A Detailed Study of the Lucky Strike Hydrothermal Site and Discovery of a New Hydrothermal Site: Menez Gwen; Preliminary Results of the DIVA1 Cruise (5-29 May, 1994)

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Nineteen dives were completed with Nautile on three different volcanic segments located between 37°17'N and 38°20'N on the Mid-Atlantic Ridge (MAR) near the Azores. Cruise participants included scientists from IFREMER (France), University of Lisbon (Portugal) and Woods Hole Oceanographic Institution (USA). The cruise was part of the French-American FARA program on the Mid-Atlantic Ridge. The objectives of the cruise were to survey and sample the Lucky Strike (37°17'N) site in detail, and to extend exploration efforts to two other volcanic segments further north, in order to study the influence of water depth on volcanic and hydrothermal processes. The three dive sites investigated during the DIVA1 cruise, are located at the topographic highs of the volcanic segments which are called, respectively from south to north, the Lucky Strike segment (37°17'N), the Menez Gwen segment (38°50'N), and the 38°20'N segment (Fig. 1). Detailed geological mapping and rock and hydrothermal fluid sampling were carried out at Lucky Strike and the newly discovered Menez Gwen sites (Fouquet et al., 1994).

Since 1991, this area of the MAR has been extensively surveyed during five cruises conducted as part of the French-American co-operative agreement (FARA). The first bathymetric maps of the area were obtained using the EM12 system during the FARA-SIGMA cruise (H.D. Needham, IFREMER, Chief Scientist) in 1991. In 1992, during the 2 FAZAR survey cruises, (C. Langmuir, LDEO, and G. Klinkhammer, OSU, Chief Scientists) sulphides were dredged from the top of the Lucky Strike segment (FAZAR Scientific Team, 1992; Langmuir et al., 1993a), and Mn and CH_4 chemical anomalies were identified in the seawater column (Charlou et al., 1992). Sediments were sampled on both sides of the ridge during the GEOFAR cruise (G. Auffret; IFREMER, Chief Scientist). Six dives were carried out with Alvin in 1993 on the Lucky Strike site (Langmuir et al., 1993a-b). Eight discrete active vents were found. Massive sulphides, basalt, hydrothermal fluids and biological samples were collected (Langmuir et al., 1993a-b; Humphris et al., 1993; Colodner et al., 1993).

Lucky Strike

The Lucky Strike segment is located between 37°00'N and 37°35'N. The rift valley is 15km wide and up to 950m deep. At its central part is a composite volcano 13km long, 7km wide, and 430m high, and divided into two parts separated by a N-S valley. The western part is an elongated narrow ridge while the eastern part has a semi-circular shape with three volcanic cones at its summit. The hydrothermal site is located in a depression between these three cones.

One of the major results of the DIVA1 cruise, is the discovery of a lava lake at the central depression among the three summit cones. The lava lake has a circular shape and is about 300m in diameter and up to 6m deep at water depths of between 1730m and 1736m. Very fresh lavas, exhibiting low vesicularity, are present at the bottom of the lake (pillars up to 3 m high, collapsed lobate lava flows). In contrast, most of the three volcanic cones are composed of older, highly vesicular volcanic breccia. This lava lake was visible on the EM12 images as a black area contrasting with the grey color of the volcanic breccia on the three volcanic cones.

Active vents surround the lava lake, with the most active venting (dominated by large areas of low temperature diffuse flow) present on the western side. A large amount of older, inactive massive sulphide occupies ~80% surface area of the square kilometer surface area of the lava lake. These deposits are observed at water depths of 1730m to 1645m. They do not occur as a discrete, localised mound, but as an area of extended sulphide deposits around a circular depression which, at its base, is occupied by the lava lake. The sulphide deposits clearly correspond to several hydrothermal episodes spatially controlled by the lava lake. Hydrothermal discharge occurs through high temperature, active black smokers with anhydrite (324°C) flanges rich in barite and iron and zinc sulphides (170°C), and as low temperature diffuse flow with deposition of amorphous silica. Inactive portions of the deposits include iron and copper-rich massive sulphides and an unusual type of deposit termed hydrothermal slab, rarely observed but typical of this site. These slabs form very flat, layered deposits which are up to 10m thick in some places. Composition of the slabs vary, and include: breccia of massive sulphides cemented by silica, volcanic

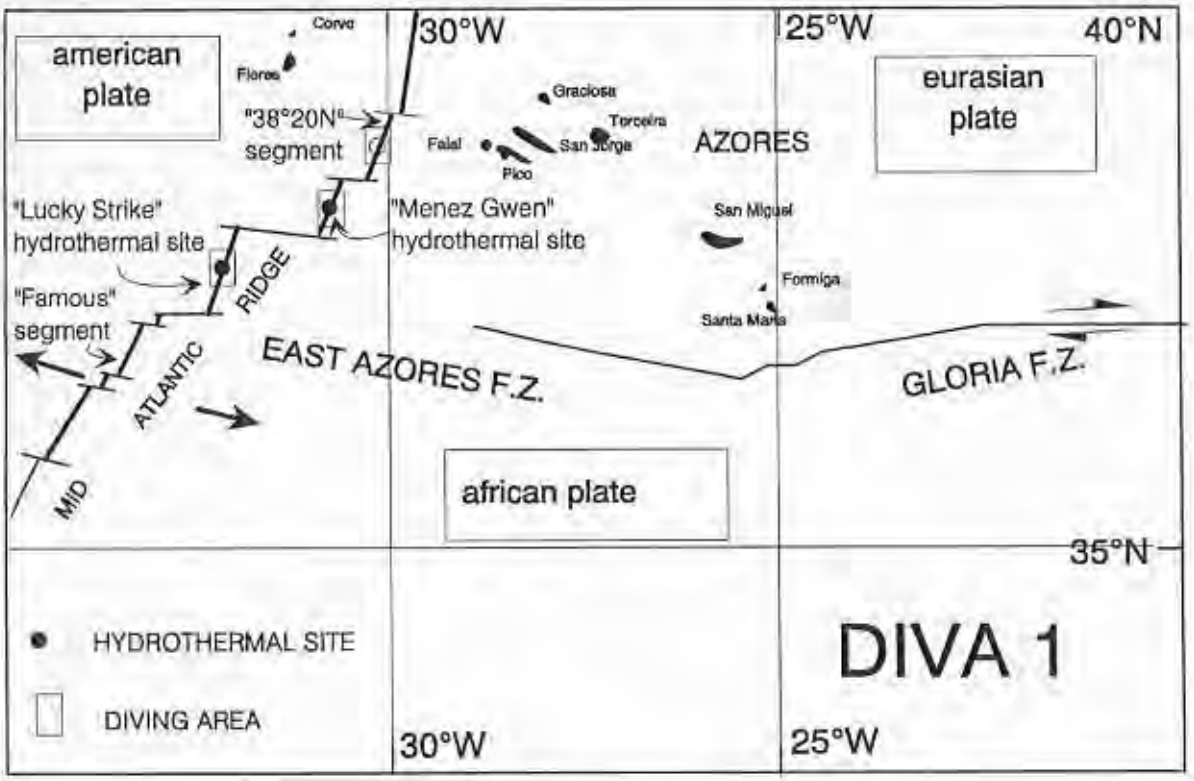

Figure 1

breccia cemented and altered by silica and sulphides, or silica and iron oxides, or iron oxides and iron/manganese. We confirm the dispersed nature of hydrothermal discharge at the Lucky Strike site compared to focused black smoker activity observed at the top of the sulphide mounds at the Snake Pit and TAG sites, also in the Atlantic.

Temperature anomalies associated with salinity anomalies were detected in the seawater column 100 m above the seafloor. A distribution map was made of H_2S and CH_4 at 2-5m above the bottom (Radford-Knoery et al., 1994). At the active vents, temperatures measured in 1994 were similar to those measured in 1993. A temperature probe left in May 1993 and recovered in May 1994 revealed a remarkable stability for the same vent throughout the year (D. Fornari, pers. comm.). Temperature probes left for 18 days during the DIVA1 cruise, likewise all revealed stable temperatures. The highest recorded measured temperature (324°C) is close to the boiling point of seawater at 1700m water depth (356°C; Bischoff and Rosenbauer, 1985).

During exploration dives to the west and north of the vent field, volcanic cones of very fresh pillows were observed at the top of the western ridge. This contrasts with the volcanic breccia observed on the three cones near the lava lake. The northern part of the 150m deep, 1 km wide valley between the two volcanic systems is covered with very fresh sheet flows. This may indicate that the present-day axial valley is in this depression. However, the abundance of sediments in the southern part of the valley indicate that volcanic activity is not continuous along strike.

Menez Gwen Site

The Menez Gwen site, discovered during the cruise, is on the volcanic segment just north of the Lucky Strike segment (between 37°35' and 38°N). One of the particular characteristics of the segment is the absence of a central rift. EM12 sonar images indicate that relatively fresh lava occurs all along the segment. However, the main volcanic system is a circular volcano at the central part of the segment. This volcano is 700m high with a diameter of 17km. At its top is an axial graben 6km long, 2km wide and 300m deep. The graben is open both at its northern and southern part, and thus cannot be considered as a simple caldera system. A new volcano (600m in diameter, 120m high) is growing at the northern end of the graben.

Five dives were conducted to examine the central graben at water depths between 1000m and 700m. Most of the graben bottom is comprised of relatively fresh to very fresh lava. At the deepest part (1045m) is a 1400m long, 400m wide and up to 8m deep lava lake where very fresh lavas were sampled (as fresh as on super-fast spreading ridges). Lava pillars form at two to three distinct levels, each 1-3m high. On both sides of the lava lake are fresh lobate flows. The northern extension of the lake is comprised of fresh pillows in a highly fissured area. On a 400m high cross-section on the western central side of the graben, different types of volcanic products were seen. At the very base is the lava lake, and lobate and pillow flows corresponding to the recent

volcanic episode. Proceeding upward, there are two well separated units corresponding to a section across the older split volcano. The first unit at the core of the volcano is 60m high and comprised of several massive prismatic lava flows up to 3m thick. Very often the tops of these lava flows are composed of brecciated lava. At the top of the section is a 240m thick unit of volcanic ejecta starting at a water depth of 939m. This unit consists of variably layered volcanic ash, sand and lapilli. The contact with massive lava is sharp, and no lava flow was observed within the unit.

A new strategy to search for hydrothermal activity with the submersible was developed for the DIVA1 cruise. This strategy combines CTD measurements and mini-rosette water samples where both CH_4 and H_2S concentrations were measured. Sulphide concentrations range from <2-15mmol/L in vent fluids, while background sulphide concentrations are "zero" in deep water unaffected by plumes, making sulphide a potentially attractive tracer of hydrothermal plumes. However, vent fluids are typically diluted 106-fold in the overlying plume, and sulphide is rapidly removed (oxidized) from the water column. Therefore, analytical performance (detection limits, sample size, shipboard analyses) is central in using sulphide as an hydrothermal plume tracer. A new sulphide analysis method (detection limit 0.1nmol/L) was developed in the laboratory and tested onboard during the cruise (Radford-Knoery et al., 1994). A distribution map of sulphide at 2-5m above bottom at Lucky Strike (MAR at 37°20'N) was drawn. Sulphide anomalies (10-1000nmol/L) are observed in the vicinity of known venting sites, but not above the lava lake or near sedimented areas. Methane concentrations (up to 42nmol/L) from the same samples were always significantly above the background levels expected at this depth (0.4nmol/L) and showed more variability. Sulphide and methane data from the first exploration dive in the 37°50'N MAR segment allowed discovery, during the subsequent dive, of the Menez Gwen site. Again, a distribution map of near bottom sulphide in the Menez Gwen segment was drawn. It shows two distinct sources of sulphide: the identified hydrothermal venting site, and an as yet unidentified site located near the contact surface between basalt and volcanic ejecta on the western graben wall.

The Menez Gwen site is near the top of the young volcano at the bottom of the graben. The volcano is composed entirely of extremely fresh pillows with no sediment cover. Compared to the Lucky Strike area, and more generally to the other sites on the MAR, the site is very young, but already very active. The first chimneys are just starting to grow on the fresh pillows. The site covers a 200m² area at a water depth of between 871m and 847m. The highest temperature measured (281°C) is close to the boiling point for this depth (305°C; Bischoff and Rosenbauer, 1985). Chimneys are typically less than 5m high and essentially composed of white anhydrite, formed by heating the seawater by hot, but clear, hydrothermal fluid. Around these white chimneys are small, relatively flat, mounds with hot water diffusing through all surfaces. These mounds are enriched in barite. At lower temperature, silicic slabs with some sulphides are formed. At one place white "smoke" with no deposits percolates slowly from a deep hole in the pillows. One major characteristic of the site is the scarcity of animals. This, together with the very fresh pillows, argue for the site being extremely young. However, the size of the mussels indicate that the site is probably at least a few years old. In 1993, a hydrocast from near the southern limit of the graben detected no methane anomaly.

38°20'N Segment

Only two dives were made on this segment at a water depth of between 930m and 510m. The morphology of the segment is very similar to the Menez Gwen segment. There is no rift valley and the central volcano is comparable in size (25km in diameter and 1200m high). The axial graben is 2km wide, 800m long and 500m deep. Water sampling with mini-rosette and CTD records show no evidence of hydrothermal activity on the segment at this time. Methane values near the bottom are close to background levels. However, some very recent lava flows were observed at the northern end of the graben. The EM12 images reveal relatively fresh lavas present along the segment. During the dives we saw that most of the graben bottom is occupied by more or less tectonised volcanic ejecta very similar to the material observed at the top of the Menez Gwen segment. As at the Menez Gwen segment, there is a young volcano at the northern part of the graben. This volcano is composed of pillows, sometimes relatively brecciated. One characteristic of these pillows is their red color, indicating rapid oxidation of the hot lava. Past hydrothermal activity on this segment is expressed as silicification and iron oxidation in many of the volcanic ejecta samples are indicators of past hydrothermal activity on this segment. No other evidence of past or current hydrothermal activity was observed.

Hydrothermal Fluids

Twenty hydrothermal fluid samples were collected at the Lucky Strike (LS) site (1700m) and five on the new Menez Gwen (MG; 840m) site. At Lucky Strike, vents sampled in 1993 were revisited and new vents were also discovered with temperatures ranging from 170°C to 320°C and with pH 3.8-4.5. Menez Gwen vents exhibit temperatures between 265°C and 281°C with pH values between 4.2 and 4.8. Silica concentrations are different at the 2 sites (12-16mmol/kg at LS and 8-11mmol/kg at MG) but are consistent with control by quartz solubility. At Lucky Strike, major and minor elements are very similar to 1993 data (Colodner et al., 1993). Differences in major and minor elements are observed between the 2 sites. Menez Gwen chlorinities (360-380mM) are lower than Lucky Strike chlorinity levels (450-530mM). Similar differences are observed for other major elements. Na, K, and Ca levels are also lower in Menez Gwen hydrothermal fluids. Compared to other hydrothermal fields, all of the fluids collected at LS and MG have low sulphide concentrations (<2 mmol/kg). At the two

sites, all fluids are gas-enriched. Total gas volumes (520 to 957ml NTP/kg of fluid) are 3 to 5 times higher than those found in TAG black smokers. CH_4 (up to 2.2mmol/kg), H_2 (up to 0.7mmol/kg) and N_2 (up to 1.7mmol/kg) concentrations are high at the 2 sites compared to on the EPR, with CH_4 values 2 or 3 times higher at MG than at LS. All of the fluids have low concentrations of metallic elements. Chloride, hydrogen suphide and metal depletion associated with gas enrichment in LS and MG fluids confirm the expectation that phase-separated effluents are delivered to the deep ocean in this area (Donval et al., 1994).

Conclusions

To conclude, we summarize the new findings of the DIVA1 cruise as follows:

- Discovery of the new Menez Gwen hydrothermal site.
- Use of a new strategy for exploration of vents with a submersible: CH_4 and H_2S measurement in near bottom seawater.
- Discovery of the first lava lake ever observed on a slow spreading ridge.
- Observation of the limit between effusive and explosive volcanism producing layered volcanic ejecta at water depths shallower than 900m.
- Complete cross-section of a volcano, including massive lava and volcanic ejecta.
- Detailed sampling (water and rocks) and geological mapping of the Lucky Strike site.
- Deployment of temperature probes for 18 days on the vents, showing a remarkable stability of temperature.
- Fluids sampled at Lucky Strike and Menez Gwen show low chlorinities, low H_2S content, low concentrations of metallic elements, and are gas enriched suggesting that phase-separated effluents are delivered to the deep ocean at these two sites.
- Hydrothermal precipitates cover a very large surface area (1km^2), and correspond to several hydrothermal episodes. The size of the active discharge zone contrasts with the well focused flow observed at black smokers sites in the Atlantic.
- Hydrothermal products are distinct in their mineralogy (enriched in barite) and morphology (hydrothermal slabs) when compared with other Atlantic hydrothermal deposits.
- Preliminary results will be presented at the AGU 1994 Fall meeting (oral and poster; Fouquet et al., 1994; Donval et al., 1994; Radford-Knoery et al., 1994).

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