Natural variability of geochemical conditions, biogeochemical processes and element fluxes in sediments of the CCZ

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Introduction

During RV SONNE cruise SO239 in March/April 2015 five sites in the area of the Clarion-Clipperton Fracture Zone (CCZ) in the eastern equatorial Pacific were visited as part of the JPI Oceans pilot action "Ecological Aspects of Deep-Sea Mining". Here, we present a comparable study on (1) the redox zonation in the sediments induced by the input flux of organic matter, (2) biogeochemical reactions including the driver of organic matter degradation and (3) diagenetic manganese redistribution and implications for manganese nodule formation.

Methods

Four European exploration license areas including the German BGR area, the InterOceanMetal (IOM) area, the Belgian GSR area and the French IFREMER area were visited as well as one of the Areas of Particular Environmental Interest (APEI) and referred to as APEI3 (Fig. 1). Sediment cores were taken using a multiple corer (MUC) for the retrieval of undisturbed surface sediments and a 10 m long gravity corer (GC) which were subsequently sampled and analysed:

	Analysis	Method	Protocol
Onboard	*Ex-situ* O_2	Clark-type electrode (Unisense)	Revsbech (1989)
AWI lab	NO_3^-, DIC	QuAAtro (Seal Analytical)	
AWI lab	Mn^{2+}	ICP-OES (IRIS Intrepid)	
AWI lab	Total acid digestion	ICP-OES (IRIS Intrepid)	Nöthen and Kasten (2011)
AWI lab	TOC, TS	Eltra CS2000	
AWI lab	Radionuclides	ICP-MS (Element2)	Anderson et al. (2012)

For the determination of organic carbon (OC) oxidation rates, a one-dimensional reaction transport model was used (Boudreau, 1997).

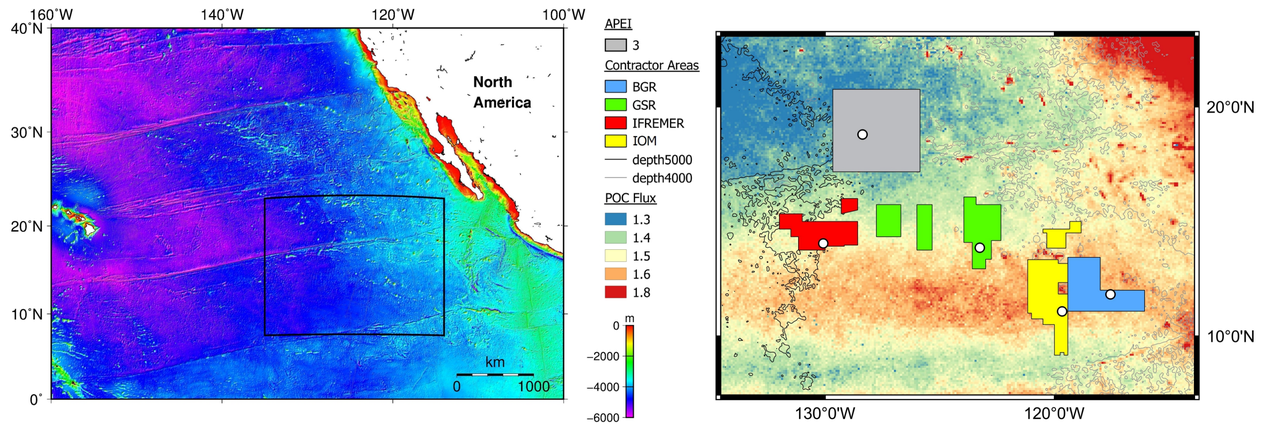
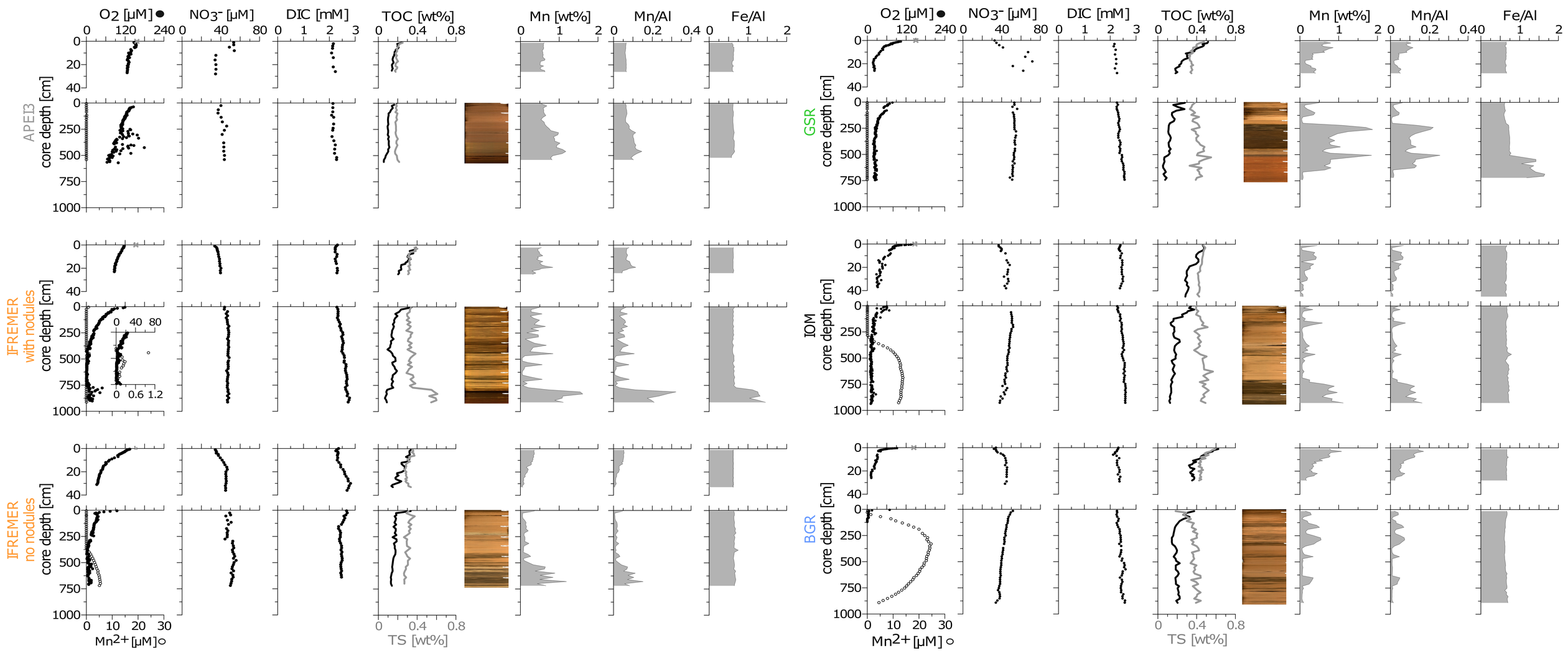


Figure 1: Maps of the study area during RV SONNE cruise SO239 showing the bathymetry of the Pacific Ocean (left), the five investigated areas (right) with sampling locations (white circles) and estimated upper limit in POC flux [mg C_{org} m^{-2} d^{-1}] to the seafloor by Lutz et al. (2007) (modified after Vanreusel et al., 2016).

Results and Discussion



- The **redox zonation** varies from throughout oxygenated sediments (APEI3, GSR) and oxygen penetration depth (OPD) of 3 m, 3.8 m and 4.5 m (IOM, IFREMER without nodules, IFREMER with nodules) to an oxic zone limited to the 1 m (BGR). Below the OPD, the suboxic zone extends from a horizon of 3 m with low conc. (5 µM, IFREMER with nodules) to at least 8 m with high conc. (25 µM, BGR). Below the suboxic zone, O_2 might re-increase at 3 stations (IFREMER with nodules, IOM, BGR; Mewes et al., 2016). Variations in the POC flux to the seafloor (Fig. 1) correlate with surface sediment TOC and TS contents: 0.4-0.6 wt% in BGR, IOM, 0.3-0.4 wt% in IFREMER, GSR, ~0.2 wt% in APEI3 (Fig. 2).
- The **main biogeochemical process** during OC degradation is aerobic respiration with diffusive O_2 fluxes within 0.172 and 0.057 mmol m^{-2} d^{-1} (BGR, APEI3). Bioturbation is limited to the upper 7 cm of sediment and 13 cm at the IOM site. Close correlation of TOC, TS and Ba indicate biogenic barite deposition that could be used as paleoproductivity proxy.
- The **diagenetic redistribution of Mn** in the suboxic zone is caused by the abiotic reduction of Mn oxides (Fig. 2) with no recent suboxic diagenetic formation of nodules.

Area	Sedimentation rate [cm kyr^{-1}]	POC flux [mg m^{-2} d^{-1}]	POC oxidation [mg m^{-2} d^{-1}]	Nodule coverage
BGR	0.35-0.6 0.35 for model	2.012	1.87	
IOM	1.15	1.054	0.95	
GSR	0.65	1.304	1.18	
IFREMER	0.18	0.712	0.68	
APEI3	0.2	0.667	0.5	

Table 1: Sedimentation rates, POC fluxes for the model input and modelled POC oxidation rates. Sedimentation rates for the BGR area were published by Mewes et al. (2014). Nodule coverage was derived from nearby box corer stations with a nodule sampling area is 0.25 m². The length of scale corresponds to 10 cm.

Figure 2: Pore-water profiles and solid-phase contents for the five investigated sites including high-resolution pictures of the GC sediments.

Conclusions

- The distinct differerences in geochemical zonations (and TOC degradation) within the studied license areas in the CCZ are a result of (1) surface water productivity and POC fluxes to the seafloor, (2) sedimentaton rates, (3) abiotic Mn reduction and (4) diffusive upward flux of O_2 from basal sediments
- Productivity ultimately determines the intensity of OC degradation and in turn the consumption of O_2 close to the sediment surface
- Recently, there is no suboxic diagenetic formation of nodules at any site
- The APEI3 site is not representing the natural geochemical setting of the investigated European license areas

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