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Hydrothermal activity along the slow-spreading Lucky Strike ridge segment (Mid-Atlantic Ridge): Distribution, heatflux, and geological controls

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ABSTRACT

We have reviewed available visual information from the seafloor, and recently acquired microbathymetry for several traverses across the Lucky Strike segment, to evaluate the distribution of hydrothermal activity. We have identified a new on-axis site with diffuse flow, Ewan, and an active vent structure ∼1.2 km from the axis, Capelinhos. These sites are minor relative to the Main field, and our total heatflux estimate for all active sites (200–1200 MW) is only slightly higher than previously published estimates. We also identify fossil sites W of the main Lucky Strike field. A circular feature ∼200 m in diameter located on the flanks of a rifted off-axis central volcano is likely a large and inactive hydrothermal edifice, named Grunnus. We find no indicator of focused hydrothermal activity elsewhere along the segment, suggesting that the enhanced melt supply and the associated melt lenses, required to form central volcanoes, also sustain hydrothermal circulation to form and maintain large and long-lived hydrothermal fields. Hydrothermal discharge to the seafloor occurs along fault traces, suggesting focusing of hydrothermal circulation in the shallow crust along permeable fault zones.

1. Introduction and geological setting

Hydrothermal activity along mid-ocean ridges controls cooling of the oceanic lithosphere, and impacts its thermal structure and the processes operating there (e.g., magmatic emplacement, faulting, seismicity, diking and melt delivery to the seafloor). Understanding the distribution of hydrothermal activity and its nature is necessary to quantify the associated heatflux, its partition between diffuse and focus flow recognizable at the seafloor, and to evaluate the amount of cooling with no expression at the seafloor (e.g., conductive cooling or low-temperature, diffuse percolation).

Slow spreading ridge sections with significant melt supply typically define linear ridge segments with lengths of a few tens of kilometers to up to ∼100 km. These segments typically develop ridge-parallel normal faults on both flanks, and thick crust at their center indicating melt-focusing along-axis. As in the case of the Lucky Strike segment, sustained volcanism may lead to the development of central volcanoes (Escartín et al., 2014). The slow-spreading Lucky Strike segment is unique in that it has been extensively studied during more than two decades, following the discovery of the Lucky Strike hydrothermal field, from hereon referred to as the Main Lucky Strike hydrothermal field (MLSHF), located at its segment center and at the summit of the central volcano (Langmuir et al., 1997). This is one of the most extensive hydrothermal fields discovered to date, and it is located along a recent graben dissecting the Lucky Strike central volcano (Humphris et al., 2002; Ondréas et al., 2009; Barreyre et al., 2012; Escartín et al., 2014). Water-column studies have also revealed hydrothermal plumes at greater depths than that of the MLSHF

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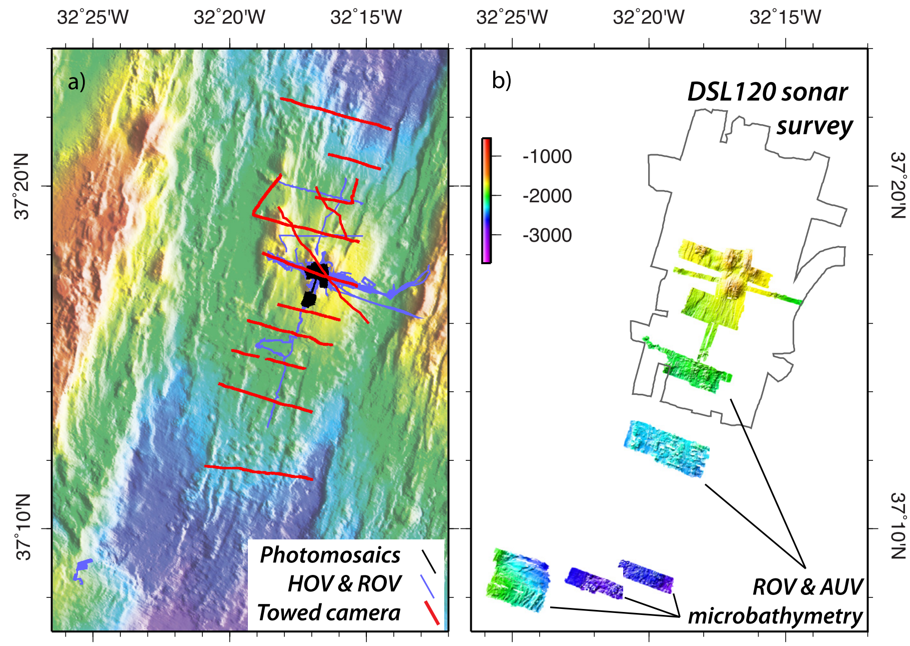

Fig. 1. a) Visual information of the seafloor is available from ROV photomosaics, and along tracks of HOVs, ROVs, and deep-towed cameras. b) Available microbathymetric data from the Lucky Strike ridge segment, acquired during near-bottom ROV and AUV surveys (Momareto'06 and MOMAR'08 and Bathyluck'09 cruises). The outline of the DSL120 sonar survey, acquired during the Lustre'96 cruise, is also shown. See Supplementary Table 1 for additional details on these cruises, the deep-sea vehicles deployed, and types of data acquired.

(Wilson et al., 1996; German et al., 1996; Thurnherr et al., 2008). These authors proposed a yet unidentified source at the southern end of the segment and at a depth of 2000 m.

A ∼3–3.5 km deep magma chamber (Singh et al., 2006) at the base of a ∼600 m thick Layer 2A (Seher et al., 2010) underlies the MLSHF (Fig. 2). Major faults within the rift valley (Escartín et al., 2014) can be linked to fault reflectors that do not reach the magma chamber depth in seismic reflection profiles (Combier et al., 2015). Microseismicity below the hydrothermal field (Crawford et al., 2013) is unrelated to these fault reflectors, and likely corresponds to hydrothermal cooling instead (Fig. 3).

In this paper we provide a synthesis of available information along the Lucky Strike ridge segment, from seafloor observations and imagery to microbathymetric and acoustic data (Fig. 1). We analyze these data to identify and map new hydrothermal sites, and use other observables (presence of a magma chamber, microseismicity, faulting) to constrain the processes controlling distribution and location of hydrothermal activity along this segment, to re-evaluate heat fluxes at the segment scale, and to discuss the implications for heat extraction and magmatic supply. Finally, we review evidence of hydrothermal activity along the segment based on water-column studies.

2. Data and indicators of hydrothermal activity at the seafloor

The Lucky Strike area has been targeted by numerous cruises in the last 25 years, providing extensive visual information from direct human observations, video imagery, and electronic still-camera images acquired with human-operated vehicles (HOVs), remotely operate vehicles (ROVs), and deep-towed camera systems. These visual observations are complemented with near-bottom high-resolution bathymetry data acquired both with ROVs and Autonomous Underwater Vehicles (AUVs) during cruises in 2008 and 2009, in addition to a prior deep-towed sonar survey (Scheirer et al., 2000; Humphris et al., 2002; Escartín et al., 2014), as summarized in Fig. 1 and Supplementary Table 1. Near-bottom ROV and AUV bathymetry data have a resolution of several decimeters to a few meters per pixel, depending on survey altitude, and provide detailed information on the seafloor texture that can be used to discriminate between hydrothermal structures (e.g., hydrothermal mounds and chimneys, Fig. 2) from other structures whose origin is instead volcanic (e.g., hummocks, lava channels and flows), tectonic (e.g., faults, fissures), or related to secondary mass-wasting processes (e.g., landslides along fault scarps).

2.1. Visual observations

The bulk of the field work involving visual observations at the seafloor focuses on the MLSHF, which is yearly visited since 2008 (MoMAR08) and is instrumented for monitoring since 2010 as part of the MOMARSAT European Multidisciplinary Seafloor and water column Observatory (EMSO) deep-sea seafloor observatory (Colaço et al., 2011). In this study we use imagery and visual observations along with HOV, ROV, and deep-towed camera systems (Fig. 1a) that extend both along the Lucky Strike segment, and across the full rift valley width (Fig. 1a), and present large-area seafloor photomosaics from vertically-acquired imagery. The first systematic survey of the MLSHF was conducted with ARGO II towed-camera in 1996 (Humphris et al., 2002; Escartín et al., 2008). Subsequent surveys conducted with the ROV VICTOR low-light camera covered fully the MLSHF (Barreyre et al., 2012), extending beyond prior surveys, and south along the ridge axis (Fig. 1). Vertical imagery was processed into a single georeferenced seamless giga-mosaic. Details on the ARGO II and OTUS image surveys at MLSHF, and on image processing and mosaicing are provided elsewhere (Escartín et al., 2008; Barreyre et al., 2012; Prados et al., 2012); here we present for the first time the 2009 photomosaic ∼1 km south of the MLSHF.

Active hydrothermal sites are readily identifiable visually from venting fluids (high-temperature black smokers and clear-fluid vents, diffuse outflow at lower temperatures), hydrothermal macrofauna and microbial communities (e.g., bacterial mats and mussel beds), or white anhydrite deposits that require venting temperatures of 120–150 °C (Bischoff and Seyfried, 1978). These visual features have been used to extensively map the MLSHF