Evidence of a Probable Magmatic Episode at the Lucky Strike Segment, Mid-Atlantic Ridge, March 2001

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Introduction

During March 16-17, 2001 a swarm of 128 earthquakes occurred along the Lucky Strike segment of the Mid-Atlantic Ridge (MAR) near 37EN (Figure 1). The earthquakes were detected and located using six NOAA/PMEL autonomous hydrophones moored within the ocean sound channel along the flanks of the MAR from 15E-35EN. The hydrophones were first deployed in February 1999 (see InterRidge News 8.1, March 1999) by a consortium of U.S. investigators (National Science Foundation and NOAA) and the experiment will continue to at least February 2007. The hydrophones are deployed and recovered on a yearly schedule with data being processed within 6 months of recovery. Generally, hydroacoustic monitoring provides a lower threshold for detecting MAR earthquakes than land-based seismic networks

The Lucky Strike spreading segment is strongly influenced by its proximity to the Azores Hotspot, and is magmatically robust compared to other segments of the MAR (Scheirer et al., 2000). The segment is characterized by a broad rift valley (~12 km wide), and exhibits the greatest depth contrast of any segment on this part of the MAR (Detrick et al, 1995). The center of the segment is dominated by the 8 km wide, 1 km high Lucky Strike Seamount. The seamount hosts a vigorous hydrothermal system and a lava lake (Humphris et al, 2002). Recently, the MOMAR Project was formed to promote international cooperation to establish long-term multidisciplinary MOnitoring on the Mid-Atlantic Ridge near the Azores region. The Lucky Strike area was selected at the first MOMAR workshop as the most appropriate site to begin vent and segment scale monitoring experiments.

Event Description

The Lucky Strike earthquake swarm recorded on the hydrophone array began on March 16 at 1528Z and continued for 29 hrs until 2036Z on March 17. Nearly half of the 128 events occurred in the first 1.5 hrs reaching a peak of 42 events/hr, but thereafter activity rapidly declined to #5 events/hr. The first four earthquakes of the swarm occurred along the summit and flanks of Lucky Strike Seamount and were accompanied by continuous, low frequency (<15 Hz) tremor-like energy (Figure 2). Within minutes, however, the events began locating north of the volcano and within the Lucky Strike rift valley (Figure 1, black dots), giving the appearance that the entire Lucky Strike segment was undergoing a seafloor spreading episode. The earthquake locations in Figure 1 are shown with attendant errors (1s), which are somewhat higher than location errors for earthquakes within the array. While it is not possible to associate earthquakes with individual faults or volcanic features, it seems clear the Lucky Strike segment is the source of the seismicity.

Furthermore, analysis of the time-distribution and magnitudes of hydroacoustic seismicity suggests this was not a mainshock-aftershock (tectonic) sequence, but fits the definition of an earthquake swarm with a likely magmatic component.

The U.S. National Earthquake Information Center (NEIC), using land-based seismometers, located 30 earthquakes (3.6 # mb # 5.0) from the Lucky Strike swarm (Figure 1; white triangles). NEIC locates three of the earthquakes along the Lucky Strike segment, the rest are located in an intraplate region north of the rift valley. The teleseismic locations of the Lucky Strike earthquakes differ significantly from the hydroacoustically derived locations. This is likely a function of the more accurate ocean sound-speed models available from years of oceanographic sampling and proximity of the hydrophones to the earthquake source (Smith et al, 2002). The largest earthquake (M_w=5.0; large triangle on Figure 1) has a normal-fault CMT solution, but occurred 5.5 hours into the swarm after the majority of the hydroacoustic seismicity (78 events) had occurred, supporting the interpretation that this not a mainshock-aftershock sequence. Relative event depths, estimated from the rise-time of each earthquake's hydroacoustic signal, suggest events were shallow during the initial 5 hrs of the swarm, then deepened following the M_w=5.0 earthquake.

Summary

Analysis of the seismic and hydroacoustic data from Lucky Strike indicate that several characteristics present in this episode are similar to documented plume-producing, extrusive events observed on the Juan de Fuca Ridge (JdFR) (e.g. Fox, 1999). These include a vigorous earthquake swarm (30 earthquakes/hr during the first two hours), continuous tremor-like energy at the swarm's onset, and no initial mainshock. Intrusion tremor observed at Krafla Volcano in Iceland is very similar to the tremor observed here, with a broad spectrum and predominant frequencies >3 hz (Brandsdottir and Einarsson, 1992). Small earthquake swarms (<100 events) at Krafla (Bjornsson, 1985) and Axial Volcano along the JdFR (Dziak and Fox, 1999) have been shown to represent intrusions of magma beneath the volcano's summit and into adjacent rift zones. Intrusion tremor and earthquakes typically stop once magma reaches the surface or the dike stops propagating.

There are, however, notable elements missing as compared to previously documented mid-ocean ridge eruption episodes. Typically eruptions on the JdFR produce earthquake swarms with durations from one to several weeks, while the Lucky Strike swarm lasted only 29 hrs. Documented eruption events have also exhibited significant (>10 km) migration of earthquakes that are caused by the lateral propagation of a magma dike into the shallow crust of the rift zone. The Lucky Strike swarm showed no obvious earthquake migration, rather the seismicity appeared to occur almost simultaneously at the summit of Lucky Strike Seamount and northward along the ~50 km ridge segment.

In addition, previously documented mid-ocean ridge eruptions have produced an abundance of seafloor and water-column observations confirming magmatic activity. Preliminary analysis of *in situ* observations of the Lucky Strike hydrothermal field obtained from submersible dives during July 2002 suggest an increase in diffuse venting, especially along the sides and base of the black smoker mounds, since the site was last visited in 1997 (T. Shank, pers. com.). However, no evidence of recent lava flows has yet been observed, and all pre-existing hydrothermal vents appear to still be intact.

We interpret the March 2001 earthquake swarm at Lucky Strike as representing a

probable magmatic/dike-emplacement episode that may have occurred without an eruption of lava on to the seafloor. Even without a seafloor eruption, a dike emplacement event would in all likelihood have produced a measurable increase in the fluid temperatures and flux rates at pre-existing hydrothermal systems. The earthquake activity itself, independent of any magmatic influence, can cause significant changes (via ground motion) to vent fluid temperatures and flux rates which can have a profound effect on the populations of macro- and microorganisms inhabiting the hydrothermal vent sites (Dziak and Johnson, 2002).

The March 2001 Lucky Strike earthquake swarm was very similar to the small swarms, detected only using hydrophones, at Axial Volcano (JdFR) during the 7 years prior to a massive eruption in 1998. Thus the Lucky Strike swarm could be a precursor to increased seismic and volcanic activity at Lucky Strike Seamount. Since only two years of MAR hydrophone data have been processed to date, it remains to be seen how the March 2001 earthquake swarm fits into the overall volcanic cycle of Lucky Strike Seamount. Nevertheless, this earthquake swarm provides strong evidence that the Lucky Strike area is an excellent candidate for monitoring volcanic activity, seafloor deformation, and hydrothermal vent processes along the MAR.

Contact Information and Acknowledgements

For additional information regarding this and other significant Mid-Atlantic Ridge hydroacoustic seismicity, visit http://www.pmel.noaa.gov/vents/acoustics/seismicity/mar/LuckyStrike2001.html. This study was made possible through the support of the U.S. National Science Foundation (grant numbers OCE-9811575, OCE-0137164, and OCE-0201692) and the NOAA Vents Program.

References

Bjornsson, A. Dynamics of crustal rifting in Iceland, *J. Geophys. Res*., 90, 10151-10162, 1985.

Brandsdottir, B and P. Einarsson. Volcanic tremor and low-frequency earthquakes in Iceland, in *IAVCEI Proceedings in Volcanology*, P. Gasparini, R. Scarpa, and K. Aki, Eds., Springer-Verlag, Berlin, Germany, 212-222, 1992.

Detrick, R.S., H.D. Needham, and V. Renard. Gravity anomalies and crustal thickness variations along the Mid-Atlantic Ridge between 33EN and 40EN, *J. Geophys. Res*., 100, 3767-3787, 1995.

Dziak, R.P. and C.G. Fox. Long-term seismicity and ground deformation at Axial Volcano, Juan de Fuca Ridge, *Geophys. Res. Lett*., v:26, 3641-3644, 1999.

Dziak, R.P. and H.P. Johnson. Stirring the oceanic incubator, *Science*, 296, 1406-1407, 2002.

Fox, C.G., In situ ground deformation measurements from the summit of Axial Volcano during the 1998 volcanic episode, *Geophys. Res. Lett*., v:26, 3437-3440, 1999.

Humphris, S.E., D.J. Fornari, D.S. Scherier, C.R. German, L.M. Parson. Geotectonic setting of hydrothermal activity on the summit of Lucky Strike Seamount (37EN 17' Mid-Atlantic Ridge), G^3, 3, No 8, 2001GC000284, 2002.

Scheirer, D.S., D.J. Fornari, S.E. Humphris, and S. Lerner. High-resolution seafloor mapping using the DSL-120 sonar system: Quantitative assessment of sidescan and phase-bathymetry data from the Lucky Strike Segment of the Mid-Atlantic Ridge, *Mar. Geophys. Res*., 21, 121-142, 2000.

Smith, D.K., J. Escartin, M. Cannat, M. Tolstoy, C.G. Fox, D.R. Bohnenstiehl, S. Bazin. Spatial and temporal distribution of seismicity along the northern Mid-Atlantic Ridge (15E-35EN),

J. Geophys. Res., in press, 2003.

Figure Captions

Figure 1: Bathymetry and earthquake locations from the Lucky Strike Segment. Black circles show hydroacoustic earthquake locations (128 events; error bars = 1s), white triangles show teleseismic locations (30 events) from the March 16-17 2001 swarm. Dark triangle shows teleseismic location of largest event detected (M_w=5.0) during the swarm. Inset map shows location of hydrophone array (stars) and Lucky Strike Segment along the Mid-Atlantic Ridge.

Figure 2: Time series and spectrogram of the northeast hydrophone (closest to the Lucky Strike Segment) showing the onset of the earthquake swarm. Broadband, impulsive earthquake arrivals standout against a background of low-frequency (3-15 Hz) continuous tremor energy.