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Development of High-Resolution Underwater Mapping Techniques

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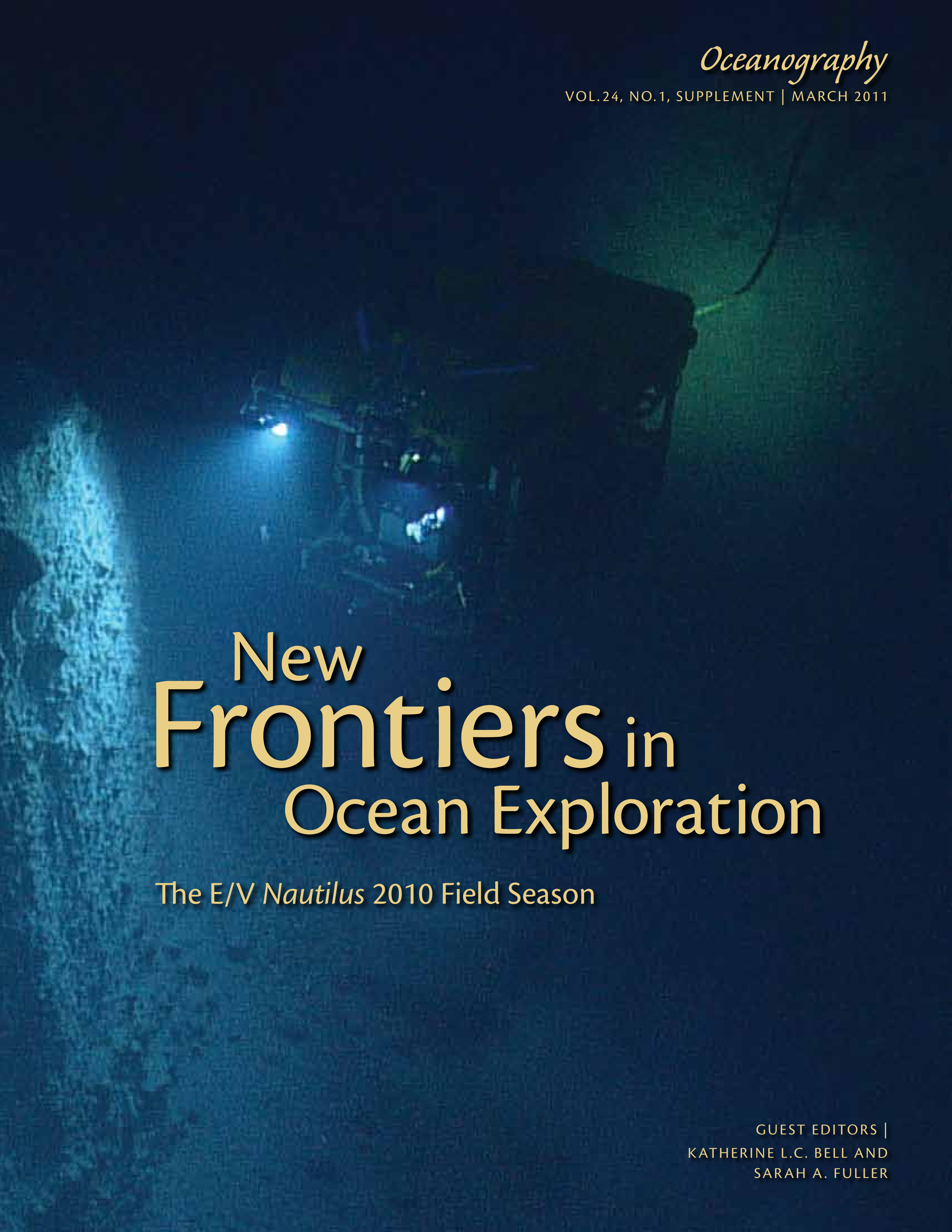

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New Frontiers in Ocean Exploration

The E/V *Nautilus* 2010 Field Season

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Development of High-Resolution Underwater Mapping Techniques

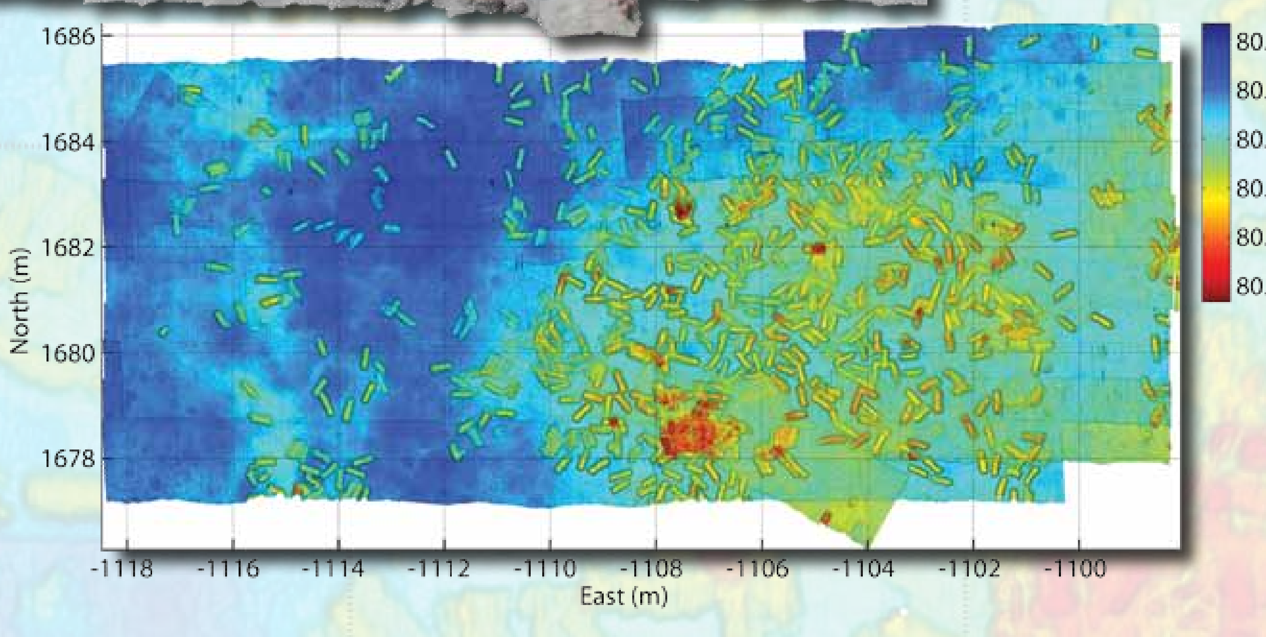
By Christopher N. Roman, Gabrielle Inglis, J. Ian Vaughn, Stefan Williams, Oscar Pizarro, Ariell Friedman, and Daniel Steinberg

Detailed photographic and bathymetric maps of the seafloor with resolutions better than 5 cm are broadly applicable for studies in marine geology, biology, and archaeology. Developing the tools and techniques to produce these data products is a central focus of the *Nautilus* program, enabled by a collaborative effort among several robotics groups. The overall goal of this work is to digitally document the seafloor and to determine which suite of sensors provide the most effective means for creating scale-accurate renderings with resolutions meaningful for archaeological and scientific diagnostics.

Hercules is equipped with a suite of mapping instruments that allow detailed visual and acoustic seafloor surveys. During the 2009 and 2010 field seasons, we used a 2250-kHz BlueView Technologies multibeam, a 240-kHz Imagenex multibeam, a verged stereo pair using color and black and white 12-bit 1360 x 1024 Prosilica cameras, and a 100-mW, 532-nm green laser sheet. The sonar, camera, and laser geometry were optimized for surveys between 2- and 4-m altitude off the bottom. We navigated the vehicle using an RDI Doppler Velocity Log (DVL), an IXSEA OCTANS fiber-optic gyroscope, and a Paroscientific depth sensor, and we used an ultra-short baseline system to georeference the surveys.

Our data-processing and map-making techniques are based on the Simultaneous Localization and Mapping (SLAM) concept, which is an active research area in both marine and land robotics (Singh et al., 2007). SLAM techniques combine direct navigation information with mapping sensor data to concurrently improve the direct navigation estimates and produce maps with resolutions consistent with the mapping sensors themselves. This type of approach is necessary to achieve centimeter-level resolution in the face of navigation uncertainly that quickly becomes the leading source of error.

Figure 1. (top) A three-dimensional stereo reconstruction of the Yalikavak III wreck. (bottom) A BlueView multibeam map of the same wreck gridded at 2 cm.



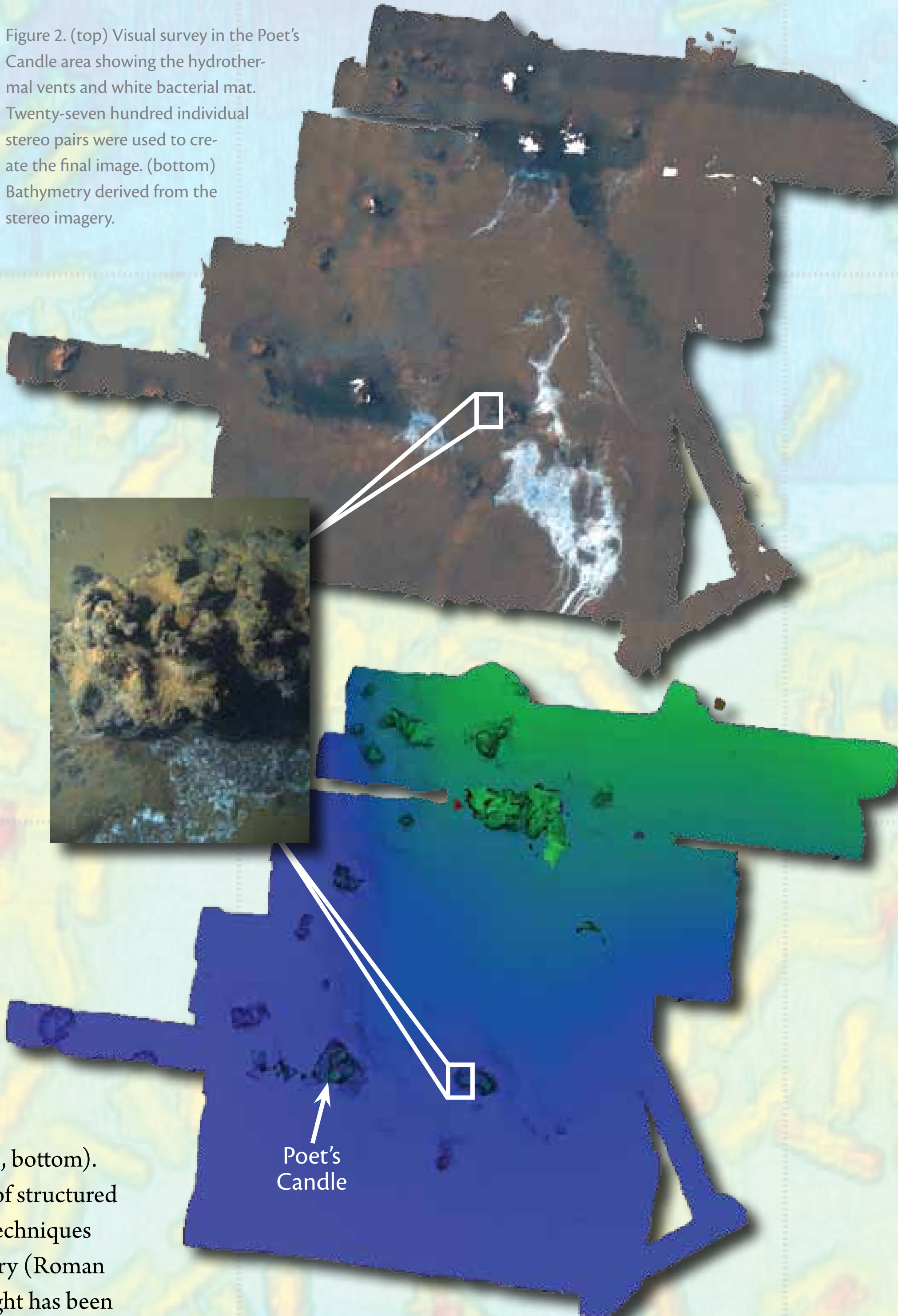


Figure 2. (top) Visual survey in the Poet's Candle area showing the hydrothermal vents and white bacterial mat. Twenty-seven hundred individual stereo pairs were used to create the final image. (bottom) Bathymetry derived from the stereo imagery.

During the eastern Aegean legs of the 2009 and 2010 seasons, we mapped 17 different wrecks in the Bodrum, Datcha, and Marmaris areas (see pages 18–19). Given the small size of the sites, typically 10 m x 20 m, the survey work was usually completed in just a few hours. Figure 1 shows example data for the Yalikavak III wreck. We produced the three-dimensional (3D) texture photographic mosaics using a stereo mapping and visual SLAM software pipeline (Mahon et al., 2008; Johnson-Roberson et al., 2010). The texture-mapped 3D models can be viewed in an interactive display that allows detailed investigation down to the pixel level of the original images (Figure 1, top). The high-frequency multibeam sonars were used at altitudes between 2 and 5 m to produce bathymetric maps (Figure 1, bottom).

We are also investigating the use of structured light laser imaging and developing techniques to obtain centimeter-level bathymetry (Roman et al., 2010). Although structured light has been a common machine vision technique in industrial applications for many years, it has had limited use underwater. By imaging a projected laser line, produced by shining the laser sheet on the bottom, it is possible to obtain a 3D profile of the seafloor with subcentimeter resolution. Our initial results using 2.5-mm gridding are encouraging (page 18, Figure 1). We are able to capture fine-scale features in the archaeological artifacts and subtle details in the shape of the seafloor. Data from the 2010 field season will be used in our research to expand the scale of the laser surveys while maintaining the 2.5 mm gridding using bathymetric SLAM techniques (Roman and Singh, 2007).

Our mapping capabilities were also used in the Kolumbo crater to document the hydrothermal vent field and steep pumice walls. We completed a large visual and bathymetric survey in the northern vicinity around the Poet's Candle vent (see page 25, Figure 3C) to map the distribution of nearby hydrothermal vents and bacterial growth on the seafloor (Figure 2). Over the main southern vent field, we performed detailed laser surveys to evaluate the resolution of the structured light mapping over the chimney features.

Our goal is to create a centimeter-level map of the features and obtain accurate estimates of their true shapes and volumes. A complicating factor in the active areas south of Poet's Candle was the hot water discharge and gas bubbling. The bubbles caused incidents of erroneous navigation drift by interfering with the DVL bottom tracking and the hot venting introduced blur and refraction in the green laser sheet. Looking forward, our future data processing

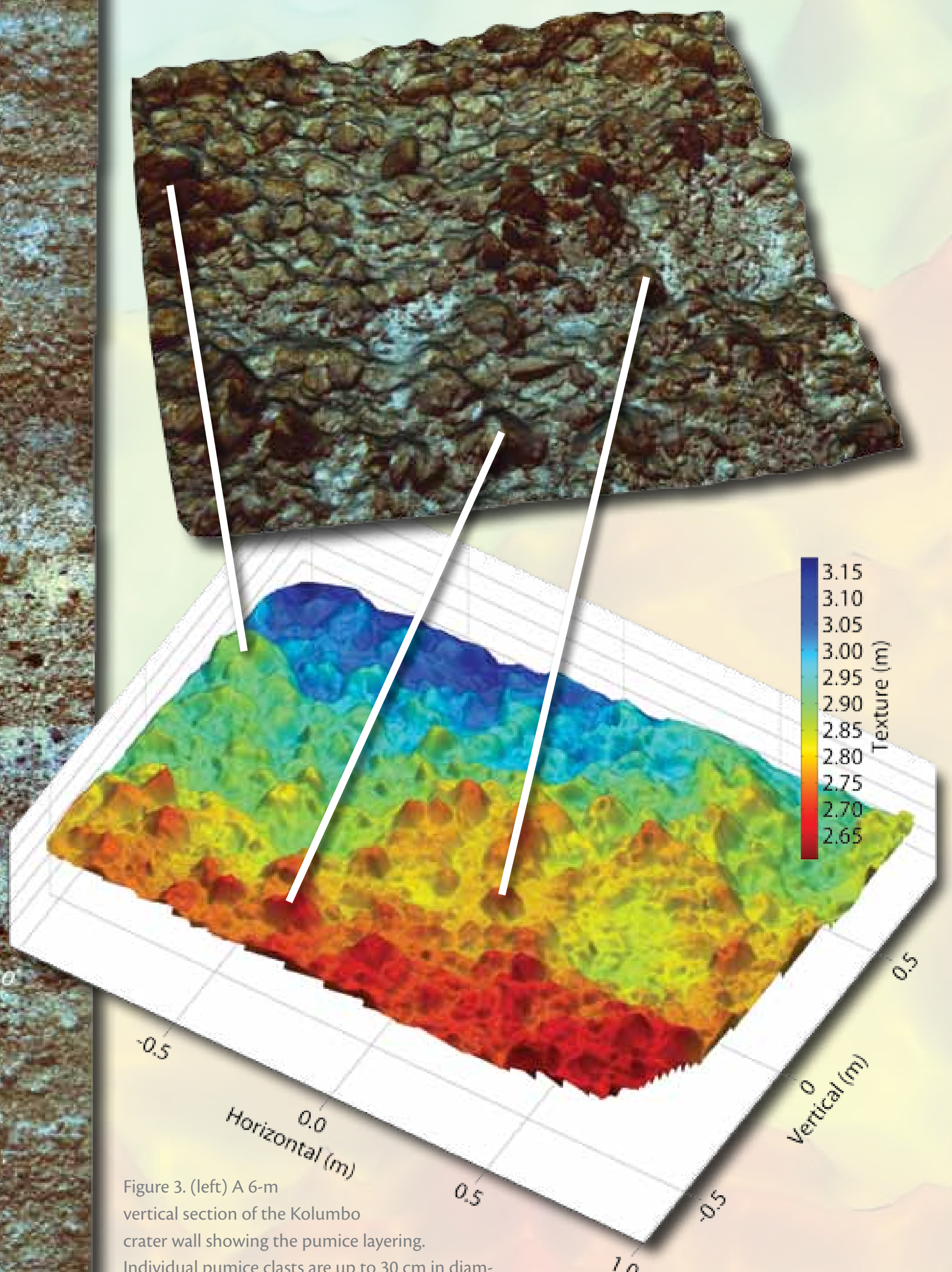


Figure 3. (left) A 6-m vertical section of the Kolumbo crater wall showing the pumice layering. Individual pumice clasts are up to 30 cm in diameter. (right) Small-scale textural maps of the vertical pumice outcrop made from the stereo cameras showing individual pumice clasts (top) and surface relief (bottom).

will need to contend with these distortions while also trying to exploit them as detectors of vent activity.

By mounting the cameras, sonar, and DVL on the front of *Hercules* to look forward, we were able to execute sequential "picket fence" vertical tracklines up and down the pumice wall from depths of 240–120 m (Figure 3 and page 25, Figure 2). We will use the collected data to construct a detailed, high-resolution record of grain size variations produced by submarine explosive eruptions.

At ANZAC cove, we were able to map a stone circle feature (pages 20–21) both acoustically and photographically (Figure 4). The maps enabled us to ground truth the apparent low relief of the site seen in the side-scan sonar data, and better understand the size distribution of the rocks comprising the circle. This survey will also be used in our research efforts to blend the camera and multibeam data into a single hybrid product.

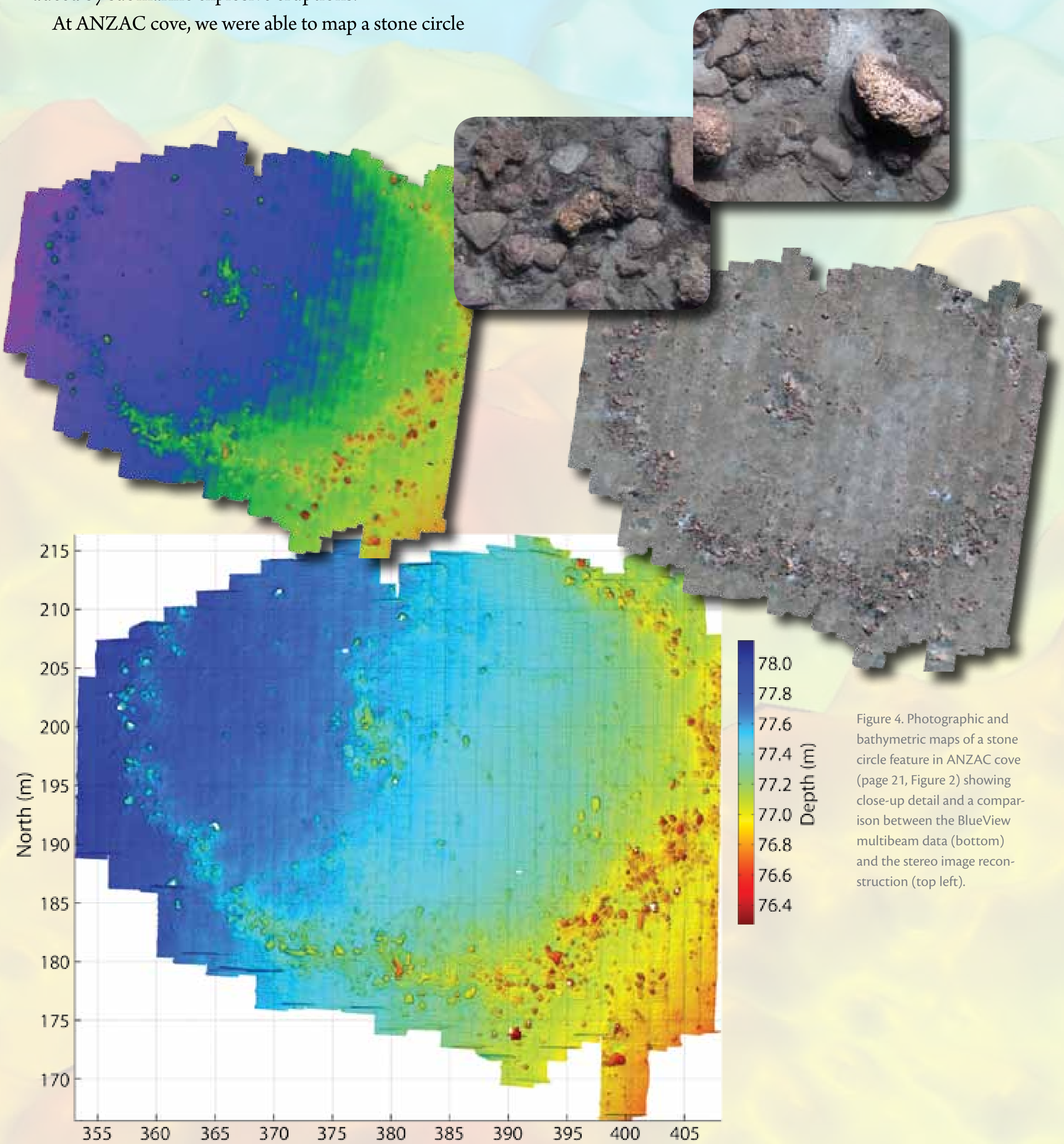


Figure 4. Photographic and bathymetric maps of a stone circle feature in ANZAC cove (page 21, Figure 2) showing close-up detail and a comparison between the BlueView multibeam data (bottom) and the stereo image reconstruction (top left).