International Ridge-Crest Research: **Hydrothermal Fluxes**

FLORES diving cruise with the Nautile near the Azores - First dives on the Rainbow field: hydrothermal seawater/mantle interaction

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Introduction

The FLORES diving cruise was part of the three years MAST III AMORES (1995-1998) program funded by the EEC (Contract n° 95-0040CT) which followed the previous MAST II MARFLUX/ATJ program conducted between 1993 and 1995. The MAST II program is a collaboration of five EEC countries (France, UK, Portugal, Ireland and Belgium) to investigate four volcanic segments along the Mid-Atlantic Ridge (MAR) between south AMAR and the Azores Triple Junction (ATJ) (Fig. 1). The major objectives of the program are: (1) to compare the physical, geochemical and biological fluxes from different hydrothermal fields on a segment scale, (2) to study the geological setting, structure and composition of hydrothermal systems on a vent field scale, and (3) to examine the influence of depth on hydrothermal processes and its consequences on vent ecosystems.

South of the ATJ, the ocean crust has a southward gradient in: (1) depth (from 800 m to 2800 m), (2) chemical properties of rocks, (3) nature of volcanism and (4) certain characteristics of the segmentation of the ridge axis. All of these characteristics are directly or indirectly controlled by the Azores hot spot.

During the summer of 1997 three cruises were coordinated through AMORES: Flame, Flores and Marvel. The objectives of the Flame surface cruise (May/June) were to pinpoint the location of the Rainbow hydrothermal field from physical and chemical tracers, and to study mixing processes, the dispersion of the neutrally buoyant plume, and biogeochemical fluxes in the Rainbow area and in the Famous segment (Fig. 1) (German et al., 1997; German et al., 1998). The Marvel diving cruise (Aug./Sept.) focused on biological studies.*

Following up on the results of the Flame cruise, (German et al., 1998) diving operations were conducted during the Flores cruise (July/Aug.) to find the Rainbow field and to study various aspects of hydrothermal processes on the MAR between 36°N and 37°N. Prior to the cruise two hydrothermal sites, Lucky Strike (Langmuir et al., 1997) and Menez Gwen, were known in this area. Three major factors were considered in selecting the dive targets for the Flores campaign: magma budget, rock composition and depth variations. Two targets were selected at central topographic highs where the magmatic budget is at a maximum within the segment (Menez Gwen and Lucky Strike). On the basis of previous nephel and CH_4 plume anomalies (Charlou et al., 1997; German et al., 1997) two other targets were selected at the end of two ridge segments where tectonic activity dominates volcanic activity (South Famous and Rainbow). The depth in the study area varies between 2400 m at Rainbow, 2800 m at south Famous, 1700 m at Lucky Strike and 800 m at Menez Gwen. There were three main objectives of the cruise: (1) to quantify the variability of hydrothermal activity, (2) to compare the nature and composition of fluids and massive sulfide formations in the four different environments, and (3) to sample fluids from diffuse flow, and from high-temperature, focused venting at Menez Gwen and Lucky Strike to assess temporal variability.

Cruise operations

The FLORES cruise took place between Jul. 6 - Aug. 10, 1997 aboard the French R/V *L'Atalante*, the mother vessel of the manned submersible the *Nautile*. The night program conducted high resolution mapping (slow speed and narrow beam) with an EM12 multibeam system and took a series of vertical hydrocasts to optimize diving targets. The *Nautile* submersible was equipped with a CTD and minirosette water sampler, a H_2S *in-situ* analyzer, a nephelometer, titanium syringes and gas tight titanium samplers for hot vent fluids, bottles for particles sampling, a push core system, and markers to identify new sites. Additionally, a Medusa system for diffuse flow sampling, and time lapse temperature probes were placed on the seafloor for long term sampling and measurements.

A total of 29 dives were success-

*Editor's Note: See the Dixon et al. article on pg. 20 for some results from the Marvel cruise.

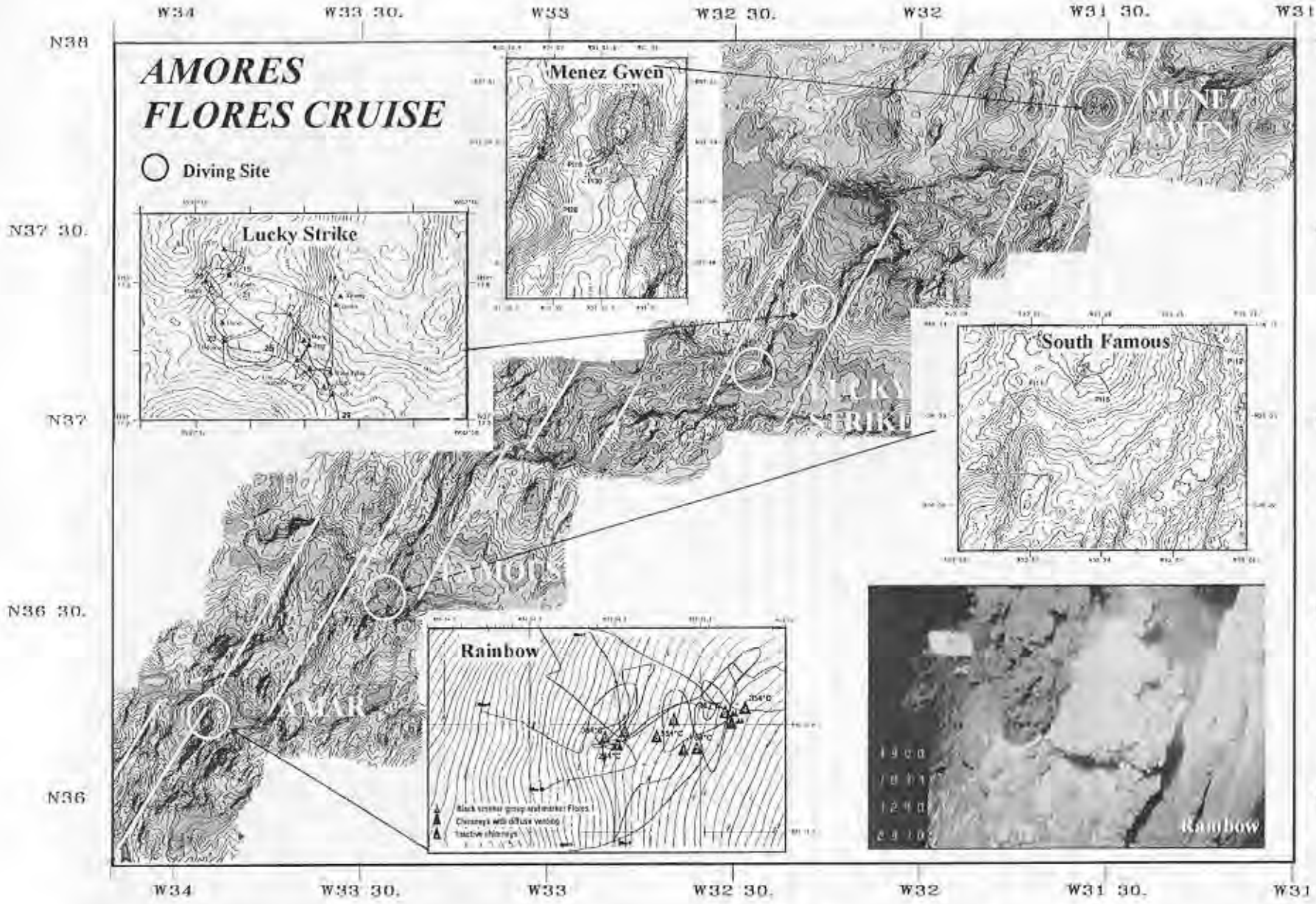

Figure. 1. Location of the 5 diving areas during the Flores cruise. Detailed maps show the diving tracks and the major active chimneys in the main diving targets.

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fully performed at water depths ranging between 2800 m and 800 m. The 149 hours spent on the seafloor covered 68 km of track and completed 7 minirosettes, 29 horizontal CTD tracks, 11 *in situ* H_2S analyses, 6 Medusa operations, and collected 57 vent fluid samples and 200 rock samples. The night program completed 18 vertical hydrocasts, 9 dredges and extensive high resolution mapping and imagery in the four segments.

Principal Results:

The Rainbow hydrothermal field

One of the major findings of the FLORES cruise was the discovery of the Rainbow active site in an environment of ultramafic rocks from the mantle. Ultramafic rocks were also recovered in the South Famous and the south Lucky Strike segments at places where intense methane anomalies have been identified (Charlou et al., 1997). The results from the FLORES cruise demonstrate that the composition of hydrothermal fluids and mineral deposits, and the associated chemical flux into the ocean, will vary depending on the geological setting and the underlying rock composition (E Morb vs. Ultramafic rocks).

Regional tectonic environment

RAINBOW and FAMOUS are two sites of quite distinct hydrothermal activity (Charlou et al., 1997; German et al., 1997). Both are located in second order discontinuities cutting the MAR south of the Azores (Parson et al., 1997) and have been surveyed and sampled during the FLORES cruise. The high temperature venting at the Rainbow site occurs along the shoulder of a W-facing hanging wall of a tilted ultrabasic block, the shoulder of which is cut by a network of intersecting N-S and NE-SW faults. Active and relict hydrothermal activity indicates persistent and precise tectonic control of this vigorous site at a range of scales. Around the site, and throughout the non transform discontinuity (NTD) a relative chronology of normal dip-slip extensional faulting, conjugate transtensional faulting and Riedel populations can be determined in the context of the evolution of the offset and the venting. At the southern end of the FAMOUS segment, the combination of new high-resolution multibeam bathymetry, sidescan sonar, dive data, and strong CH_4 hydrothermal anomalies (Charlou et al., 1997) indicates that venting is associated with serpentinisation of an unroofed ultrabasic diapir in this area. Similarly, elevated Crystal blocks mapped within non transform discontinuities on the MAR further point to significant tectonic/ultrabasic controls on hydrothermal circulation at slow spreading ridges.

Geological setting and sulfide composition of the Rainbow field

Based on the nephel, CH_4 and TDM (total dissolvable manganese) anomalies observed during the FLAME cruise, (Charlou et al., 1997; German et al., 1997; Radford-Knoery and Aballéa, 1997) one month before the FLORES cruise, ten dives were conducted at the Rainbow ridge on the AMAR segment. The active vent field (Rainbow), 250 m long and 100 m wide, is located at 36°13.80N-33°54.12W, on the western flank of the Rainbow ridge, between 2270 and 2320 m depth (Fouquet et al., 1998; Fouquet et al., 1997). This vent field is unique in several ways:

1. It is one of the most active hydrothermal field along the MAR in terms of heat and chemical flux, with about 10 major groups of extremely active black smokers dispersed over the entire field.

2. High resolution EM12 bathymetric maps (slow speed and narrow beam) and detailed submersible investigations show a clear tectonic control of the hydrothermal field that is located at the intersection between the non-transform

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fault system (N40) and the ridge faults (N00). The western border of the field is a 25 m high fault scarp where stockwork mineralization is observed.

3. The entire vent field is located in an ultramafic environment. Only a small veneer of old basalt occurs at the east tilted summit of the Rainbow ridge, 1 km east of the active vents.

4. Chimneys and massive sulfides are enriched in Cu, Zn, Co and Ni compared to other sites in basaltic environments. At Lucky Strike and Menez Gwen the E-MORB composition of the source rocks results in Ba and Pb enrichment in the deposits, while at Menez Gwen phase separation results in hydrothermal precipitates which are mainly anhydrite, barite and silica with minor sulfides.

Hydrothermal alteration

The Rainbow hydrothermal site is hosted by serpentinite which composes the Rainbow crest. The rocks consist mostly of coarse- and fine grained, porphyritic and non-porphyritic serpentinites with well developed mesh textures. Additionally, a few samples show brittle and/or ductile deformation, with at least partial preservation of the original mesh structure. The main components of the Rainbow serpentinites are serpentine group minerals (antigorite/lizardite+fibrous chrysotile in late fractures), magnetite (chromite) and aragonite in late veins (Barriga et al., 1997). Bastite phenocrysts are present in some specimens. No relics of igneous silicates were found in any of the specimens. The lack (or scarcity) of brucite suggests that most serpen-tinization took place at temperatures between 350-500°C (Barriga et al., 1997). The textures of the serpentinites suggest that they may derive from a serpentinite diapir and not from a major shear zone, such as a transform fault. A serpentinite diapir origin is also supported by the local ridge topography. The basalts and spilites from Famous depict intense hydrothermal alteration at least up to the greenschist facies. Some epidosites were collected. Submarine weathering/low temperature alteration is superimposed on high temperature events.

Fluid composition

The vent fluids from Rainbow exhibit temperatures of 360°C with pH between 2.9 and 3.1, and they have a uniform chemical composition for the major and minor trace elements as well as for gases (Charlou et al., 1997; Donval et al., 1997; Douville et al., 1997). Chlorinity is above 750 mmol/kg and silica is around 7 mmol/kg. Although the H_2S content is relatively low, all fluids show extraordinarily high H_2 and CH_4 content, compared to other fluids collected along the MAR. The fluid chemistries of the revisited Lucky Strike and Menez Gwen vents were close to those measured in 1993 and 1994. Variability in the composition of fluids from vents located around the lava lake was again observed at Lucky Strike. Menez Gwen fluids had a uniform composition and the low salinity has been stable for at least three years. Pressure, controlling the phase separation process, influences the chemistries of both these sites. On the AMAR segment, the Rainbow fluids, which are high in H_2 and CH_4 are issued from an ultramafic environment where serpentinization is occurring. These results show that fluid chemistry is affected by serpen-tinization, which generates a high flux of H_2 and CH_4 along the axis of the slow spreading MAR.

Biology

Contrary to the Lucky Strike and Menez Gwen vent fields, which are dominated by dense colonies of mussels, the Rainbow biological communities are dominated by shrimps. However, unlike other sites in the Atlantic many of the vents have no animals. Only three dense swarms (a few m^2 in total at each site) of the caridean shrimp *Rimicaris exoculata* (Bresiliidae) (Desbruyères et al., 1998), as found at TAG, Snake Pit and Broken Spur, are observed. Two other species occur, *Mirocaris fortunata* (Bresiliidae) and *Chorocaris chacei*, in lower abundance than other species (Desbruyères et al., 1998). Mussel-beds are much smaller and the densities of Mytilid are lower than in the shallow Lucky Strike and Menez Gwen fields.

Preliminary conclusions

The results from the FLORES cruise indicate that even if the hot spot influence increases to the north, for a single segment there is a strong contrast between the shallow central topographic high with a large magmatic budget and the ends of the segments where ultramafic rocks and high methane anomalies have been observed for three of the four investigated segments. In addition the occurrence of active hydrothermal systems in these two distinctly different environments enlarges considerably the areas where potential hydrothermal fields can be found on slow spreading ridges. The composition of hydrothermal fluids and mineral deposits, and the associated chemical flux into the ocean, will vary depending on the geological setting and the underlying rock composition (E Morb vs. Ultramafic rocks). Our results show that fluid chemistry is affected by serpentinization, which generates a high flux of H_2 and CH_4 along the axis of the slow spreading MAR.

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If you'd like to bring a 'bio-box' on your next cruise, contact:

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