Autonomous Underwater Vehicle Maps Seafloor

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Autonomous underwater vehicles (AUVs)—which operate without a tether or human supervision—represent an emerging technology that can be used to solve many scientific problems in the deep ocean, the last unexplored frontier on Earth. AUVs are well suited to "lawn-mower" style geophysical surveys for mapping bathymetry, magnetic field, or water column properties. They are fast and efficient synoptic mappers and are inexpensive to operate.

Manned submersibles and remotely operated vehicles (ROVs) allow intensive study of an area, but can remain at a site for only a few hours, days, or weeks. AUVs can remain in an area gathering data in between submersible and ROV visits to provide information on temporal variations and can respond rapidly to events such as volcanic eruptions when large oceanographic vessels and equipment cannot be mobilized quickly.

The Autonomous Benthic Explorer (ABE) being developed at Woods Hole Oceanographic Institution (Figure 1) is powered by lead-acid gel cells for a total range of 12 km, although this can be significantly extended with lithium batteries. For navigation, it uses four medium-frequency transponders similar to those used by submersibles. Data collected by ABE is stored on board and retrieved after the dive. The craft can operate in terrain avoidance mode within a few meters of the seafloor, and it can also stop and hover. For more information on ABE and other AUV systems, see http://www.marine.whoi.edu/ships/auvs/auvs.htm on the World Wide Web.

In 1995 and 1996 the ABE completed two month-long field cruises in the deep ocean investigating a recently erupted lava flow on the Coaxial ridge segment of the Juan de Fuca Ridge [*Yoerger et al.*, 1996]. T-phase earthquake activity originally located near 46°15'N, 129°53'W migrated 40 km north over 2 days, coming to rest at 46°31.5'N, 129°35'W, a location later confirmed to be the site of a seafloor lava eruption. The eruption formed a lava flow ~30 m thick, 1500 m long, and 300 m wide on the seafloor. Event response cruises visited the lava flow a few weeks and months after the eruption and found fresh lava, hydrothermal venting, and vigorous bacterial mat colonies [*Embley et al.*, 1995].

Hydrothermal activity was also found along a narrow graben that emerges from the southern end of the flow and lies along the same trend as the new lava flow. The graben and associated hydrothermal activity are evidence of a subsurface dike that fed the new flow. The diking event and lava flow emplacement represent the basic building blocks of the upper oceanic crust and provide insight into the volcanic architecture and structure of oceanic crust. Knowing the age of the lava flow opens possibilities for studying the temporal evolution of physical properties of the new lava, venting fluids, and biological communities.

In 1995, ABE collected 35 km of track lines in collaboration with an ALVIN submersible dive program to establish a set of baseline geophysical measurements over the new lava flow (Figure 2). The AUV science sensor package included a magnetometer, conductivity-temperature-depth (CTD) recorder, and a video camera system. The AUV mission was to map the regional magnetic field of the new lava flow and ascertain its thickness and subsurface structure. AUV track lines were navigated over the northern end of the lava flow using dead reckoning. In 1996, ABE joined ROV JASON in a return expedition to the new lava flow area and completed the regional mapping of the central and southern end of the lava flow using autonomous acoustic navigation.

The AUV magnetic field data (Figure 2) show that the new lava flow produces a strong magnetic anomaly of ~15,000 nT. A mean crustal magnetization of 60 Amps per meter (A/m) is obtained from direct inversion [*Hussenoeder et al.*, 1995] of the AUV magnetic data assuming a constant lava thickness of 30 m estimated from repeat swath bathymetric mapping [*Chadwick et al.*, 1995]. This result is consistent with rock sample measurements that show an average magnetization of ~67 A/m [*Johnson and Tivey*, 1995].

The sensitivity of the magnetic approach is demonstrated by the rapid increase in magnetic field at the boundaries of the new lava (Figure 2). While repeat bathymetric swath mapping successfully located the new lava flow [*Chadwick et al.*, 1995], the system has a footprint of approximately 100 m and a thickness resolution of about 5 m, which is barely adequate for resolving such small volcanic events. High-resolution magnetic mapping provides another way to detect such flows. To estimate the thickness of the new lava, the AUV magnetic data were forward modeled. Magnetic field data were corrected onto a level plane and the seafloor topographic effect was removed, assuming a mean magnetization of 26 A/m (estimated from rock sample values of the surrounding terrain).

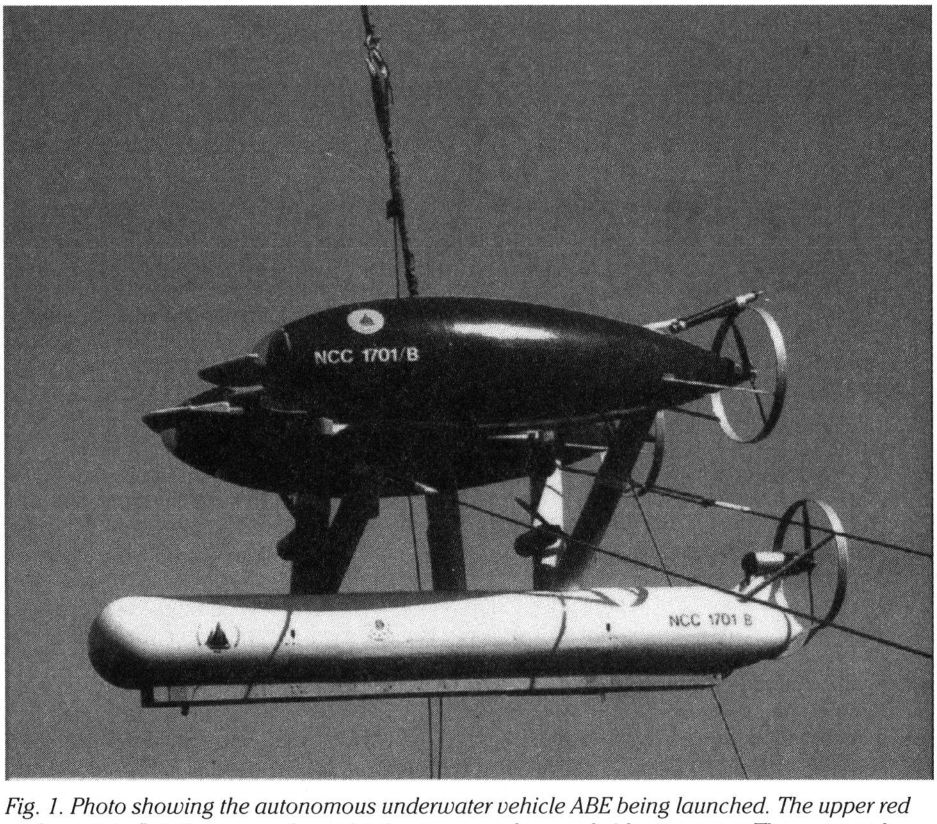

Fig. 1. Photo showing the autonomous underwater vehicle ABE being launched. The upper red pods contain flotation, acoustic navigation transponders, and video cameras. The pressure housing (white, lower center) contains the main electronics, batteries, and magnetic sensor. Original color image appears at the back of this volume.

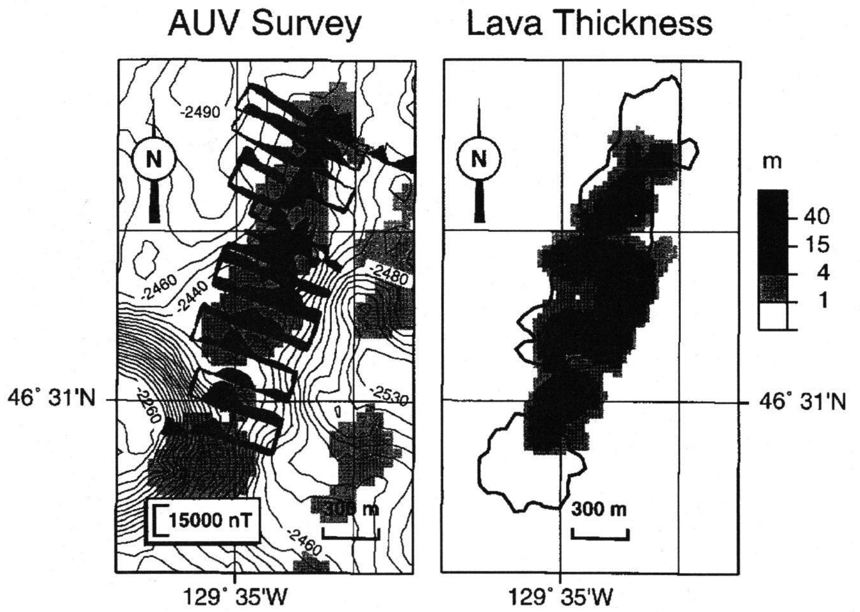

Fig. 2. (Left) The bathymetry of the new lava area (10-m contours) on the Coaxial ridge segment of the Juan de Fuca Ridge in the northeast Pacific. The 1993 lava flow extent determined from differential bathymetric mapping is shaded gray and overlain by ABE tracks and the magnetic field anomaly measured along the track. Note the strong positive anomaly located over the new flow. Eastern gray areas represent a 10-year-old eruption. (Right) The calculated magnetic thickness of the 1993 lava flow in comparison with the extent of the lava flow, which was determined by depth differencing from surface ship surveys (bold line).

An iterative forward modeling approach varied the lava layer thickness, assuming a constant magnetization of 34 A/m, to match the residual magnetic field. The "magnetic" thickness map produced is consistent with submersible observations and the differential bathymetric anomaly (Figure 2). The higher-resolution magnetic data detect the lava flow where it was too thin for detection by differential bathymetry and give similar maximum estimates for lava flow thickness. Anomalous magnetic field can thus be a useful proxy for detecting and mapping new lava. Linked with AUV technology, it provides a high-resolution, rapid response tool for marine volcanic events.

The AUV represents the latest and perhaps most efficient way in which oceanographers can begin to comprehensively explore this vast domain.—*Maurice A. Tivey, Department of Geology and Geophysics, Woods Hole Oceanographic Institution, Woods Hole, Mass.; Albert Bradley, Dana Yoerger, Rodney Catanach, Alan Duester, Steve Liberatore, and Hanu Singh, Department of Applied Ocean Physics and Engineering, Woods Hole Oceanographic Institution, Woods Hole, Mass.*

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Life on Mars Vigorously Debated at Conference

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Life on Mars was a hot topic at the 28th Lunar and Planetary Science Conference, the first major conference on meteorites since *McKay et al.*'s [1996] stunning report of possible evidence for Martian life in the meteorite ALH 84001. The meeting, which was held March 17–21, 1997, featured 35 presentations and talks based on evidence for and against Martian life in the meteorite.

There was no widespread agreement about Martian life in ALH 84001, and no obvious converts from one view to the other. The meteorite is difficult to interpret, with each thin section or sample seeming to show different aspects of its history. Similarly, knowledge of possibly similar biological organisms and environments on Earth is sketchy, making analogies with Earth life somewhat tenuous. Carbonate mineral globules in ALH 84001 (Figure 1) host the possible traces of Martian life. The presentations focused debate on a few questions: Did the globules form at temperatures too hot for life? And could the nanophase magnetite crystals within the carbonate globules only form through biogenic processes? In the carbonate globules, *McKay et al.* [1996] found elongate and sausage-shaped objects that look like Earth bacteria. Are they really fossil bacteria, or could they be inorganic or artifacts of sample preparation?

Sulfur isotope measurements were not consistent with bacterial sulfur metabolism, but most of the sulfides analyzed were not part of the possible biogenic mineral assemblage, and some analytical procedures were challenged. Polycyclic aromatic hydrocarbons (PAHs) were barely mentioned, but were featured at the American Chemical Society conference in mid-April. G. Flynn reported finding concentrations of 2% or more carbon in ALH 84001, using a novel synchrotron X-ray method. New evidence from McKay seems to show that many grain surfaces in ALH 84001 are coated by thin films of carbonaceous material. This evidence is still in its infancy, and it remains to be seen whether the films are biological and/or Martian.

Temperature of Carbonate Formation

All of the possible evidence for Martian life in ALH 84001 is in its carbonate mineral globules; if the globules formed above ~170°C, life as we know it would seem pretty unlikely. *McKay et al.* [1996] accepted a low formation temperature, as proposed by *Romanek et al.* [1994], but *Harvey and McSween* [1996] cited evidence for a high temperature, >600°C! Most of the new data at the LPSC was consistent with temperatures lower than this, but perhaps not low enough for life. The carbonate globules preserve extensive zoning of major element abundances and oxygen isotope ratios, which suggest low-temperature growth. However, fast growth at high temperature would still be permitted, as championed by R. Harvey, J. Bradley, and E. Scott.

Among the strongest results were the remanent magnetism measurements of J. Kirschvink and co-workers. They found that ALH 84001 had trapped a fairly strong, stable remanent magnetism, and that the trapped field was oriented differently in various fragments from a fracture zone. They inferred that

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