Cruise Report AT3-31

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A PIGGY-BACK NEAR-BOTTOM GEOPHYSICAL SURVEY USING THE ABE VEHICLE

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Summary

The Autonomous Benthic Explorer (ABE) of the Woods Hole Oceanographic Institution acquired an extremely high resolution near-bottom dataset of bathymetry, magnetics, temperature, optical backscatter, conductivity, and digital video imaging along and across the narrow neovolcanic and active tectonic zone of the southern East Pacific Rise (17° to 19°S) during a total of 19 individual nighttime deployments of cruise AT3-31 of the *Research Vessel Atlantis*. Its pencil-beam scanning sonar provided an echo-sounding capability unprecedented in tight coverage (2x5 m footprint) and the detail of measured relief. Contouring of gridded sounding at 50 cm resolution produces a convincing picture of individual fault scarps, fissures, lava mounds, collapse pits, summit troughs, breached lava tubes, open-lava channels and lava pillars. Maps of seabed slopes (derived by taking the derivative of the gridded data) are also remarkable in defining bulbous shapes that take on the appearance of lava flows superimposed on each others like shingles on a roof. The absence of track parallel artifacts is astonishing in the derivative calculations. The three-axis magnetic measurements reveal a low magnetization of the active zone of diking compatible with the upper crustal layer of the ridge crest being still warm from recent intrusion. Contours of the magnetic anomalies portray a sequence of ridge-normal belts of magnetization contrast that point to the lateral spilling of magma through the imaged channels and subsurface conduits and carrying of molten fluid across the summit and down the flanks of the axial high as an important process for the continued surficial thickening of the ocean crust away from the axial zone of intrusion. The temperature and optical backscatter probes discovered hot-water vents on the flanks of the axial high and along fault scarps that bound the zone of contemporary extension and collapse. In addition, the ABE group tested the feasibility of recovering basalt glasses with ABE. It turned out that all three trials successfully recovered rock core samples, and each one is fully documented with video snapshots of the seafloor.

Nineteen deployments were undertaken in three areas between 17°24'S to 18°39'S, which we call northern, middle, and southern. Although not all produced satisfactory data, they provided a beneficial learning experience (described below) that improved the performance and reliability of this unique mapping tool. We found that the strategy of running closely-spaced (15 to 40 m) and parallel tracks in a "mowing-the-lawn" type exercise to be the most effective use of ABE's survey capability. From this approach we believe that we have gained a greater understanding of what we were exploring than with zig-zag lines across features of interest laid out in a reconnaissance mode.

Acknowledgments

The success of this piggy-back program was due in large part to the professional and efficient operation of *R/V Atlantis* by her Officers and Crew. The efforts of the Shipboard Technical Staff are greatly appreciated, and the interactions between the scientists and crew were all positive. No additional ship time was requested for this piggy-back program, and we are particularly indebted to John Sinton, Rodey Batiza, and Ken Rubin, the host PIs for this cruise, for their patience during the first several ABE deployments. Some time was deducted from their night sampling program to monitor ABE's capabilities, and we hope that by sharing our results with them, we will compensate for that set-back. We are also indebted to them for inviting us to participate in several Alvin dives, which has contributed to widen our perspective on the accretionary processes of the neovolcanic zone. Most of all, we are indebted to the ABE group, comprised by Al Bradley, Dana Yoerger, Al Duester, and Rod Catanach. Throughout the cruise, they went out of their way to understand and meet our scientific expectations, spending very long hours in this endeavor. The success of this project is a tribute to their expertise and professionalism. This piggy-back project was funded by the U.S. National Science Foundation, under the auspices of its RIDGE Initiative.

Objectives

The characterization of three discrete eruptive events along the superfast spreading East Pacific Rise at 17°24'-18°39'S was the main focus of the Alvin and night sampling program led by John Sinton, Rodey Batiza, and Ken Rubin. Based on the identification of individual flow units during previous submersible and sampling cruises, three areas were targeted for detailed geological mapping (Figures 1 and 2): The northern area (17°24' - 33'S), the middle area (18°10' -22'S), and the southern area (18°33' - 37'S). The objectives of the ABE program was to contribute near-bottom high-resolution bathymetry, magnetic data, and stereo snapshot video to the main program in order to constrain the dimensions, along-axis continuity, and morphology of individual flows .

There are no substitute for direct observations of the seafloor from a submersible, and the capability for experienced observers to guide exploration in real-time. However, remotely operated or autonomous underwater vehicles can gather near-bottom images between Alvin tracks, as well as systematic high-resolution geophysical profiling over an entire study area. The Autonomous Benthic Explorer (ABE) vehicle recently developed at WHOI is uniquely suited to supplement Alvin surveys, and it was deployed during most night programs to operate while rock-coring and dredging. ABE followed pre-programmed track lines with great accuracy, continuously acquiring geophysical data with a variety of sensors, including a 3-component magnetometer, an Imagenex pencil scanning sonar, a digital stereo camera system, a CTD sensor, an optical backscatter sensor, and a forward looking narrow beam sonar.

Very high resolution bathymetry maps were acquired with the Imagenex in the northern and middle areas, two areas of contrasting morphologies. While the northern area is characterized by a broad, smooth axial dome with only a small (< 100 m wide, < 12 m deep) "axial summit caldera" at its summit, the middle area is notched by a large (500-1000 m wide, 50-100 m deep) summit trough, whose morphology is clearly dominated by tectonism (Figure 2). The footprint of the acquired depth soundings averages 2m x 5m, and the vertical resolution exceeds 50 cm. Near-bottom magnetic data acquired by ABE are expected to outline individual flow units, and potentially, their associated less-magnetized (still warm) feeder dikes. For additional constraints, slabs from 70 basalt samples collected with Alvin have been prepared during the cruise and their magnetization properties will be measured in the Paleomagnetic Laboratory at Lamont-Doherty in collaboration with Dennis Kent (samples are listed in Tables 1, 2, and 3). Four deployments were dedicated to the acquisition of continuous video imagery in order to ground truth specific bathymetric features and evaluate the variability of flow morphologies.

ABE operations: Limitations, improvements, and compatibility with other night programs

This program represents the first intensive use of ABE, which had proven its potential during several pilot projects over the past few years. Despite the difficulties encountered at the beginning, the preliminary results are stunning and the data quality largely exceeds our wildest expectations.

The first few deployments were devoted to testing each acquisition component of ABE while it operated within the apex of three acoustic transponders used for its navigation. Because ABE is hardwired to listen to 4 transponders frequencies only, and because switching to another set of transponders requires swapping the appropriate electronic boards (a task not easily done on a daily basis), deployments were restricted to the center of the three areas investigated by Alvin. In this way, we mostly remained within 1/2 hour steaming distance from the rock core and dredging sites explored during the night program, making it possible to acoustically monitor ABE's progress while sampling. As we gradually smoothed out all of the initial technical problems with ABE, we became able to stop monitoring ABE altogether while rock core and dredging operations took place as far away as 8 miles. It also made it possible to develop a survey strategy that optimally utilized ABE unique capabilities of following pre-programmed tracklines. One major improvement concerned the navigation software. Dana Yoerger conceived an algorithm to assign for each track segments the appropriate time window expected for each transponder frequencies. This gating of the travel-time eliminated spurious heading switches which ABE would have otherwise followed when it interpreted surface bounces as direct water paths. The navigation was also greatly enhanced in the post-processing stage. By adjusting the relative transponder positions by a few meters in an iteration process until the scatter in the transponder fixes was minimized, the survey tracks became very precisely defined. As a results, we adopted a different survey strategy consisting in surveying along parallel tracks spaced only 15 to 40 meters apart. This approached produced maps (rather than sets of single tracks) of the bathymetry and geophysical anomalies .

The battery capacity was a limiting factor during the first phase of the cruise, when deployments averaged 1 to 3 hours. However, after several charge/discharge cycles, every ABE deployments exceeded 5 hours on-bottom; the last few deployments provided up to 12 km of bottom-following tracks (over smooth topography).

Dive narratives

Southern area (Figure 3):

ABE 22 (February 4): ABE descended slowly describing large circles, due to a problem with compass heading calibration.

ABE 23 and 24 (February 5 and 6): two surveys describing long zig-zags across the ridge crest. Imagenex operation was tested during ABE 23. However, the Imagenex pressure bladder leaked oil on deck after that deployment and Imagenex was removed and replaced by an equivalent weight for ABE 24

ABE 25 (February 7): Imagenex was still under reparation for that deployment. Consequently, we planned a video survey on the east flank, with a series of ridge-parallel tracks following approximately the bathymetry contours. The goal was to systematically map the ratio of lava channels to pillow flows per unit length of ridge, as a function of distance from the ridge axis.

ABE26 (February 8): Sea state was relatively high, and the bow thruster was not operational. To our chagrin *Atlantis* and ABE collided immediately after ABE was released, and ABE's descent weight separated. ABE was recovered with some serious damage: the protective housings around the two aft propellers were sheared off. It took two days to assess that ABE electronic and mechanical components were sound.

Middle area (Figure 4):

ABE 27 (February 10): Closely spaced survey tracks were planned for this dive, but the program aborted after 45 min. on bottom due to battery limitation. Other problems limited the quality of the collected data, including poor attitude sampling and a gap in the magnetic record.

ABE 28 (February 11): ABE went on a walkabout up the wall of the large summit trough rather than along the zig-zag tracks planned on the floor of the trough. While the range gates were tightened to prevent bounce returns from getting in after the vehicle reached bottom, a bad fix received just before ABE touched down made ABE think it was beyond the limits of its programmed survey. Accordingly, ABE made a bee-line southward on a dead-reckoning trajectory. When it recovered navigation, it turned toward the nearest way point, which unfortunately happened to be the last one. ABE quit once it reached that way point after 45 min. on-bottom.

ABE 29 (February 12): ABE once more did not get the right fixes at the beginning of the survey, and skipped through the first two track lines. It then recovered and nicely completed the planned zig-zag lines.

ABE 30 (February 13): In view of the previous navigation difficulty, it was decided to begin the survey at the top of the wall bounding the summit trough, where ABE would receive unambiguous fixes, rather than on the floor of the trough. This proved a successful strategy, and it also provided spectacular bathymetry data of the fault scarps. Tracks were laid 30 m apart, slightly oblique to ridge-axis-perpendicular The goal was to obtain good bathymetry data of the fissures and fault scarps and thus measure the tectonic strain of the landscape. It was decided not to run ridge-parallel to prevent ABE from bottom-following into some large open fissures and to obtain good magnetic survey tracks across the tectonic fabric.

ABE 31 (February 14): In view of the success of ABE30, the same survey strategy was adopted, laying 4 additional survey tracks to the south. The line ended with a long transect over the ridge flank to the west. ABE was slowed down on the downhill sections, which helped to keep it in proximity to the seabed.

ABE 32 (February 15): Four more lines were added north of ABE 30, and this time the survey ended with a long track on the east flank of the ridge axis. However, this line was not completed because of lack of time (ABE needs to leave bottom by 3:00 am to be on board a few hours before Alvin deployment)

ABE 33 (February 16): ABE collided with *Atlantis* during deployment and lost one of its aft motor. The pressure housing for one of the camera developed a leak, eliminating the possibility to run stereo video surveys. It took two days to repair ABE - an effort that required swapping one of the side thruster (which were not used for bottom following surveys) for the missing aft motor, and machining a new motor mount.

Northern area (Figure 5):

All 9 deployments in this area were successful (**ABE 34 to ABE 41,** February 18 to 25). In view of the positive results from the ABE 30, 31 and 32, we decided to devote the remaining deployments to acquire detailed bathymetric and geophysical maps of the axial summit region near 17°28'-29'S. To that end, we navigated closely-spaced lines parallel to the ridge axis (013°), which is the optimal direction for Imagenex to sample ridge-parallel fissures. All combined, the surveys of consecutive nights map an area with approximate dimensions of 800 m x 2600 m. We increased the track spacing from 30 to 40 m after it became clear that the swath data were accurate at least to that range. No track parallel artifacts are visible in the compiled gridded data. Just north of 17°28'S where the local topography varies by less than a few meters, we dedicated two deployments (ABE 39 ad ABE 40) to video acquisition, navigating ABE 5-7 m over the bottom. The video coverage is about 50%, and clearly details a network of lava channels converging downslope. The associated Imagenex data have sufficient resolution to map these channels, even though they have a relief smaller than 2 m.

Data quality

Attitude: ABE is equipped with both a flux-gate compass and a (pseudo) gyro compass used to continuously monitor heading, roll, and pitch. All three parameters are continuously recorded every 10 s. In order to evaluate any systematic bias in compass heading or bottom current, two short test lines were navigated in the NS and EW direction and backtracked using only dead-reckoning during deployment ABE32. ABE backtracked the NS line exactly, while it navigated both EW line with a constant set to the south, indicating that the compass system is accurate to better than a few degrees and that there exists a small southward bottom current within the study area.

Robertson forward looking sonar provided beautiful, highly accurate data (Figure 6). Data were recorded every second for the middle and northern areas (corresponding to a sample every 50 cm along track with an optimal speed of 50-65 cm/s), clearly detailing fissures, faults and even single pillow lava protrusions. Data were recorded every 10 s only for the southern area.

Imagenex: Imagenex was programmed to acquire 25 pings per sweep, with equal angle increment of 3.9° every 250 ms. Each sweep cycle lasted 10 sec: 8 seconds for sweeping with 25 ping from starboard to port, followed by a rapid non-sampling return to the starboard position. With an average survey speed of 50 cm/s, each sweep angled only 7° from the track-normal direction. When adopting a mean survey altitude of 20 m, this configuration samples the seafloor approximately every 2 m across-track and every 5 m along-track. Initially, we selected a conservative track spacing of 30m, providing a significant overlap between tracks. Later in the cruise, we successfully experimented with higher altitude of ABE and higher amplifier gains without degradation of the Imagenex performance; in fact, the proportion of good to bad returns exceeded 99% almost all the time. We spaced the survey tracks by 40 m for the last few deployments, without noticeable penalty with data coverage. Imagenex roll-bias was determined for each deployment by minimizing the variability of the return through a 360° on-site turn of ABE as soon as it reached bottom and was about to begin its first trackline. Estimated roll bias ranged from 4° to 8°. After applying these corrections, Imagenex data were gridded at 2m x 5m interval (across-track and along-track, respectively). The preliminary maps show no visual track-parallel artifacts - a testimony to the high quality of the data (Figures 7 and 8). We estimate the vertical resolution of the gridded maps attached to this report to be much superior to 1 m, and for the video surveys navigated 5 to 7 m off-bottom, to be much better than 50 cm.

3-component magnetometer: Overall, the magnetic data provided a clear, noise-free signal (Figure 6). Calibration loops were systematically run during each of ABE's descent. These loops reveal a significant variability in the measured amplitude of the total field. In order to evaluate whether most of this variability can be attributed to subtle differences in the gains of the amplifiers for each field component, we sought to minimize the variability of the total field through a stationary loop by applying different proportionality coefficients to each of the three components of the field. Preliminary results suggest that the two sub-horizontal components are 4-8% too high relative to the sub-vertical component. They also suggest that ABE possesses a small permanent field (about 100-150 nT) oriented sub parallel to its long axis. Additional on-land processing should determine these correction coefficients with greater accuracy.

To our knowledge, the 15 to 40 m spacing of the survey tracks in the northern study area provide the first 2-dimensional near-bottom magnetic survey of a sizable portion of the mid-ocean ridge axis (Figure 9). Preliminary processing suggests that at a scale of a few 100m, variations in intensity of magnetization are aligned perpendicular rather than parallel to the spreading direction, at least for robust segments of the ultrafast EPR. It may be interpreted to indicate that surface flows extend at least several hundred m off-axis, or that the magmatic segmentation of the ridge is stable over at least 5000-6000 yr (= 400 m off-axis / (72 m / 1000 yr half spreading rate).

Temperature and optical back-scatter probes

ABE is equipped with a Sea-Bird CTD probe and a Seapoint Turbidity meter which both recorded data continuously throughout all the deployments. The optical backscatter probe drifts somewhat during and between surveys, but this can be corrected to provide relative measurements which appear stable and repeatable. The temperature probe also seems to shift slightly from dive to dive, but relative measurements appear consistent throughout the cruise (Figure 12): all dives display similar trends of temperature with depth, and maps of potential temperatures will be produced for the middle and northern area.

Video snapshots (Figure 14)

Digital video images were automatically acquired each time ABE descended within 7 m from the bottom. However, except for five deployments (ABE 25, portions of ABE 37 and 38, and most of ABE 39 and ABE 40), the effort was focused on Imagenex and magnetic acquisition, and the survey tracks were navigated 20-30 m off-bottom. The 5 video surveys produced thousands of black-and-white snapshot video every 5 s along track. The strobe lights triggered approximately 95% of the time, providing almost continuous video coverage along track. After ABE 36, one of the camera pressure housing developed a leak, which could not be fixed at sea. The stereo capability was lost, and subsequent video surveys relied on the starboard camera only.

Rock Coring:

We tested the feasibility of recovering basaltic glasses with ABE using rock coring methods during ABE 40 and ABE 41. Aluminum tubes approximately 2' long were filled with wax and attached vertically underneath ABE. For ABE 41, 2 cores were mounted in such a way that one would be retracted out of the way in a horizontal position when the other one was spring loaded into position. At selected positions, ABE was programmed to slowly descend until touching bottom and to "twist", with the expectation that basaltic glass would smear into the waxed extremities of the tubes. All three trials successfully recovered basaltic glasses, and the operations are continuously documented with video snapshots of the seafloor.

Preliminary results

Preliminary results are described in the captions of Figures 7 through 14

Table 1. Basalt samples collected with Alvin in the southern area which have been prepared for magnetic analysis. Alvin's X,Y coordinates are relative to a local origin of 18°41.00'S, 113°26.00'W.

Sample #	Date	Depth (m)	X,Y (m)	Latitude	Longitude
3343-8	2/2/1999	2672	2826,4801	18°38.40'	113°24.39'
3344-4	2/3/1999	2716	4064,10840	18°35.12'	113°23.67'
3344-6	2/3/1999	2700	3971,10384	18°35.37'	113°23.74'
3344-8	2/3/1999	2702	4566,10974	18°35.05'	113°25.41'
3344-9	2/3/1999	2686	3829,9397	18°35.90'	113°28.82'
3344-10	2/3/1999	2680	3843,9602	18°35.80'	113°28.81'
3345-2	2/4/1999	2670	3012,6346	18°37.55'	113°24.29'
3346-4	2/5/1999	2680	1932,2359	18°42.27'	113°24.90'
3346-10	2/5/1999	2676	2315,4015	18°43.17'	113°24.68'
3346-12	2/5/1999	2679	2446,4099	18°43.22'	113°24.60'
3346-14	2/5/1999	2677	2603,4273	18°43.31'	113°24.51'
3346-15	2/5/1999	2671	2700,4804	18°43.60'	113°24.46'
3347-1	2/6/1999	2664	1716,11348	18°34.85'	113°25.02'
3347-2	2/6/1999	2643	1309,11531	18°34.75'	113°25.26'
3347-3	2/6/1999	2661	1631,11572	18°34.71'	113°25.07'
3347-9	2/6/1999	2610	1778,13587	18°33.63'	113°24.99'
3348-3	2/7/1999	2618		18°31.67'	113°24.80'
3348-4	2/7/1999	2614		18°31.78'	113°24.72'
3349-2	2/8/1999	2677	3472,8414	18°36.43'	113°23.93'
3349-4	2/8/1999	2672	3590,7499	18°36.66'	113°23.96'
3349-10	2/8/1999	2679	3249,7229	18°37.08'	113°24.15'
3350-1	2/9/1999	2729		18°41.52'	113°25.62'
3350-5	2/9/1999	2678	1732,1024	18°40.38'	113°25.02'
3350-6	2/9/1999	2690	1992,1078	18°40.38'	113°24.84'
3350-8	2/9/1999	2715		18°40.32'	113°24.66'

Table 2. Basalt samples collected with Alvin in the middle area and which have been prepared for magnetic analysis. Alvin's X,Y coordinates are relative to a local origin of 18°20.00'S, 113°24.00'W.

Sample #	Date	Depth	X,Y	Latitude	Longitude
3351-6	2/10/1999	2686		18°08.67'	113°20.59'
3351-7	2/10/1999	2712		18°08.86'	113°20.52'
3351-9	2/10/1999	2686		18°09.21'	113°20.50'
3351-10	2/10/1999	2701		18°09.63'	113°20.57'
3351-13	2/10/1999	2691		18°09.93'	113°20.72'
3352-2	2/12/1999	2679		18°10.69'	113°21.00'
3352-8	2/12/1999	2673		18°12.66	113°21.23'
3353-6	2/13/1999	2666		18°21.27'	113°21.27'
3354-4	2/14/1999	2688		18°17.18'	113°22.15'
3354-5	2/14/1999	2698		18°17.38'	113°22.43'
3354-6	2/14/1999	2650		18°17.38'	113°22.59'
3354-8	2/14/1999	2657	3065,4283	18°17.83'	113°22.21'
3354-9	2/14/1999	2676		18°17.93'	113°22.38'
3354-10	2/14/1999	2677		18°17.95'	113°22.42'
3355-6	2/15/1999	2643	4245,9445	18°14.88'	113°21.59'
3355-7	2/15/1999	2689	3635,9125	18°15.05'	113°21.94'
3355-8	2/15/1999	2664	3480,9100	18°15.07'	113°22.03'
3356-11	2/16/1999	2678		18°12.71'	113°21.40'
3356-13	2/16/1999	2659		18°12.71'	113°21.22'
3356-14	2/16/1999	2639		18°12.76'	113°21.12'
3356-16	2/16/1999	2630		18°12.29'	113°21.02'

Table 3. Basalt samples collected with Alvin in the northern area and which have been prepared for magnetic analysis. Alvin's X,Y coordinates are relative to a local origin of 17°25.08'S, 113°12.853'W.

Sample #	Date	Depth (m)	X,Y (m)	Latitude	Longitude
3357-5	2/18/1999	2568	-13,-5052	17°27.82'	113°12.86'
3359-1	2/20/1999	2609	-2317,-15625	17°33.55'	113°14.16'
3359-3	2/20/1999	2591	-2700,-15784	17°33.64'	113°14.38'
3359-4	2/20/1999	2605	-2913,-15869	17°33.64'	113°14.50'
3360-1	2/21/1999	2707		17°28.65'	113°13.76'
3360-5	2/21/1999	2569		17°28.64'	113°13.11'
3360-8	2/21/1999	2572		17°29.13'	113°13.13'
3361-1	2/22/1999	2634	-627,-10933	17°31.10'	113°13.21'
3361-3	2/22/1999	2582	-1436,-10990	17°31.40'	113°13.66'
3361-5	2/22/1999	2585	-1545,-10778	17°30.93'	113°13.75'
3361-6	2/22/1999	2582	-1383,-10724	17°30.90'	113°13.65'
3361-8	2/22/1999	2596	-1324,-9633	17°30.30'	113°13.61'
3361-12	2/22/1999	2654	-1325,-8970	17°29.95'	113°13.82'
3361-13	2/22/1999	2601	-1180,-8937	17°29.93'	113°13.54'
3363-3	2/24/1999	2587	-1835,-12418	17°31.81'	113°13.89'
3363-5	2/24/1999	2590	-2007,-13088	17°32,18'	113°13.99'
3363-7	2/24/1999	2592	-2227,-13952	17°32.65'	113°14.11'
3364-1	2/25/1999	2711	-1234,-3606	17°27.04'	113°13.55'
3365-1	2/26/1999	2622	2104,-1533	17°25.88'	113°11.67'
3365-2	2/26/1999	2586	1678,1114	17°25.68'	113°11.91'
3365-3	2/26/1999	2580		17°25.67'	113°11.97'
3365-5	2/26/1999	2568		17°25.90'	113°12.28'

Figure Captions

Figure 1. Survey area.

Figure 2. Typical cross-sections of the axial high through the northern, middle, and southern study areas. Vertical exaggeration is 5. Each profile averages two successive pings acquired along-axis with the SeaBeam 2000 or Hydrosweep swath bathymetry system. Within each frame, the bottom profile is shown at its correct depth, while successive ones are offset vertically by 50 m; 100-150 m along-track separate adjacent profiles.

Figures 3, 4 (a & b), and 5. Tracks of ABE deployments in the southern, middle, and northern areas, respectively. Bathymetry is SeaBeam 2000 data gridded at 100 m spacing and contoured every 10 m (the jitters in the track lines reflects small residual artifacts in ABE's post-processed navigation rather than actual course changes.)

Figure 6. (*Bottom*) Example of the detailed topographic profiling acquired by ABE's forward looking narrow-beam sonar across the axis in the southern area (ABE23). Vertical exaggeration is approximately 16. *Compare this profile to those displayed in Figure 2 from SeaBeam 2000 data acquired over the same area*. The axial cleft which marks the present-day axis of accretion is centered on distance "0". ABE was navigated at a constant water depth of 2680 m. (*Top*) Corresponding total magnetic field. The ~500 nT negative anomaly centered above the axial cleft is an ubiquitous feature throughout the northern and southern study area.

Figures 7 and 8. Bathymetric maps derived from gridded Imagenex data for the middle and northern areas, respectively. Contour interval is 2 m for the southern area and 1 m for the northern area. Grid lines are spaced every 100 m. Data are gridded on a 2 m x 5m mesh (EW x NS), as constrained by the 1.5-2 m across-track beam spacing and the ~5 m along-track ping interval. *Compare these maps to those of SeaBeam 2000 bathymetry for the same areas which are displayed in Figures 4b and 5.*

In the middle area (Figure 7), Imagenex data clearly resolve the individual fault scarps bounding the large summit trough, as well as a several-meters-wide en echelon fissure which bisects two small constructional volcanoes on the floor of the trough. In the northern area (Figure 8), Imagenex data outline an en-echelon eruptive fissure 8-12 m deep and 50-80 m wide. Individual lava pillars within this cleft are also resolved, as well as branching networks of ~4-m-deep collapse lava tubes and tributary networks of 1-m-deep lava channels emanating from the cleft.

Figure 9. Map of the bottom gradient (northern area). Unit is degree of slope. *Note that slopes are ~0°, except for curved lineaments with slopes of ~10-15° which overprint each other in a shingled pattern . We interpret these to represent overlapping fronts of successive lava flows.*

Figure 10. Map of the bottom relief (in meter) of the northern area which has been filtered to remove the longer wavelength component of the topography. *Salient features have "negative" topography", indicating that eruptive processes in this area produce smooth lobate flows fed either by a network of lava tubes whose roofs tend to collapse, or by surficial lava channels . In this particular area, eruptive processes do not involve constructional volcanism characterized by eruptive cones and pillow mounds.*

Figures 11. Total magnetic field for the northern area contoured at 100 nT interval. The total field has been calibrated for relative variations in the amplifier gains of each of the three components, but is not upward continued to a level datum. ABE was generally navigated 20-25 m above seafloor, except for the NW corner where it hovered 5-7 m above the bottom. *Note that low field values are systematically associated with the axial cleft. At this resolution level, magnetic anomalies are oriented *parallel* (rather than normal) to spreading direction. This may indicate that the largest anomalies are associated with the most recently erupted lavas, which flow down-slope normal to the ridge axis.*

Figure 12. In-situ temperature versus depth for each of the 8 deployments in the northern area. There exists a consistent trend for all the deployments, in addition to some localized temperature anomalies (often clipped in these displays). Data need to be corrected for this trend in order to map potential temperature variations. Deployments ABE 37 through ABE 40 were navigated partly at 20-25 m above bottom and partly at 5-7 m above bottom, explaining the increased scatter in the data.

Figures 13. Temperature and optical backscatter anomalies recorded by ABE near 17°27.7'S, where a black smoker was also captured on video snapshot. CTD and optical backscatter anomalies were continuously recorded during every deployments of ABE, and maps of the temperature and optical backscatter anomalies will be produced for the middle and northern area.

Figures 14. Example of hand-stitched mosaic from ABE's video snapshots for the northern survey area. About 50% of the seafloor is imaged with video snapshots in the NW corner of that study area. There is a perfect correlation between the pattern of tributary lava channels inferred from ABE's high resolution bathymetry map and that interpreted from the video snapshots.