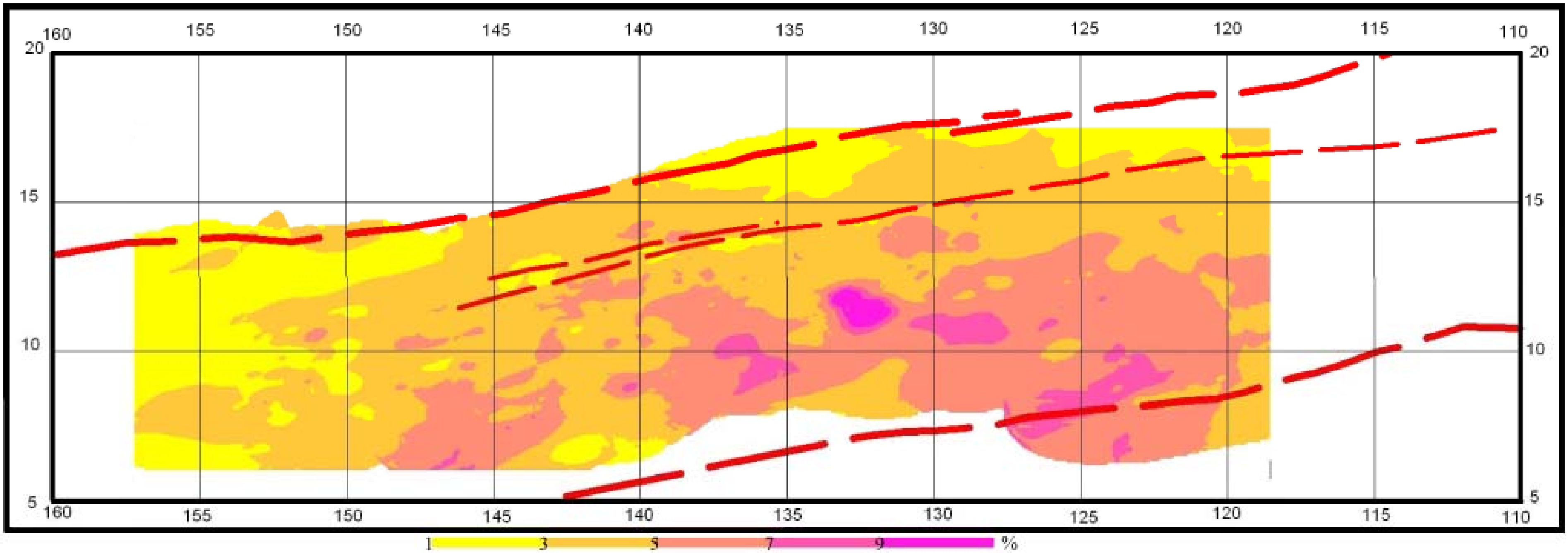
1 - Northern facies; 2 - Central facies; 3 - Southern facies; 4 - Mahi-Mahi Fracture Zone; 5 - Hydrothermal deposits; Thick black dashed line - Axial line of maximum nodule abundance

The spatial distribution of polymetallic nodules in the CCZ can be classified into three distinct zones.

POLYMETALLIC NODULES (cont.)

Mn/ Fe Ratios in the CCZ

Yubko, Kotliński, 2009



The Mn/Fe ratio clearly increases from north-south, while, less distinct, decreases from east to west.

Classification and characteristics of the types of nodules in CCZ

Lithofacies	Pelagic red clay, Siliceous-Argillaceous ooze	Siliceous-Argillaceous ooze, Argillaceous- Siliceous ooze	Argillaceous- Siliceous ooze, Siliceous ooze
Growth type	**H**	**HD**	**D**
Formation	**Hydrogenetic**	**Mixed type**	**Diagenetic**
Occurrence	**Exposed on sediment surface** extremely low sedimentation rates	**Exposed and partly sunken in semi-liquid layer** very low sedimentation rates, biogenic activity	**Partly sunken in surface sediment** low sedimentation rates, biogenic activity
Size (cm)	**< 4**	**4 – 8**	**6 – 12<**
Surface shape	**s**	**s + r**	**r**
Dominant morphotype	**S, P**	**E, T, D, I**	**D, E, I, F**
Major Mn minerals	**δ MnO_2 (vernadite)** Prevalence of amorphous phase (enriched in Fe,Co)	**7Å Manganate (birnessite) >10Å Manganate (todorokite)** Amorphous and crystalline phases	**10Å Manganate (todorokite) >7Å Manganate (birnessite)** Prevalence of crystalline phase (enriched in Mn, Cu+Ni)
Mn/Fe	**< 3**	**3 – 5**	**>5**
Abundance	On average – relatively low		On average – relatively higher
Nucleus type	Multinucleat, more seldom volcanoclastic debris or bioclasts	Lithified sediments (clayey-zeolitic), bioclasts	fragments of older nodules, micronodules
Lamination - prevailing lamina thickness (mm)	**0.1-1.0**	**0.1-2.0**	**>1.0**
Texture	**columnar**	**dendritic, concentric banding**	**concentric banding, dentritic, massive**
Physical properties: -volume density (g/cm^3) -porosity (%) -water content (nat.) (%)	**1.97** **59** **31**	**1.94** **61** **32**	**1.93-1.95** **62** **32**

Yubko, Kotliński, 2009

MODEL FOR CCZ EVOLUTION AND NODULE FORMATION

The development history of the geologic-geomorphologic structure of the CCZ is controlled by four types of factors:

- geodynamics,
- sedimentation,
- volcano-tectonic, and
- erosion-lithodynamics.

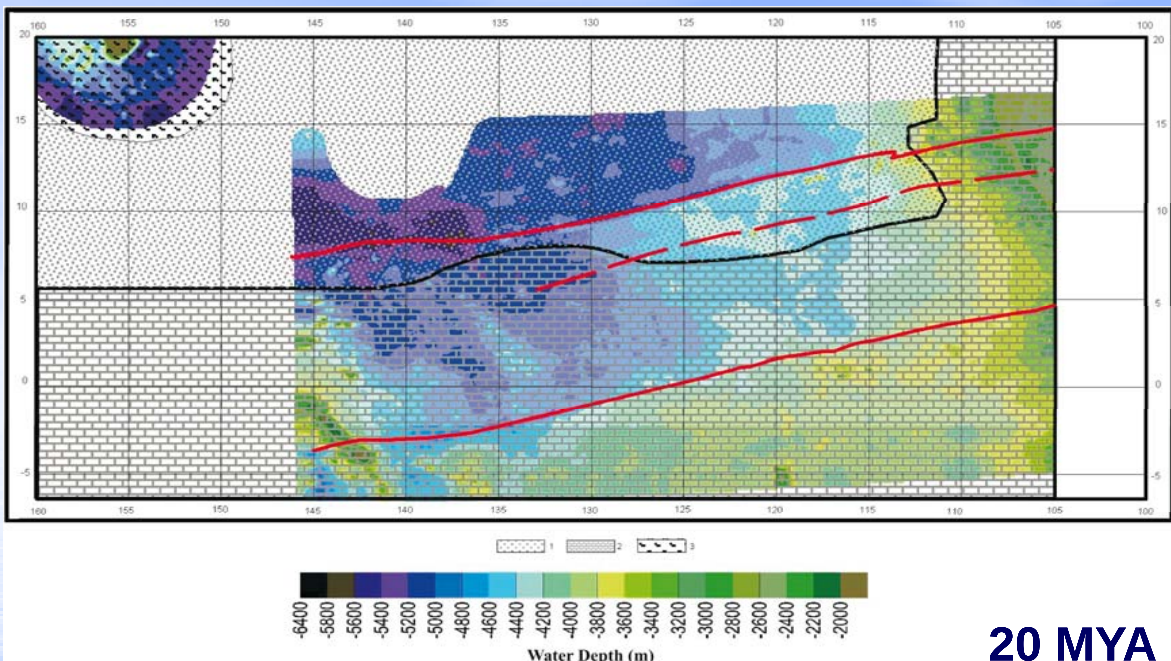
The geodynamic factor is responsible for realization of two interrelated geological processes: formation of the CCZ basement, and a successive shift towards the Pacific Plate (Hawaiian direction) and deepening to ever increasing depths of neogenic fragments (basement).

The role of the sedimentation could be displayed in two ways: relief is smooth makes favorable conditions for manganese nodule formation, and it realizes transportation functions of the prevailing mass of the ore components.

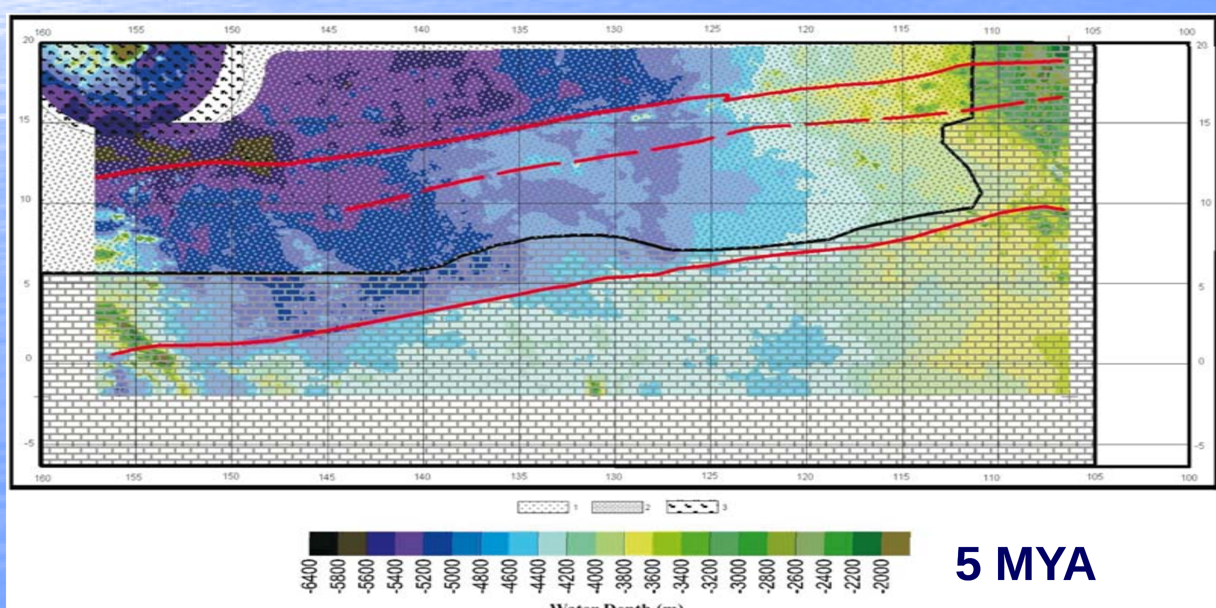
Volcanic and hydrothermal activity of the EPR is one of the main sources of the ore components.

Paleo-Reconstruction of the CCZ

Yubko, Kotliński, 2009



20 MYA



5 MYA

The axial area of the PEPR (Mathematicians' Ridge) was located at the depth of 2,500-2,600 m, ~ along a longitude of 107,5° W.

The total thickness of the earlier accumulated sediments toward increase from east to west, from tens of meters at 110° W to 300 m at 135° W.

- The most notable feature of the geological situation within the CCZ during the period of 10 – 15 MYA is a sharp increase of endogenous and exogenous processes, influencing on the formation of the current geologic and geomorphologic structure of the CCZ.

- The major geological events, happened within this period, resulted in a new structural and geomorphologic situation of the seafloor, one of the main elements of which is the **Middle Miocene** surface of unconformity. All known major nodule bearing areas of the CCZ are hosted by these sediments.

- The 5 – 10 MYA periods was characterized by the gradual attenuation of these erosional processes, by the stabilization of the normal sediment accumulation processes. Since, practically, the whole CCZ is within the zone of formation of the siliceous-argillaceous sediments the post-erosion sediments have a composition that matches the earlier sediments.

- During the last 5 million years the process of burial of the post-middle-Miocene relief has been rather steady .

- At the same time, another redistribution type of sediment material is clearly expressed: sediment particles shift to depressed bottom sections, contributing to formation of increased thicknesses of post-erosional sediments within the area of ancient structural and erosion depressions.

- The intra-plate volcano-tectonic activity of the CCZ has either remained at the prior level, or it might have increased . The recent volcanism of Shimada Seamount is the most reliable example of this activity.

- Thus, during the last 5 million years, both the sediment facies that favor nodule formation and the activities that may supply additional sources of metals suggest that the deposits are currently actively growing.

This presentation prepared for ISA Workshop December 2009, based on following papers:

Volcanic, tectonic, and sedimentary factors,
- V. Yubko and R. Kotliński

Nodule coverage, morphology &distribution in the eastern CCZ ***- V. Stoyanova and R. Kotliński***

Sediments in the Eastern CCZ **-** ***R. Kotliński***

THANK YOU