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Geochemical and physical structure of the hydrothermal plume at the ultramafic-hosted Logatchev hydrothermal field at 14°45′N on the Mid-Atlantic Ridge

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ABSTRACT

The hydrothermal plume generated in deep waters above the Logatchev hydrothermal field (LHF) about 15°N on the Mid-Atlantic Ridge was investigated and mapped for its 3D distributions using a combination of in situ optical light scattering data, temperature and salinity data, as well as concentrations of hydrogen, methane, total dissolvable Fe, and total dissolvable Mn. Based on the results obtained for these meaningful parameters, we report the geochemical and physical characteristics of the fluids expelled from the ultramafic LHF and the chemical structure of its hydrothermal plume in the water column.

The hydrothermal plume is sourced by at least seven distinct vent sites and possibly additional diffusive fluid and gas discharge. It comprises a water body characterized by strong nephelometric anomalies (expressed as ΔNTU, nephelometric turbidity units) and high concentrations of Fe and Mn (>5 times seawater concentration), and the gas plume with several times the H_2 and CH_4 concentrations of normal seawater. Up to three plume levels with a total vertical extension of about 350 m from the seafloor were classified in the hydrothermal plume. The ΔNTU plume could be followed to approximately 2.5 km to the north and to the south from the vent site while the gas plume spread several km farther from the hydrothermal source. High concentrations of H_2 (up to 1598 nmol l^{-1}) and CH_4 (up to 323 nmol l^{-1}) accompanied by relatively low dissolvable Fe concentrations (up to 270 nmol l^{-1}) as well as low concentrations of dissolvable Mn (112 nmol l^{-1}) compared to basaltic hydrothermal systems are the characteristics of the plume. The low metal/gas ratios showed a decrease with increasing distance from the vent site. Our data demonstrate that ultramafic systems such as the LHF serve both as sources and sinks for elements, with respect to metal and gas inputs into the oceanic water column. The relevance of such systems is underlined by the discovery (and postulated frequency) of further ultramafic-hosted hydrothermal systems on slow-spreading ridges.

1. Introduction

Because the plumes generated in near-seafloor waters from hydrothermal vent systems integrate the chemical and thermal signals (e.g. Lupton et al., 1993; Lupton, 1995; Lilley et al., 1993, 1995; Aballéa et al., 1998), their physico-chemical characterization provides information about the composition of fluids in the subsurface without the need for seafloor sampling. The elements and chemical compounds discharged into the water column reflect the composition of emanating fluids and, thus, type and composition of the host rock. The extent and structure of a hydrothermal plume depends on i) the temperature and mass flux of the emanated fluids and particles, ii) the strength and direction of the near-seafloor current, and iii) the morphology of the seafloor (e.g. Thomson et al., 1992). At active hydrothermal vent sites anoxic hot fluids emanate from the seafloor and mix with oxygenated bottom water. This mixing initiates a range of chemical reactions including mineral precipitations as the plume rises tens to hundreds of metres into the water column. Hydrothermal discharge from high-temperature vent sites (both basaltic and ultramafic systems) is significantly enriched in volatiles (e.g. H_2, He, CH_4, and CO_2) and dissolved metals (Fe and Mn; Lilley et al., 1995) compared to seawater. As the plume disperses laterally with the currents, it undergoes continuous dilution and chemical reactions. These include oxidation of Fe^{2+}, Mn^{2+}, H_2, and CH_4, as well as sorption of metals on freshly formed precipitates and fallout of plume particles (e.g. Feely et al., 1994). The resulting Fe and Mn-oxides and oxyhydroxides create turbidity in the water column, which for instance can be analysed by light backscattering (Section 3).

Basaltic and ultramafic influenced systems are frequently found. Fluids from basaltic-hosted vent fields are characterized by high

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concentrations of dissolved and particulate metals and low concentrations of gases (e.g. Charlou et al., 1991; Charlou and Donval, 1993; James et al., 1995; Lalou et al., 1990; Rudnicki and Elderfield, 1993; Von Damm, et al., 1998), while high concentrations of gases and relatively low concentrations of metals characterize fluids from vents associated with ultramafic mantle rocks. Except for the Rainbow hydrothermal field on the Mid-Atlantic Ridge (MAR; e.g. Edmonds and German, 2003; Charlou et al., 2002; Douville et al., 2002; German et al., 1996) and some studies at the Logatchev hydrothermal field (LHF; Douville et al., 2002; Schmidt et al., 2007) little is known about the role of ultramafic rocks in modifying the composition of vent fluids.

The goal of this study was to record the three-dimensional extent and the temporal variability of the chemical composition, and the physical characteristics of the plume created in the water column above the active ultramafic-hosted LHF at 14°45′N on the Mid-Atlantic Ridge (MAR). Here we present detailed geochemical studies of the plume by displaying the chemical composition and temperature distribution within the hydrothermal plume. In order to determine the spatial extent and chemical and thermal structure, plume mapping was carried out during cruise M64/2 (May 2005) with the German R/V Meteor, using the MAPR and CTD equipment (Section 3). Measurements comprised in situ turbidity as well as ex-situ analysis of Eh, dissolved H_2, CH_4, total dissolvable Mn, and Fe (TDM and TDF). Some of the Mn and Fe data were collected on cruise M60/3 (January 2004).

With the knowledge of the physico-chemical specifics of the plume, the chemical composition of the sourcing fluids can be evaluated and compared to plume characteristics from other hot vent sites. In addition, such information contributes to the understanding of the chemical fate of elements expelled from ultramafic hydrothermal systems into the ocean. These systems are expected to be a common feature of slow-spreading ridges, such as the MAR. More than 90% of this approximately 10,000 km long ridge system are still unexplored, but fluid data indicate the existence of high-temperature ultramafic systems also on the southern MAR (Koschinsky et al., 2006; Keir et al., 2008).

2. The Logatchev hydrothermal field

The LHF is located on the MAR with its centre at 14°45.20′N and 44°58.75′W, at approx. 3000 m water depth (Fig. 1). It was discovered by Russian scientists in 1991 (Bogdanov et al., 1995) based on findings of Klinkhammer et al. (1985), who reported a number of hydrothermal plumes along a 1700 km long section of the MAR. In the course of the explorative study by Klinkhammer et al. enhanced Mn concentrations in the water column originating from hydrothermalism on the rift valley were observed and led to the discovery of vent systems on the MAR, amongst other the LHF. The entire LHF is located 35 nautical miles to the south of the Fifteen–Twenty Fracture Zone (at 15°20′ on the MAR). It is situated on a plateau between 3050 m and 2950 m water depth near the eastern slope of the rift valley and extends at least 800 m along a NW–SE and 400 m along a SW–NE direction (Kuhn et al., 2004). During our cruises it comprised several highly active vent sites (see below).

The LHF is hosted in ultramafic rocks within steeply faulted blocks of peridotites (harzburgite), pyroxenites and serpentinites, which have undergone serpentinization to various degrees (Augustin et al., 2008; Sharapov and Simonov, 1991). Basalt pillows are common in the western slope of the median rift valley. Most of the area is covered by carbonate sediments with sulphide patches (Sudarikov and Roumiantsev, 2000). The LHF itself is characterized by two types of venting (Douville et al., 2002; Schmidt et al., 2007). High-temperature fluids (up to 365 °C) creating "black smoke" in the water column due to sulphide precipitation are discharged from both, massive chimney-like structures and from crater-like depressions associated with sulphide chimneys. Low-temperature fluids (up to 30 °C) emanate from diffuse vents throughout the field. Several high-temperature

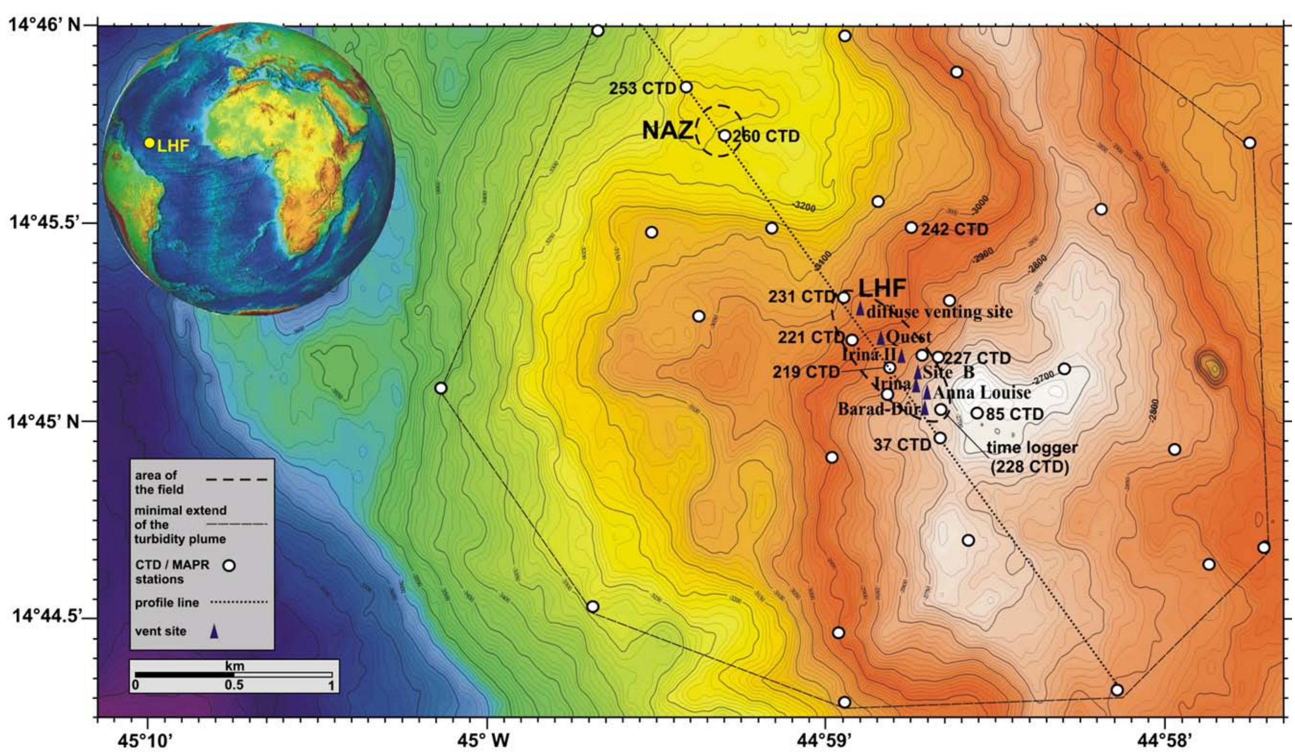

Fig. 1. Bathymetric map of the area around the LHF (with its individual vent sites) and the northern anomalous zone (NAZ) with CTD and MAPR stations (white dots). The inset shows its location on the northern Mid-Atlantic Ridge. The dashed line surrounding the area marks the zone where a ΔNTU anomaly was recognized. Dashed circles around the LHF and the NAZ show zones, where high ΔNTU signals were observed in near-bottom waters. The dotted line through these zones indicates the orientation of the vertical profiles shown in Figs. 6 and 8. Triangles indicate individual vent sites within the LHF area.