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# Taking the temperature of the Lucky Strike area

***Luckyflux Science Party:***
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**Introduction and geological setting**

The Mid-Atlantic Ridge south of the Azores Island shows a large bathymetric and gravity gradient associated with the effect of the nearby Azores hotspot. The portion of the ridge between ~35°N and 39°N is oblique to spreading, with several segments hosting hydrothermal vent sites occurring **o**ver a wide range of depths (from <1000m to >3000 m) and hosted both in basalt and peridotite. This area is also the MOMAR (**MO**nitoring the **M**id **A**tlantic **R**idge) site selected by InterRidge for implementing long-term observations, due to the variety of hydrothermal vent sites and slow-spreading segments found in the area. The Lucky Strike vent field, located at the summit of a central volcano along the Lucky Strike segment (Fig. 1)**,** is one of the primary investigative objectives of the MOMAR. Quantification of heat flow and constraints on hydrothermal circulation in the MOMAR area in general, and the Lucky Strike segment in particular, is an important component to understand the mode of heat loss in the area and the mechanisms driving and influencing lithospheric cooling in proximity to the ridge axis. These studies require a first-order, regional study of the region prior to more localized, long-term observations at or near the hydrothermal areas. While good bathymetric and gravity coverage of the area (Cannat *et al.*, 1999; Escartín *et al.*, 2001), as well as detailed studies of the Lucky Strike system exist (Humphris *et al.*, 2002), there is little information on the thermal state of the area, the mode of fluid flow in the crust and sediments, and the rate of cooling of the lithosphere in this area.

The ‘ Lucky Flux ’ project that we report in this note is part of this effort, and has been initiated with a cruise to conduct heat flow measurements around the Lucky Strike segment, both near- and off-axis. While some recent detailed studies exist in fast-spreading crust (*e.g.*, Fisher *et al.*, 2003), these data represent one of the most comprehensive studies of the heat flow in young (<10 Ma) oceanic lithosphere formed along a slow-spreading ridge. Older data along a non-transform offset in the FAMOUS area (Williams *et al.*, 1977) just south of Lucky Strike (Fig. 1), have suggested that this zone could be the locus of intense hydrothermal circulation. These early data were obtained with short probes (1-2.5 m) and were possibly affected by ocean bottom temperature fluctuations. The Lucky Strike area is located in the immediate vicinity of the Africa-America-Eurasian plate triple junction, and is characterized by two V-shaped ridges that emanate from the Azores Islands, propagating southwards. These ridges record the southward propagation of a magmatic pulse that initiated at ~14 Ma at the Azores hotspot, which weakened with time, and that is not visible at the present time. The seafloor at these ridges rises to <1000 m above the surrounding seafloor, is associated with crustal thickness that locally exceeds >12 km, and is characterized by lack of faulting and numerous volcanic edifices (Cannat

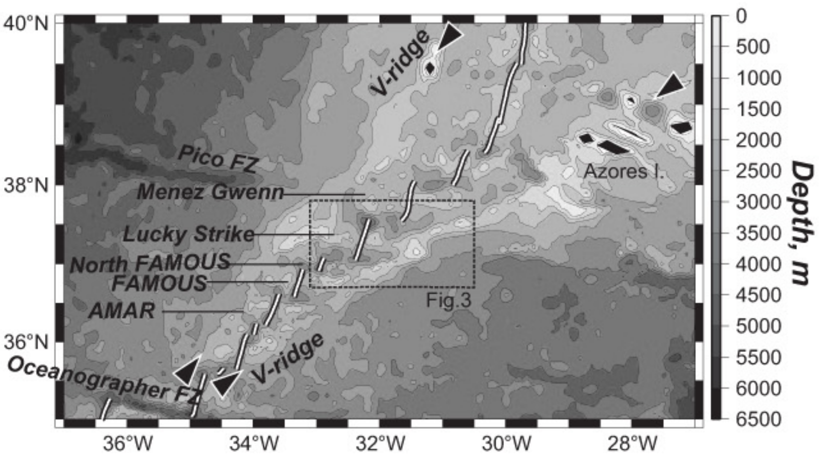


**Figure 1.** Location map of the study area South of the Azores hotspot. Double lines mark the ridge axis segmentation, with the names of the different segments indicated. The triangles indicate the ends of 2 V-shaped ridges (*e.g.* Cannat et al., 1999) that emanated from the Azores hotspot >10 Myrs ago. Bathymetry from Smith and Sandwell (1997).

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*et al.,* 1999; Escartín *et al.*, 2001). The seafloor within the V-shaped ridges has a typical slow-spreading texture, with numerous axis-parallel faults, and a sediment cover that shows significant variations in thickness both along- and across-axis. Outside the V-shaped ridges the oceanic crust is blanketed by a smooth 200-400 m thick sediment layer, with very few and partially sedimented basement outcrops.

**The « LuckyFlux » cruise**

The « Lucky Flux » cruise took place between June 11th and July 1st 2003, in and out of Ponta Delgada (Azores, Portugal). This project is financed by CNRS-INSU, and was carried out onboard *R/V Poseidon* (Germany), as part of an exchange program of ship time between France and Germany. We performed a total of 186 penetrations of the heat flow probe, and we obtained more than 150 heat flow measurements. We also deployed 3 NOAA PMEL MAPRs (Miniature Autonomous Plume Recorders) in collaboration with Ed Baker, to obtain nephelometry profiles during the deployment of the heat flow probe.

*Heat flow Probe*

The heat flow probe deployed (Fig. 2), which was originally designed and operated by R. Von Herzen and colleagues at Woods Hole Oceanographic Institution during the 70's through the 90's, is operated by the Laboratoire de Geosciences Marines (IPGP). The 5-m long probe was equipped with 7 thermistor and heater wire sensors, and with two pressure cases hosting the batteries, acoustic transmission system, and the measurement circuitry. The probe is programmed to perform a measurement cycle (~15 min duration) after each penetration (temperature measurements, continuous heating for thermal conductivity measurements, and measurement of the near-bottom water temperature). Battery and memory capacity allows for deployments of up to 70 hours, and the probe is operated in a 'pogo' mode during each deployment.

**Figure 2**. Deployment of the heatflow probe during the LuckyFlux cruise. The 1-Ton weight holds the acquisition and power supply system. The thermistors protruding from the 7-m long probe are also visible.

*MAPR*

We deployed 3 NOAA PMEL autonomous nephelometry-temperature-pressure recorders (MAPR; Baker and Milburn, 1997) during the heat flow probe lowerings in proximity to the ridge axis. These instruments were loaned by NOAA PMEL to carry out the measurements in cooperation with Ed Baker. In each lowering a MAPR was placed 50 m above the heat flow probe. In the lowerings performed the MAPRs functioned properly, but we identified no nephelometry anomaly in the water column that may be associated with hydrothermal plumes.

*Heat flow Profiles*

Heat flow measurements were conducted along profiles with a spacing of ~1 mile, both near-axis (within the v-shaped ridge) and off-axis, over older sedimented seafloor East of the ridge axis (Fig. 3). Measurements were restricted to areas with sufficient sediment cover, as indicated by 6-channel and 3.5 kHz seismic profiles from the *Sudaçores'98* cruise (Cannat *et al.*, 1999).

***Off axis heat flow profiles*** (A-B, C-D, O-P). One of profiles followed the ~10 Ma isochron as interpreted from the Sudaçores magnetic data (*Cannat et al.*, 1999; Escartín *et al.*, 2001), sub-parallel to the overall

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trend of the ridge axis. Two additional profiles were conducted along flow-lines, between the isochron profile and the outer base of the V-shaped ridge (Fig. 3).

***Near-axis heat flow profiles*** (E-F, G-H, K-L, M-N). Due to the irregular distribution of sediments, the rugged terrain, and the available data, we restricted our axial heat flow measurements to the outside corner crust at each side of the ridge axis (Fig. 3). The sediment thickness decreases from the outside corners towards the inside corners, and sediments are almost absent at the axial valley. We obtained useful data along 6 axis-perpendicular profiles, following existing seismic profiles from the *Sudaçores* cruise, and one profile subparallel to the axis. Due to the presence of rocks and the rugged terrain, we were unable to complete and obtain profiles with regularly spaced measurements for the 2 profiles west of Lucky Strike (K-L, M-N, Fig. 3).

**Preliminary results**

The off- and near-axis oceanic crust show distinct heat flow patterns, probably due to the presence of the V-shaped ridge, and the difference in the geometry, thickness and continuity of the sediment cover. Below we present preliminary results, and updates on work related to LuckyFlux will be available at: *http://www.ipgp.jussieu.fr/rech/lgm/luckyflux*

*Near axis*

The near-axis profiles are located in outside-corner crust at the end of the segment, between the rift-bounding fault and the inner limits of the V-shaped ridge. Seafloor ages interpreted from the *Sudaçores'98* magnetic data are between ~1.5 and 4.5 M.y. (see Fig. 5 in Escartín *et al.,* 2001). Measured values are in general ~30% or less of those theoretically expected for these seafloor ages (Stein and Stein, 1992). Heat flow stations exceeding the theoretical values appear to be very localized, and do not define broad, systematic variations in heat flow. These patterns may be caused by fluid circulation and heat loss through exposed basement, such as along fault scarps, or along the inside corner terrain. Fluid flow in the crust is expected to be highly variable along both parallel and across-axis directions.

*Off-axis*

One of the off axis profiles follows the ~10 Ma isochron (profile A-B, see Fig. 3 and Fig. 5 in Escartín *et al.*, 2001), with two profiles extending from the ~10 Ma isochron to the outer limit of the V-shaped ridge. The age of the crust at the westward end of profiles C-D and O-P is not well constrained from existing data due to the diachronous emplacement of the V-shaped ridge, but is probably 6 and 8.5 Ma. This area has a continuous and thick (>200-m) sediment cover, and a smooth basement with vertical relief <200 m that is completely sedimented. Overall the measured heat flow is in good agreement with the theoretical values expected for this seafloor age, with superimposed long-wavelength (>10 km) anomalies.

The two most prominent heat flow anomalies are at the West end of profile C-D and at the vicinity of the intersection of profiles A-B and O-P (Fig. 3). The low at the end of profile C-D shows relatively constant values of 20-50 mW/m$^2$, and is ~100 mW/m$^2$ below the average value of the profile. These low values extend ~15 km away from the base of the V-ridge, and transition to a local heat flow high ~45 km from the end of the profile. In contrast, the West-end of profile O-P shows constant and normal heat flow values in the immediate vicinity of the V-shaped ridge. The second anomaly at the intersection of profiles A-B and O-P is also a two-dimensional heat flow low (~100 mW/m$^2$ in amplitude), extending >25 km along profile A-B and >15 km along profile O-P. A local heat flow high is observed at the midpoint of profile O-P (~31°W, Fig. 3). These relatively large variations in heat flow at lateral scales of tens of km demonstrate that, despite the presence of a thick and homogeneous sediment layer in >6-8.5 Ma old crust, there is probably important fluid flow through the upper oceanic crust, perhaps with diffuse discharge zones through the sediment column. Mostly linear gradients over a 5-m-length probe preclude discharge at rates greater than a few tens of cm/yr.

Detailed analysis of the heat flow

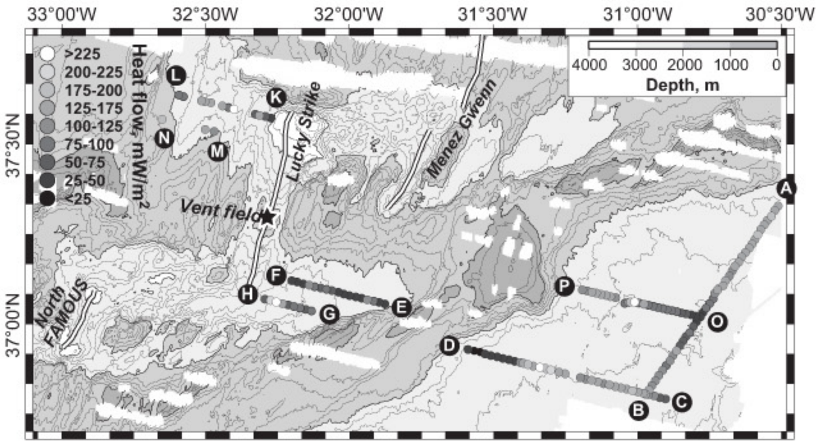


**Figure 3**. Heat flow stations and values along profiles realized during the « Lucky Flux » cruise around the Lucky Strike area. Off-axis heat flow data show systematic two-dimensional variations at scales of >10 km. The Lucky Strike hydrothermal vent field is indicated by the star. Multibeam bathymetry from the Sudaçores cruise (Cannat *et al.*, 1999; Escartín *et al.*, 2001) with 200 m contours.

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data needs to be integrated with bathymetric and seismic data available in the area. In particular, buried basement structures, as seen in Pacific crust (abyssal hills, seamounts; *e.g.* Fischer *et al.*, 2003) and faults in the sediments may strongly control the zones of recharge/discharge. Comparison of these data with results from numerical models of fluid flow and heat flow will provide constraints on the different modes of cooling both near- and off-axis of slow-spreading ocean crust.

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# Multibeam sonar survey of the central Azores volcanic islands

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In September-October 2003, we surveyed the central Azores islands (Fig. 1) with a portable Reson Seabat 8160 multibeam echo-sounder installed on the University of the Azores *R/V Arquipélago*. The cruise was a unique collaboration between marine geophysicists from Cardiff University, and marine biologists and geologists from the University of the Azores. Besides revealing the volcanic and tectonic structure of parts of the Azores spreading plate boundary, the data will aid the assessment of spawning grounds for pelagic fish, which form an important resource for the local economy, and will inform local authorities of geological hazards to coastal populations.

The Azores islands are often visited by scientists as they provide convenient and pleasant ports for research vessels working in the central Atlantic but they have been less a focus for marine geophysics themselves. Along with the 1999 Italian-UK AZZORRE99 TOBI deep-tow sidescan sonar survey around the central islands (Ligi et al 1999), forthcoming multibeam sonar surveying by the Portuguese STAMINA group around Terceira (N Lourenço, pers. comm.) and rock dredging from FS Poseidon (CW Devey, K Haase pers. comm.), this project represents a renewed interest in the Azores.

**The Azores as an ultra-slow spreading plate boundary**

There has been much recent interest in the volcanic and tectonic structure of ultra-slow spreading ridges such as the Southwest Indian Ridge and Gakkel Ridge in the Arctic, because the extreme spreading rate may potentially shed light on melting processes in the underlying mantle and delivery of melt through the lithosphere to form the oceanic crust (Mapping and Sampling the