Mapping Giant Scours in the Deep Ocean

PAGES 274-275

Mapping the deep-ocean floor in high resolution (i.e., meter scale) is a technological challenge. However, with increasing interest in submarine geohazards and deep-sea habitats, understanding the detailed morphology of the seafloor is vital for the correct interpretation of geological and biological processes. Such high-resolution data are now becoming increasingly accessible for the scientific community, as demonstrated during the first scientific missions of Autosub6000, the new UK purpose-built deepwater autonomous underwater vehicle (AUV). The missions, carried out on board the RRS *James Cook* in August 2008, were aimed at mapping giant erosional scours in several submarine canyons along the northeastern Atlantic margin. Scours are seafloor depressions that are generated through erosion beneath submarine flows. Scours are most commonly associated with high-energy environments, such as submarine canyons and channels.

Using AUV Technology to Study the Deep-Ocean Floor

Currently, shipborne multibeam echo sounders are the main tool for deepwater bathymetric mapping. However, these systems struggle with decreasing resolution at increasing water depths, due to the absorption of higher sound frequencies in the water column and to the increased footprint size of the acoustic beams. Deep-towed systems are hampered by cable drag and navigational uncertainty, unless they are supported by expensive transponder networks. Consequently, to achieve optimal resolution and spatial coverage, AUVs are increasingly being used. They provide the additional advantage of freeing up the host vessel for other operations. To date, the hydrocarbons industry has been the primary user of deepwater AUVs. Scientific use of AUVs still is quite limited, and there are only a few scientific AUVs capable of detailed bathymetric survey work below 3000 meters. At these depths, accurate navigation and vehicle endurance are critical issues, and they need to be achieved in a cost-effective way.

The potential of deepwater AUVs for science was first revealed by the Woods Hole Oceanographic Institution's 5000-meter-depth-rated Autonomous Benthic Explorer (ABE; see *Yoerger et al.*, [1998]). Other instruments with similar capability include the 4500-meter-rated "r2D4" developed by the University of Tokyo (http://underwater.iis.u-tokyo.ac.jp/top/sado/sado-e.html) and the 6000-meter-rated "D. Allan B." developed by the Monterey Bay Aquarium Research Institute (MBARI), Moss Landing, Calif., which recently has operated in various environments to a depth of 1600 meters [*Caress et al.*, 2008]. Commercial systems include the 4500-meter-rated Hugin AUV from Kongsberg Maritime in Norway, and the company's Hydroid Remus 6000, which is rated to 6000 meters. The Bluefin-21 AUV from the Bluefin Robotics Corporation also is rated to 6000 meters. However, scientific publications featuring AUV bathymetry from water depths greater than 4000 meters remain sparse.

Autosub6000 is depth rated to 6000 meters and has more than 0.5 cubic meter of space available for scientific payloads (e.g., multibeam echo sounder, side-scan sonar, conductivity-temperature-depth (CTD), or biochemical sensors). It has a unique approach to the key issue of absolute positioning. With the AUV using dead reckoning, based on an inertial navigation system and a Doppler velocity log (DVL; tracking the seabed when the vehicle is less than 200 meters off the bottom), there is no need for a seabed transponder network to be deployed for the Autosub6000's navigation. This saves considerable expedition time and results in a drift of less than 0.1% (1 meter per kilometer of survey track).

However, without DVL tracking during the AUV descent, the absolute positioning accuracy degrades significantly. To correct for this, Autosub6000 uses a "range-only" navigation technique: Once the AUV is close to the seabed, it executes a preset track while its range to the ship is constantly monitored acoustically. Data-fusing algorithms, which combine the AUV's dead-reckoned navigation with the ranges to the well-positioned ship, produce an accurate estimate of the navigation offset, which is telemetered acoustically down to the AUV.

To obtain maximum endurance for minimal weight and volume, Autosub6000 is equipped with recently developed, pressure-tolerant, lithium polymer rechargeable batteries. These do not require heavy and voluminous pressure-resistant housings, allowing the AUV to carry a larger number of batteries or more scientific payload than otherwise possible. The AUV's current endurance is 36 hours at a speed of 5 kilometers per hour (180 kilometers total), and there is capacity to extend this to 72 hours (360 kilometers). This long endurance, together with the AUV's fully independent operation for the duration of the dives, frees the host vessel for other activities, such as seafloor sampling.

Imaging Deepwater Scours in Unprecedented Detail

The image presented in Figure 1 was obtained in August 2008 in the lower reaches of the Agadir Canyon, offshore Morocco, during the Autosub6000's first scientific expedition. A specific aim of the expedition was to better understand the process of scour formation by analyzing the detailed morphology

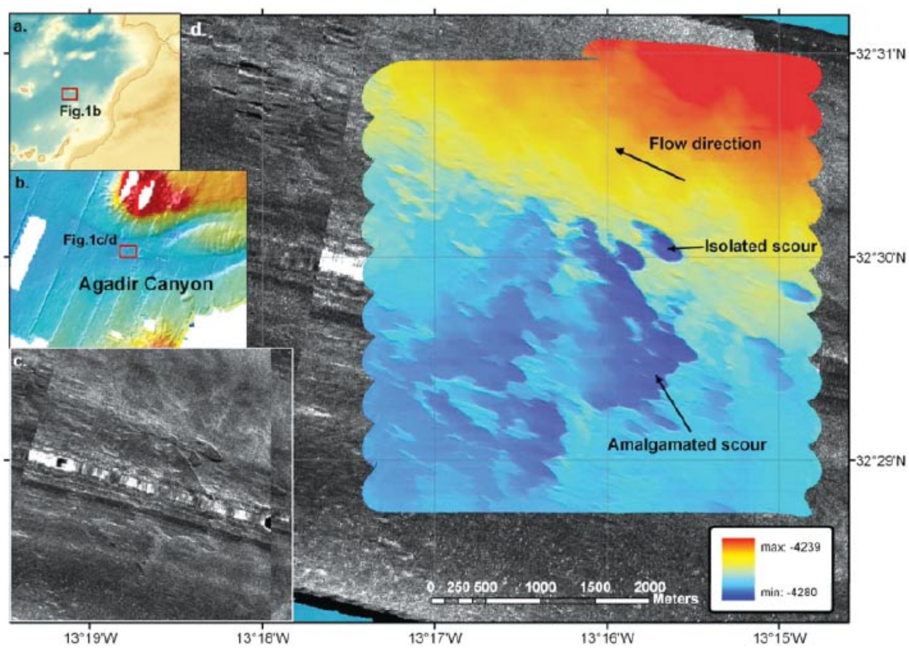

*Fig. 1. Autosub6000 high-resolution bathymetry showing kilometer-scale scours in the lower Agadir Canyon, offshore northwestern Africa (Morocco). (a) Regional location map. The red box is enlarged in Figure 1b. (b) Shipborne EM12 multibeam bathymetry over the lower canyon [*Talling et al., *2007]. The red box is enlarged in Figures 1c and 1d. (c) Thirty-kilohertz deep-towed side-scan sonar imagery illustrating the overall shape of the scour features. (d) Autosub6000 bathymetry illustrating isolated and amalgamated scours. The isolated scours are 10–20 meters deep and are up to 500 meters across, while the amalgamated features can be up to 1200 meters wide and 20 meters deep.*

of kilometer-scale isolated and amalgamated scours. The scours are generated by large-volume submarine gravity flows [e.g., *Talling et al.*, 2007], which can erode large amounts of seafloor sediment and pose a significant geohazard to seafloor infrastructure. Current knowledge of deepwater scours is biased toward larger features, as smaller scours are typically beyond the resolution of standard mapping tools [*Wynn et al.*, 2002]. In contrast, studies of scours in the rock record tend to be biased toward smaller examples, due to limitations in the extent of rock outcrops. Very few rock outcrops, e.g., cliff or quarry sections, extend over distances that would allow for clear imaging of large, kilometer-scale scours. High-resolution AUV-based multibeam surveys may help to link the observations in outcrops with those from the seabed.

The surveys were performed using a Kongsberg Simrad EM 2000 multibeam system at about 100 meters above the seafloor, with a typical 24-hour mission covering an area of approximately 25 square kilometers. Data processing was carried out with the CARAIBES software suite from the French Research Institute for Exploitation of the Sea (Ifremer). The final grid has a vertical resolution of approximately 15 centimeters and a pixel size of 2 meters. Maps were imported immediately into a geographic information system (GIS), and they were available for the planning of new coring sites within 2 hours of the AUV reaching the sea surface.

The example in Figure 1 shows an area in the lower reaches of the Agadir Canyon, at a water depth of approximately 4200 meters. Large scours had been imaged previously in this region using deep-towed 30-kilohertz side-scan sonar (Figure 1c; see also *Wynn et al.*, [2002]). However, the new high-resolution images (Figure 1d) clarify the process of the scours' formation, which is through lateral amalgamation of smaller, isolated, spoon-shaped scours. Ongoing analyses of accurately positioned piston cores from within and outside the scours will provide further insight into the nature and timing of the scour formation.

With technological breakthroughs now focused on endurance and cost-effectiveness, deepwater AUVs will become more accessible for science, especially for high-resolution mapping. The new Autosub6000 data presented here provide an example of how AUV technology will advance the understanding of geological and biological processes operating in the deepest reaches of the ocean.

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References

Caress, D. W., H. Thomas, W. J. Kirkwood, R. McEwen, R. Henthorn, D. A. Clague, C. K. Paull, J. Paduan, and K. L. Maier (2008), High-resolution multibeam, sidescan, and subbottom surveys using the MBARI AUV *D. Allan B.*, in *Marine Habitat Mapping Technology for Alaska*, edited by J. R. Reynolds and H. G. Greene, pp. 47–69, Alaska Sea Grant Coll. Program, Univ. of Alaska, Fairbanks.

Talling, P. J., et al. (2007), Onset of submarine debris flow deposition far from original giant landslide, *Nature, 450,* 541–544, doi:10.1038/nature06313.

Wynn, R. B., et al. (2002), Characterization and recognition of deep-water channel-lobe transition zones, *AAPG Bull., 86,* 1441–1462.

Yourger, D. R., et al. (1998), Surveying a subsea lava flow using the Autonomous Benthic Explorer (ABE), *Int. J. Syst. Sci., 29,* 1031–1044, doi:10.1080/00207729808929596.

—Veerle A. I. Huvenne, Stephen D. McPhail, Russell B. Wynn, Maaten Furlong, and Peter Stevenson, National Oceanography Centre, Southampton, UK; E-mail: vaih@noc.soton.ac.uk

NEWS

Plume 1400 Meters High Discovered at the Seafloor off the Northern California Margin

PAGES 275

On 17 May 2009, the Kongsberg EM302 multibeam echo sounder on board the U.S. National Oceanic and Atmospheric Administration's (NOAA) *Okeanos Explorer* was collecting bathymetry and water column acoustic data offshore of northern California when it suddenly imaged a previously undiscovered 1400-meter-high plume (Figure 1) rising from the seafloor at 40º32.13'N, 124º47.01'W. The ship was mapping in water depths of approximately 1830 meters and heading east up the northern California continental margin 20 kilometers north of the Gorda escarpment. The continental shelf in this area is known to have subsurface and water column thermogenic and methane gas, although no plumes from this area previously have been reported from deeper than the continental shelf.

The plume, which rises vertically 1000 meters before being deflected to the north, was recorded for approximately 5 minutes before it disappeared from the data. The recording was made at night, so the ship's bridge watch was not able to see any surface manifestations of the plume at that time. The plume is composed of individual streams of acoustic reflectors, best seen in a video assembled from the water column data (http://ccom.unh.edu/NOAA_oceanexploration). The digital terrain model created from the multibeam bathymetry shows that the plume rises from the base of a large, previously unknown, amphitheater-like failure.

The plume was mapped again by the multibeam echo sounder on board the *Okeanos Explorer* on 3 June 2009 during daylight. The ship's bridge watch was alerted by scientists to look for bubbles, discolored water, and other signs of irregularities on the sea surface, but the watch did not report anything unusual. The ship stayed over the plume for 2.5 hours and lowered a conductivity-temperature-depth instrument equipped with water bottles and a redox sensor. Preliminary shipboard analysis of the data found no temperature anomaly and no unusual redox values. The thermosalinograph showed no indications of any surface events during that time.

Given this information, it is believed that this plume is not a hydrothermal vent and is not associated with the Mendocino transform fault. It appears from the characteristics of the feature that it is a plume of methane gas bubbles coated with a methane hydrate.

—James V. Gardner, Center for Coastal and Ocean Mapping, University of New Hampshire (UNH), Durham; E-mail: jim.gardner@unh.edu; Mashkoor Malik, Office of Ocean Exploration, U.S. National Oceanic and Atmospheric Administration (NOAA), UNH, Durham; and Sharon Walker, Pacific Marine Environmental Laboratory, NOAA, Seattle, Wash.

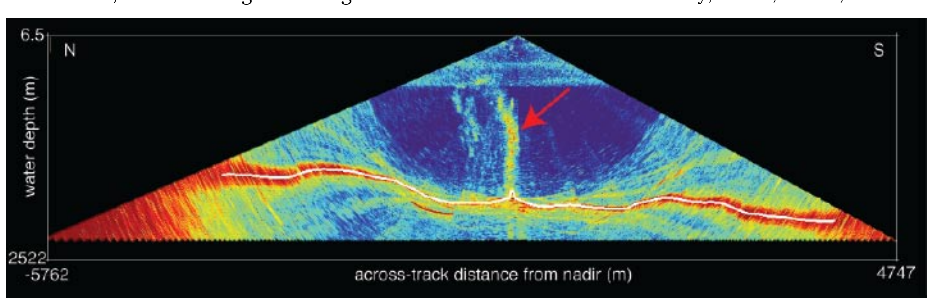

Fig. 1. Screen grab of the multibeam echo sounder water column display showing the plume (red arrow). The horizontal axis is across-track distance, and the vertical axis is water depth. The somewhat horizontal white line embedded in the red band is the seafloor acoustic return. The plume disappears from the water column at roughly 400 meter water depth.