Journal of Marine Systems xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Journal of Marine Systems

journal homepage: www.elsevier.com/locate/jmarsys

Mineralogy, geochemistry, and Sr-Pb isotopic geochemistry of hydrothermal massive sulfides from the 15.2°S hydrothermal field, Mid-Atlantic Ridge

Hao Wang [1], Xiaohu Li *,[1], Fengyou Chu *, Zhenggang Li, Jianqiang Wang, Xing Yu, Dongwei Bi

SOA Key Laboratory of Submarine Geoscience, Second Institute of Oceanography, State Oceanic Administration, Hangzhou 310012, China

A R T I C L E I N F O

Article history:
Received 30 April 2016
Received in revised form 13 February 2017
Accepted 28 February 2017
Available online xxxx

Keywords:
Massive sulfides
Geochemistry
Sr–Pb isotopes
Hydrothermal field
Mid-Atlantic Ridge

A B S T R A C T

The 15.2°S hydrothermal field is located at 15.2°S, 13.4°W within the Mid-Atlantic Ridge (MAR) and was initially discovered during Cruise DY125-22 by the Chinese expedition during R/V *Dayangyihao* in 2011. Here, we provide detailed mineralogical, bulk geochemical, and Sr–Pb isotopic data for massive sulfides and basalts from the 15.2°S hydrothermal field to improve our understanding of the mineral compositions, geochemical characteristics, type of hydrothermal field, and the source of metals present at this vent site. The samples include 14 massive sulfides and a single basalt. The massive sulfides are dominated by pyrite with minor amounts of sphalerite and chalcopyrite, although a few samples also contain minor amounts of gordaite, a sulfate mineral. The sulfides have bulk compositions that contain low concentrations of Cu + Zn (mean 7.84 wt%), Co (mean 183 ppm), Ni (mean 3 ppm), and Ba (mean 16 ppm), similar to the Normal Mid-Ocean Ridge Basalt (N-MORB) type deposits along the MAR but different to the compositions of the Enriched-MORB (E-MORB) and ultramafic type deposits along this spreading ridge. Sulfides from the study area have Pb isotopic compositions (^{206}Pb/^{204}Pb = 18.4502–18.4538, ^{207}Pb/^{204}Pb = 15.4903–15.4936, ^{208}Pb/^{204}Pb = 37.8936–37.9176) that are similar to those of the basalt sample (^{206}Pb/^{204}Pb = 18.3381, ^{207}Pb/^{204}Pb = 15.5041, ^{208}Pb/^{204}Pb = 37.9411), indicating that the metals within the sulfides were derived from leaching of the surrounding basaltic rocks. The sulfides also have ^{87}Sr/^{86}Sr ratios (0.708200–0.709049) that are much higher than typical MAR hydrothermal fluids (0.7028–0.7046), suggesting that the hydrothermal fluids mixed with a significant amount of seawater during massive sulfide precipitation.

1. Introduction

The discovery of modern seafloor hydrothermal vents and associated massive sulfide deposits in 1977 (Corliss et al., 1979; Francheteau et al., 1979; Spiess et al., 1980) has led to the investigation of >300 seafloor vent fields, the majority of which (65%) are located in Mid-Ocean Ridge (MOR) settings (Hannington et al., 2005). However, the search for hydrothermal sites to date has largely been constrained to the northern Atlantic and Pacific oceans, meaning that vast segments of MOR within the South Atlantic, Indian, and Arctic oceans remain virtually unexplored for hydrothermal activity. The majority of known black smoker vents are located on fast-spreading MOR although the largest massive sulfide deposits are located at intermediate- and slow-spreading centers (German et al., 2016). In addition, hydrothermal activity is more long-lived on slow- to intermediate-spreading ridges than within axial deposit settings associated with fast-spreading ridges in the northeastern Pacific. This relates to the fact that slower spreading rates enable the longer preservation of fissures and faults, meaning that hydrothermal fluid pathways can exist for several thousands of years and can generate the generally larger massive sulfide deposits associated with slower spreading ridges (Lalou et al., 1995). This in turn indicates that intermediate- and slow-spreading MOR settings have the potential to host large seafloor massive-sulfide deposits.

The southern Mid-Atlantic Ridge (MAR) forms part of a slow-spreading ridge system that extends from the northern Romanche transform to the southern triple junction at Bouvet Island in the Indian Ocean. This area remains relatively poorly studied, meaning that the geological and geophysical characteristics of this area remain unclear. Six hydrothermal fields between 4°S and 14°S along this ridge have been recently discovered (German et al., 2008; Haase et al., 2009; Koschinsky et al., 2006; Melchert et al., 2008). A hydrothermal field at 15.2°S has been discovered using miniature autonomous plume recorders (MAPR), towed cameras, submarine observations and sampling devices called TV grabs, and remotely operated vehicles (ROVs) during R/V *Dayangyihao* cruises DY125-22 in 2011 (Tao et al., 2011) and DY125-26 in 2012. This hydrothermal field provides an excellent

---

* Corresponding authors.
E-mail addresses: xhli@sio.org.cn (X. Li), chu@sio.org.cn (F. Chu).

[1] The two authors contributed equally to this paper.

http://dx.doi.org/10.1016/j.jmarsys.2017.02.010

opportunity to further our understanding of hydrothermal activity at slow-spreading MORs.

Here, we report new mineralogical, bulk chemical, and Sr–Pb isotopic data for massive sulfide samples and a single basalt sample collected from the 15.2°S hydrothermal field. These data are used to characterize the mineral compositions, geochemical characteristics, hydrothermal field type, and sources of metal associated with this recently discovered vent site.

2. Geological setting

The MAR between the Cardno and St. Helena Fracture zones was explored for hydrothermal activity during two cruises of the R/V *Dayangyihao* (DY125-22 in 2011 and DY125-26 in 2012; Li et al., 2014; Tao et al., 2011; Fig. 1). Previous geophysical studies of the MAR between these major fracture zones yielded an estimated full spreading rate of ~35 mm/yr (DeMets et al., 1994), indicating this is a typical slow-spreading ridge segment. The 15.2°S hydrothermal field is at a water depth of about 2540 m, located at 13.4°W (Fig. 1b), and is situated on top of a young volcanic ridge within the MAR rift valley. The basement rocks collected from this region are predominantly basalts.

3. Sample descriptions and analytical methods

A total of 15 samples (14 massive sulfide and one basalt; Fig. 2a–c; Table 1) were collected by TV grab from the 15.2°S hydrothermal field during R/V *Dayangyihao* cruises DY125-22 and DY125-26. Polished sections of the sulfides were examined under reflected light to characterize the mineralogy and textural relationships. Aliquots of the samples were milled to 200 mesh and were used for X-ray diffraction (XRD), bulk chemical, and Sr–Pb isotopic analyses. XRD analysis was undertaken at the Zhejiang University of Technology, Hangzhou, China, using a Thermo ARL X'TRA diffractometer employing CuKα radiation generated at 45 kV and 40 mA. Bulk chemical analyses were undertaken using a Finnigan Element II inductively coupled plasma–mass spectrometer (ICP–MS) at the State Key Laboratory for Mineral Deposits Research, Nanjing University, Nanjing, China. Details of the approaches used are given by Gao et al. (2003) and the analytical precision of these analyses is better than ±10%, with the majority better than ±5%. Rare earth element (REE) concentrations were measured using an Agilent 7700x ICP–MS at Nanjing FocuMS Technology, Nanjing, China. About 200 mg of powdered sulfide sample was dissolved in high-pressure Teflon vial using a $HNO_3 + HF$ mixture, and using the AG 50W-X8 cation-exchange resin column to remove the matrix elements (e.g., Fe, Zn, Cu, Pb and Ba) before analyze, and the analytical precision of these analyses is better than ±10%.

Whole-rock Rb–Sr and Pb isotopic compositions were determined using a Finnigan Triton TI thermal ionization mass spectrometer (TIMS) at the State Key Laboratory for Mineral Deposits Research, Nanjing University, Nanjing, China. These analyses used the approaches outlined by Pu et al. (2004, 2005) and mass fractionation corrections for $^{87}Sr/^{86}Sr$ were based on $^{86}Sr/^{88}Sr = 0.1194$. Repeated analyses of the NBS-987 Sr standard yielded a mean $^{87}Sr/^{86}Sr$ value of 0.710260 ± 0.000010 (2σ, $n = 30$), with total analytical blanks of 2–5×10^{-10} g for both Rb and Sr. These analyses have an analytical reproducibility of ±0.01% (2σ) for $^{206}Pb/^{204}Pb$, ±0.01% for $^{207}Pb/^{204}Pb$, and ±0.02% for $^{208}Pb/^{204}Pb$. Mass fractionation was calibrated against the NBS-981 standard (Todt et al., 1996).

4. Results

4.1. Mineralogy

Optical microscopy and XRD analysis indicate that the majority of the massive sulfide samples are dominated by pyrite with minor amounts of chalcopyrite and sphalerite, with the exception of samples

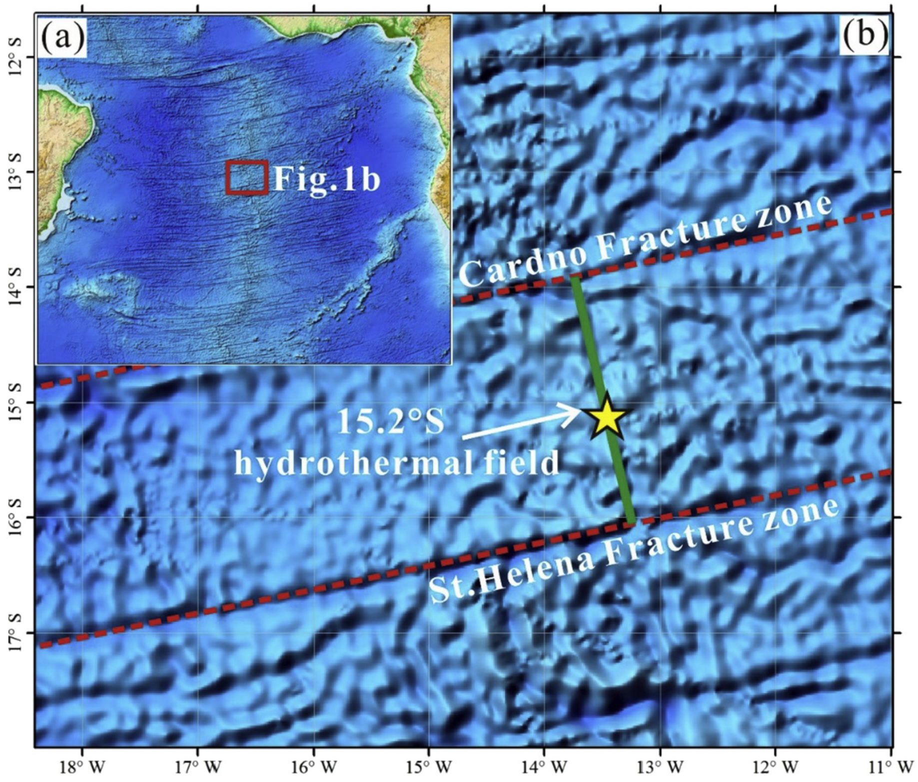

Fig. 1. (a) Bathymetric map of the southern MAR and (b) location of the spreading axis within the southern MAR between 12°S and 18°S.

Please cite this article as: Wang, H., et al., Mineralogy, geochemistry, and Sr-Pb isotopic geochemistry of hydrothermal massive sulfides from the 15.2°S hydrothermal field..., J. Mar. Syst. (2017), http://dx.doi.org/10.1016/j.jmarsys.2017.02.010