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The Rainbow hydrothermal plume, 36°15'N, MAR

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Abstract. The Rainbow hydrothermal plume was discovered during a recent geophysical survey along 200km of the Mid-Atlantic Ridge (MAR), SW of the Azores Triple Junction, in which at least seven new sites of hydrothermal activity were identified. Here, we present the first hydrographic study of the Rainbow plume, 36° 15'N, the strongest of the features located during that survey. The plume is detectable from real-time *in situ* nephelometer anomalies and extends 10-15km, W-E, in a non-transform discontinuity (NTD) between two adjacent ridge-segments. Maximum anomalies in the Rainbow plume indicate particle enrichments at least as large as those seen directly above the Trans Atlantic Geotraverse (TAG) vent-field (26°N, MAR). Analysis of hydrographic data indicates a vent source at Rainbow with a thermal output of up to 98 MW, representing 140% of the thermal output previously attributed to TAG. Both lines of evidence indicate the Rainbow plume to be the strongest such feature yet found on the MAR.

Introduction

High concentrations of metal-rich sulphide and oxide particles precipitate when "blacksmoker" hydrothermal fluids issue from the seabed [Feely et al., 1987; Mottl & McConachy, 1988]. These particles are carried upward by the turbulent plume, which mixes progressively with the surrounding water column as it rises, until some level of neutral buoyancy is attained [Lupton et al., 1985]. Because the resultant plume remains strongly enriched in suspended particulate matter relative to the ambient deep ocean, optical sensors can be used to provide real time *in situ* information on the location and lateral extent of these plumes [e.g. Baker et al., 1995].

In recent work, a 25cm SeaTech transmissometer was fitted to the SOC (Southampton Oceanography Centre) deeptow sidescan sonar instrument TOBI (Towed Ocean Bottom Instrument) and returned signals indicative of particle-rich hydrothermal plume layers, coregistered with acoustic images of the underlying seafloor, at seven discrete tectonic settings along the MAR, 36-38°N [German et al., 1996]. The most pronounced signals recorded from that work were situated at ~36°15'N in the NTD between the AMAR (American Mid-Atlantic Ridge) and AMAR Minor segments [Detrick et al., 1995]. Evidence for hydrothermal activity at this location was first identified when TOBI was towed through a particle-rich layer of water, 1900-2100m depth, between 36°18'N and 36°14'N - the Rainbow hydrothermal plume [German et al., 1996]. Here, we present results from a CTD-nephelometer study which provides a direct intercomparison of this feature with other, well-characterised hydrothermal plumes.

Methodology

The instrument package used comprised a Neil Brown MkIII CTD equipped with a Chelsea Instruments MkII

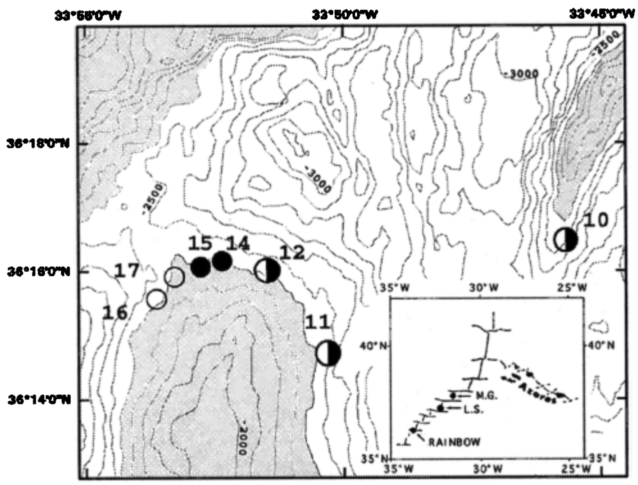

Fig.1 Bathymetric map of the Rainbow hydrothermal area, 36°15'N, MAR showing stations 10-12 (half-filled circles: dispersed plume signals), 14 & 15 (solid circles: strong plume signals) and 16 & 17 (open circles: background signals). Bathymetry is given in 100m contours and all depths shallower than 2400m are demarcated by light shading. The western wall of the MAR rift-valley is seen in the NW corner of the figure. Two relict blocks within the offset are represented by shaded areas in the NE and SW corners, the more southwesterly of these being Rainbow Ridge. *Inset:* schematic location map of the Rainbow area, Azores Triple Junction and Menez Gwen (MG) and Lucky Strike (LS) hydrothermal fields.

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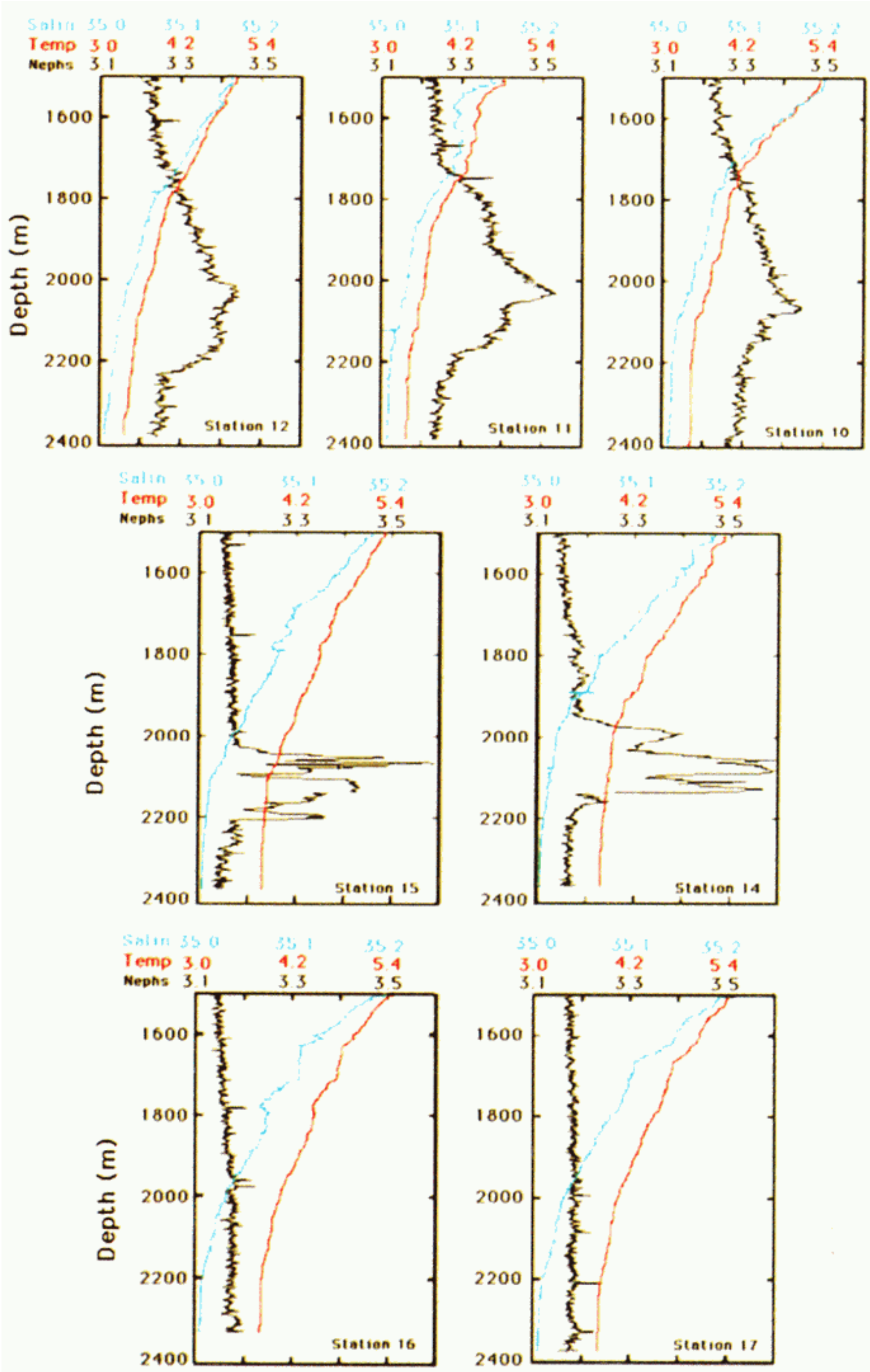

Fig.2 Vertical profiles of temperature, salinity and nephelometer voltage at CTD stations 10-12, east of Rainbow Ridge; 14 & 15, north of Rainbow Ridge; 16 & 17, west of Rainbow Ridge. High nephelometer voltages above open-ocean background values indicate layers of water with increased concentrations of suspended particulate matter, characteristic of deep-ocean hydrothermal plumes.

Nephelometer. The same instrument package has been used previously to investigate the TAG, Broken Spur and SnakePit hydrothermal plumes [Rudnicki et al., 1994; James et al., 1995]. Thus, our methodology permits for a direct intercomparison between the Rainbow plume and these other, well-characterised, hydrothermal areas. The instrument package was lowered vertically beneath the ship whilst holding station using GPS navigation. Calm weather permitted ship's position to be maintained to within 360m of target locations in all cases and, exceptionally, to within <50m.

Results

A total of seven CTD stations were occupied during RRS *Charles Darwin* cruise CD89-90, September 1994. Their locations are shown in Fig.1, (bathymetry courtesy of H.D.Needham, IFREMER). Initially, temperature,

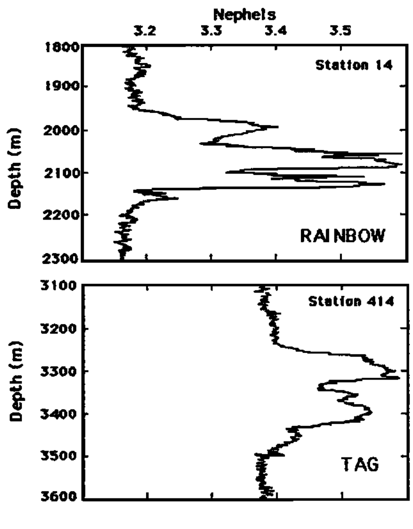

Fig.3 Vertical nephelometer profiles for station 14 (this study) and TAG [Rudnicki et al., 1994] (see text for discussion). The offset in background readings for the two profiles is understood to be due to clouding of the nephelometer lenses during the TAG [Rudnicki et al., 1994] study.

salinity and nephelometer profiles were collected at stations 10 and 11, which demarcate the section of TOBI transect along which transmissometer anomalies were originally identified, and at station 12. Pronounced nephelometer anomalies were observed at all three stations (Fig.2) and close similarities are seen in the profiles, both in terms of maximum nephelometer measurements and also in the approximate depth at which maximum particle anomalies are observed. These three profiles, with their similar signals, are observed over a distance of ~12km. This is surprising, because previous studies of the TAG and Steinahóll hydrothermal plumes, MAR 26°N and Reykjanes Ridge, 63°N [[Rudnicki & Elderfield, 1993; German et al., 1994] have failed to yield detectable hydrothermal plume signals at distances greater than 3-5km away from their source. Subsequent plume observations were recorded from stations 14 and 15, occupied 1-2 km west of station 12 in water depths of ~2400m (Fig.1). These two profiles yielded even more pronounced nephelometer anomalies (Fig.2). Further, plume structure at stations 14 and 15 indicated multiple discrete layers of particle-rich and particle-free water, unlike stations 10-12 which exhibited single broad maxima. Occupation of two further CTD stations, 16 and 17, 1-1.5km further west, revealed no detectable nephelometer anomalies at all (Fig. 2).

Discussion

The nephelometer profiles presented above, combined with the TOBI/transmissometer anomalies reported previously [German et al., 1996], are consistent with a single hydrothermal plume advecting from west to east away from a source which is located close to CTD stations 14 and 15 but to the east of stations 16 and 17. The profiles at stations 14 and 15 indicate that thin (10-20m thick) layers of particle-laden water exist, overlying almost completely particle-free open ocean water. With time, hydrothermal particles would be expected to sink from shallow, particle-rich layers into deeper, particle-free parcels of water, thereby eliminating the fine, layered structures currently observed. Therefore, the station 14 and 15 profiles must represent data collected from close to a hydrothermal vent-source because particle settling has yet to exert a significant effect. By contrast, nephelometer profiles from stations 12-10 exhibit smoother, more coalesced profiles. We interpret these to represent profiles from more distal portions of the same hydrothermal plume, at increasing distances from a common source, where particle settling has led to a more homogenised hydrothermal plume. The near-constant plume-height for maximum particle anomalies at *all* stations (2000-2100m) is also consistent with the argument that these profiles represent different portions of a common, laterally-advecting plume.

Prior work has already established TAG as the strongest hydrothermal plume yet known along the Mid-Atlantic Ridge [Rudnicki et al., 1994; James et al., 1995]. In Figure 3, nephelometer signals observed from CTD 14 at Rainbow are compared with the strongest signals yet collected from TAG [Rudnicki et al., 1994]. The TAG profile was collected during a 9-hour time series study directly above the known vent-site at TAG which also intercepted the *buoyant* hydrothermal plume. By contrast, data from this study were collected without knowledge of the precise location of venting on the seabed. Any maximum plume signals reported here, therefore, should be considered as *minimum* estimates of what would be observed directly above the Rainbow plume's source. Despite this, the nephelometer signal at station 14 is at least as high as the highest signals recorded previously at TAG (Fig.3). This provides immediate, empirical evidence that the Rainbow hydrothermal plume must be at least as strong as that at TAG.

A more quantitative measure of the Rainbow plume's strength can be achieved from a consideration of the hydrographic data. A simple mathematical model can be used to estimate the thermal flux needed to produce a hydrothermal plume at a given level of neutral buoyancy within a stratified water column [Speer & Rona, 1989]. A revised version of this model, which quantifies plume data against background CTD profiles, has recently been applied to predict a total output of 70 MW for the TAG hydrothermal plume [Rudnicki et al., 1994]. Here, we apply the same model to Rainbow hydrothermal plume data. We use CTD stations 16 and 17 to define "background" temperature and salinity profiles (Fig.2) and assume the depth for our source of venting to be 2400m - the recorded water depth at stations 14 and 15. Then, using the plume heights at which maximum nephelometer anomalies are recorded (2040m and 2060m) the model predicts thermal outputs of 63MW and 98 MW, representing 89% and 140% of the thermal output previously calculated for TAG. These results provide independent confirmation for the strength of the Rainbow plume relative to other MAR hydrothermal fields.

Features comparable to the Rainbow plume are not uncommon, however, along the faster-spreading East Pacific Rise (EPR) and Juan de Fuca Ridge (JdFR). Plume studies from the JdFR, have calculated maximum heat fluxes from individual vents of up to 50MW with total segment-scale heat fluxes estimated at 66-239MW [Bemis et al., 1993]. Further, neutrally-buoyant plumes overlying the Endeavour and Cleft segments (JdFR) commonly exceed 10-15km in extent [Thomson et al., 1992; Baker, 1994]. Studies from the EPR, 9-11°N, have detected continuous plume signals for up to 55km along axis [Baker et al., 1994] whilst along the southern EPR (17°30'-18°40'S) continuous plumes in excess of 100km along-axis have been detected [Urabe et al., 1995]. Nevertheless, the Rainbow hydrothermal plume remains unique to the MAR in both source strength *and* lateral persistence.

Conclusions

The RAINBOW hydrothermal plume represents the strongest such feature yet reported from the MAR. Particle concentrations at plume height are at least as great as at TAG, and the distance over which the plume is advected, 10-15km, is much more pronounced than any other MAR hydrothermal field. Preliminary modelling, based on simple plume theory, predicts a thermal output for the Rainbow plume of up to 98MW, representing 140% of the thermal output previously calculated for the TAG hydrothermal field. This further emphasises the apparent strength of the Rainbow hydrothermal plume because TAG had previously been considered to be the largest known vent-site on the MAR.

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