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Hydrothermal signature in the axial-sediments from the Carlsberg Ridge in the northwest Indian Ocean

Zenghui Yu [a,b,*], Huaiming Li [c], Mengxing Li [a,b], Shikui Zhai [a,b]

[a] College of Marine Geosciences, Ocean University of China, Qingdao 266100, China
[b] Key Laboratory of Submarine Geosciences and Prospecting Techniques, Ministry of Education, Qingdao 266100, China
[c] The Second Institute Of Oceanography, State Oceanic Administration, Hangzhou 310012, China

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ABSTRACT

30 sediments grabbed from 24 sites between the equator and 10°N along the Carlsberg Ridge (CR) in the northwest Indian Ocean has been analyzed for bulk chemical compositions. Hydrothermal components in the sediments are identified and characterized. They mainly occur at 6.3°N as sulfide debris and at 3.6°N as both sulfide and high temperature water-rock interaction products. The enrichment of chalcophile elements such as Zn, Cu, Pb and the depletion of alkalis metals such as K and Rb are the typical features of hydrothermal components. High U/Fe, low $(Nd/Yb)_N$ and negative Ce anomaly infer the uptake of seawater in the hydrothermal deposits by oxidizing after deposition. However, the general enrichment of Mn in hydrothermal plumed-derived materials is not found in the sediments, which may indicate the limited diffusion of fluids or plumes, at least in the direction along the Carlsberg spreading center. The hydrothermal components show their similarity to the hydrothermal deposits from the Indian Ocean Ridge. At 3.6°N ultramafic rocks or gabbroic intrusions, may be involved in the hydrothermal system.

1. Introduction

Sediments are usually scarce along the Mid-Ocean Ridges (MOR). However sediments have been discovered in some central valleys along the slow spreading ridges with weak magmatic activities (e.g., Mudholkar et al., 2002; Tucholke and Schouten, 1988). Hydrothermal materials derived from both hydrothermal plumes and from sulfide debris are significant components in these sediments and record the distribution and feature of hydrothermal activities along the ridges (Boström et al., 1969; Bender et al., 1971; Barrett et al., 1987; German et al., 1993; Mills et al., 1993). Sulfide debris occurs in small areas near hydrothermal vents, while particles settling from plumes disperse along or perpendicular to the ridge to the flanks, even to many kilometers away at East Pacific Rise (EPR, Boström et al., 1969; Dymond et al., 1973; Dymond and Veeh, 1975; Dymond, 1981). At the slow spreading ridges, hydrothermal activities are mostly controlled by not only magmatic but also tectonic activities (DeMartin et al., 2007; McCaig et al., 2007; Petersen et al., 2009; Douville et al., 2002) and plumes may be prevented by valley walls (German et al., 1993; Thurnherr and Richards, 2001). Some major vent fields show an association with serpentinite and gabbro exposures and with nearby detachment faults (Gràcia et al., 2000; Tivey et al., 2003; German and Lin, 2004). The distinct hydrothermal process and fluid compositions, the addition of high temperature alteration materials exposed by detachment faults may result in different geochemical compositions of sediments in these regions.

The Carlsberg Ridge (CR) is a typical slow spreading ridge with a half-spreading rate of 13 mm/yr in the northwest Indian Ocean (Murton and Rona, 2015). It is less explored and sampled among the MORs. Hydrothermal activities hasn't been found until a massive event plume between 5°41′N, 61°30′E and 6°20′N, 60°33′E was detected in 2003 (Murton et al., 2006). Then hydrothermal plumes were also discovered at two sites near 3°42′N (Ray et al., 2012) and polymetallic sulfide deposits were collected at this area in 2012 (Tao et al., 2013). However volcanic and hydrothermal input are ruled out in the cores from the central valley and flanks near 3°42′N and the sediments are considered as not metalliferous and devoid of sulfide minerals (Valsangkar et al., 2009). During the cruise 28 of China Ocean Mineral Resources & Association (COMRA), sediments are collected from the northern, central and southern part of the CR. In this article, hydrothermal inputs were identified in these sediment samples and hydrothermal signatures in the CR were discussed and compared with other MORs.

2. Geological setting and samples

The Carlsberg Ridge, the northwestern limb of the Indian Ocean Ridge (IOR) system, begins at the Owen fracture zone near 10°N and

* Corresponding author at: College of Marine Geosciences, Ocean University of China, Qingdao 266100, China.
E-mail address: yuzenghui@ouc.edu.cn (Z. Yu).

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joins the Central Indian Ridge (CIR) near the equator. It is a typical slow-spreading ridge with an average half-spreading rate of 11 to 16 mm/yr (Sempéré and Klein, 1995). The topography developed is of rugged nature with a deep axial valley along the ridge similar to the northern Mid-Atlantic Ridge (MAR). In the northern section sampled for this study (10°N–3°N), only two transform faults separate almost continuous 1000 km long NW-SE trending spreading segments except for some discontinuities with small or zero offsets, which may suggest a more continuous magmatic source beneath these segments (Merkouriev and Sotchevanova, 2003; Tao et al., 2013). However the segments to the north of 8.8°N generally have deeper axial valleys and more asymmetric flanks relative to the south (Murton and Rona, 2015). During the 28th COMRA cruises, 9 core complexes were identified between 10.4°N and 8.8°N and vigorous tectonic extension were also suggested in this zone (Han et al., 2012). In the southern section several segments are separated by both non-transform discontinuities and well-defined transform faults (Kamesh Raju et al., 2008). It is characterized by more negative mean axial Mantle Bouguer Anomaly value than along the northwestern part, which may be due to a combination of hot-spot influence and increasing spreading rate southward (Merkouriev and Sotchevanova, 2003).

The thick sediment cover within the axial valley has been revealed by pseudo-side scan image and retrieved by some cores (Mudholkar et al., 2002). 31 sediment samples were grabbed from 24 sites along the CR during the 26th and 28th COMRA cruises (Fig. 1). Some are from the central valley and some are from the flanks. Due to the sporadic volcanic activities and deep carbonate compensation depth in the Indian Ocean (Peterson and Backman, 1990), biogenic carbonate is the main components and accounts for >30% in 23 of these sediments. They are pale yellow calcareous ooze mixed with rock fragments. Sample S-18 is almost solidified calcareous ooze and covered with a thin black coat. Another five samples (S-29, S-13, S-22, S-37, S-38) are mainly yellow or brown clay with minor calcareous shell. Moreover, varying amount sulfide and amorphous silicon debris (mainly in sample S-22) can often be found in these samples. Sample S-4 is obtained at the north end and is almost all composed of the rock fragments. Sample S-11 is from the same site of S-10 and S-13 and almost all sulfide debris. So these two samples are used for comparison.

3. Methods

Samples were dried at 60 °C firstly and any rock fragments identified were removed except for sample S-4. Then the samples were ground in an agate pestle and mortar.

The samples were mixed with lithium tetraborate ($Li_2B_4O_7$) and melted. Major element concentrations were determined by a PANalytical Axios X-ray Fluorescence Spectrometry at the Australian Laboratory Services (ALS) Chemex Guangzhou Limited Company. The standards used were MRGeo08, GBM908-5 and GBM908-10. The measurement precision was better than 5%.

For trace element and rare earth element (REE) analyses, sediments and geochemical standards (GBW07315 and GBW07316) were dissolved following acid dissolution procedure described in Wang et al. (2014). 40 mg subsamples of the sediment were digested using a mixture of 0.5 ml HNO_3 and 1.5 ml HF in a closed Teflon vessel for 72 h at 130 °C. Then 0.5 ml $HClO_4$ was added and evaporated to dryness; and then dissolved in a mixture of 1 ml HNO_3 and 1 ml pure water for 6 h at 150 °C and diluted to 40 ml with pure water. Measurement for trace elements was carried out at the Institute of Oceanology, Chinese

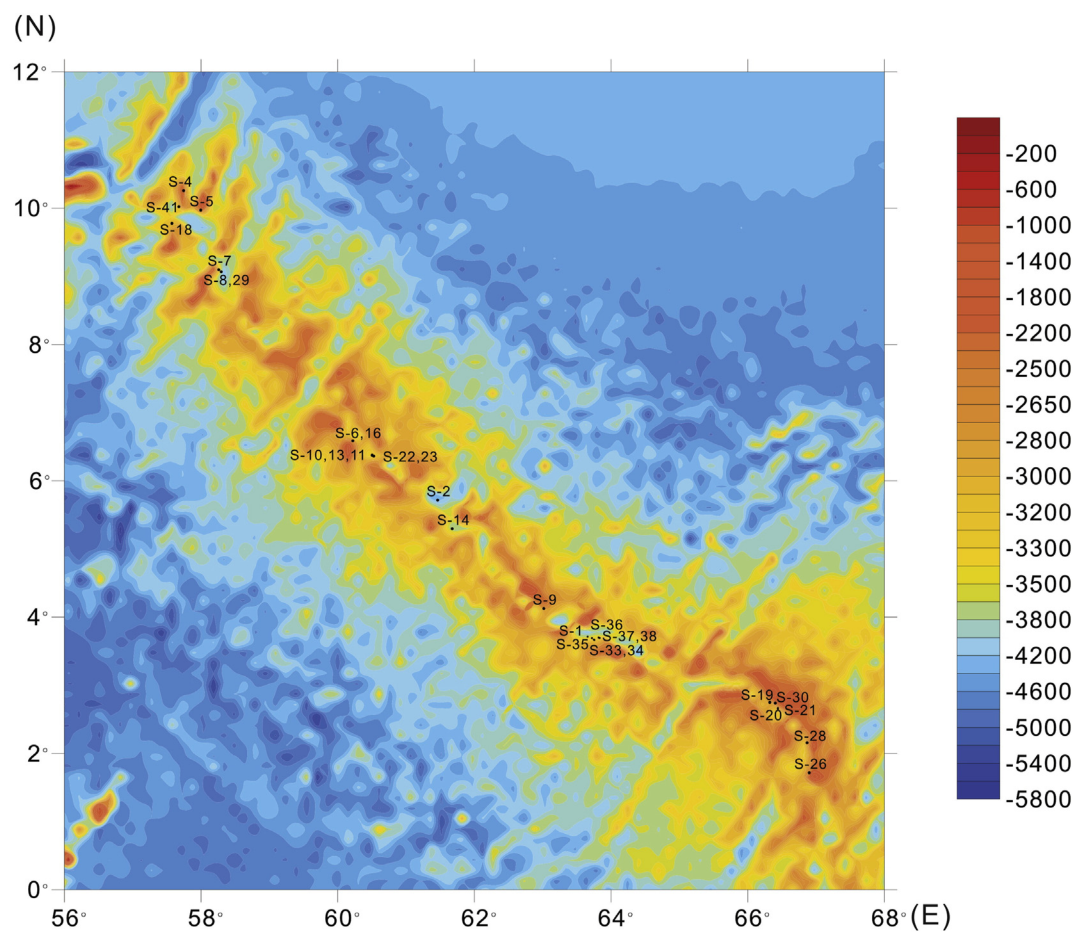

Fig. 1. Bathymetric map along the CR and sample locations. Bathymetric contours are in metres and data are from http://www.ngdc.noaa.gov.