here would represent dramatic improvements over the "do nothing" situation in which nearly all of the delta will be lost.

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Author Information

Wonsuck Kim and David Mohrig, Department of Geological Sciences, University of Texas at Austin; E-mail: delta@jsg.utexas.edu; Robert Twilley, Department of Oceanography and Coastal Sciences, Louisiana State University, Baton Rouge; Chris Paola, Department of Geology and Geophysics, University of Minnesota, Minneapolis; and Gary Parker, Department of Civil and Environmental Engineering and Department of Geology, University of Illinois, Urbana-Champaign

Seismic Imaging in Three Dimensions on the East Pacific Rise

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The U.S. R/V *Marcus G. Langseth* (operated by the Lamont-Doherty Earth Observatory of Columbia University) sailed in late June 2008 from Manzanillo, Mexico, to the 9°50'N area of the East Pacific Rise (EPR), a site of vigorous hydrothermal venting (Figure 1). The cruise, MGL0812, the first research deployment of the *Langseth*'s advanced three-dimensional (3-D) seismic imaging capability, had as its objective obtaining high-resolution images of crustal structure beneath the ridge crest and adjacent regions.

The benefits of 3-D seismic imaging had been outlined in a U.S. National Science Foundation (NSF)–sponsored workshop in 2005 [*Mutter and Moore*, 2005]. Short courses on techniques of 3-D survey planning were given at AGU Fall Meetings in 2007 and 2008. This brief report describes experiences during the cruise, with the objective of aiding future researchers in planning cruises using *Langseth*'s unique imaging capability for 3-D.

3-D Seismic Acquisition

To acquire 3-D data, researchers on board *Langseth* deployed a system similar to that used for industry acquisition (see Figure S1 in the electronic supplement to this *Eos* issue (http://www.agu.org/eos_elec/)). Four solid Thales/Sercel hydrophone array "streamers"—with no fluid inside the streamer jackets, thus improving streamer signal-to-noise ratio—were deployed. Each streamer was 6 kilometers long and contained 468 groups of hydrophones, with the groups of hydrophones spaced 12.5 meters apart. Paravanes (towed submerged planar devices; see Figure S3 in the electronic supplement) separated the streamers to 150-meter spacing so that the total spread separation between the two outermost streamers was 450 meters. The air gun source comprised four linear arrays, each with nine guns, for a total of 1650 cubic inches, towed beneath a linear float that allows towing depth to be held constant at 7.5 meters. The air gun source was fired in a "flip-flop" manner, alternating between two port and two starboard linear arrays so that each sail line along which the vessel traveled acquired eight common midpoint (CMP) profiles spaced 37.5 meters apart with a 3300-cubic-inch source and shot spacing of 37.5 meters. Streamers and air gun arrays were navigated with a combination of a Global Positioning

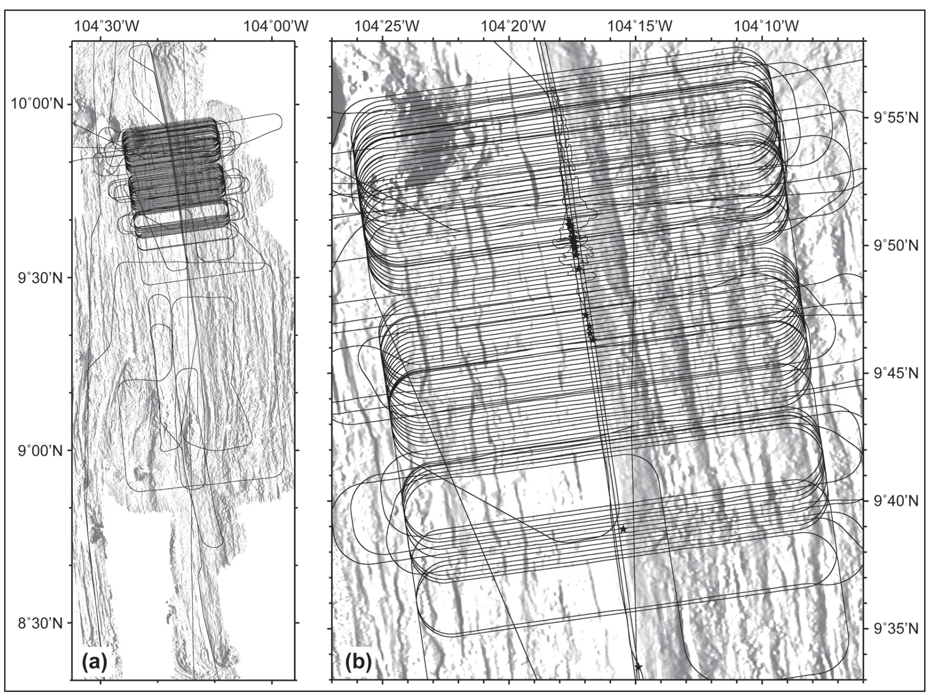

Fig. 1. (a) The complete line coverage from R/V Marcus G. Langseth *cruise MGL0812. (b) A detail from Figure 1a of the area of three-dimensional acquisition. The locations of hydrothermal vents are indicated by stars. Survey sail lines were acquired in regular racetrack pattern loops. Extended line changes that can be seen outside the regular racetracks accommodated the maintenance of air guns and other equipment.*

System instrument, acoustic transponders, and streamer compasses, providing receiver position accuracy of better than 3 meters. Twenty devices ("birds") that contained the compasses controlled the depth of each streamer to accuracies better than 1 meter (towing depth initially was 7.5 meters but then deepened to 10 meters due to weather conditions and to improve control during turns by the vessel).

Survey sail lines were separated by 300 meters and were acquired in racetrack pattern loops with each loop having a breadth of about 6000 meters (see Figure S5 in the electronic supplement). Successive racetrack loops were therefore offset 300 meters (to the south, in this instance) to achieve continuous coverage (see Figure S2 in the electronic supplement). Sail lines 24 kilometers long were acquired, providing full-fold coverage across 16 kilometers. A typical sail line took about 3 hours to acquire, and a complete loop took 8.5–10 hours. As is typical industry practice, maintenance was carried out on air guns and other systems by using extended line changes, continuing along the shooting direction, and delaying the vessel's transit to the next sail line.

Operational Experience During Summer 2008

Eventually, 3-D coverage was achieved in two areas (Figure 1b). The larger area comprises a set of 94 lines (one partial) between 9°57'N and 9°42'N made up of two complete racetracks and the northern lines of a third racetrack that was not completed.

Lines are of three types: primary (P, those acquired along the intended grid pattern), infill (I, those acquired in between P lines where streamer feathering, i.e., the angle the streamer makes to the sail line, resulted in discontinuous primary coverage), and reshoot (R, those that were reacquired along planned P tracks due to either technical problems during primary acquisition or data gaps associated with power-downs for animal sightings). Infill was performed to ensure that full data collection achieved at least 80% of the nominal fold in the offset range of about 200–3100 meters (i.e., the fold that would have been achieved in case of perfectly regular acquisition). This satisfied the survey's main objectives because the principal seismic signals of interest that permit imaging of the axial magma chamber and to some extent of the layer 2A event (i.e., a horizon in the crust that may lie at the base of the extruded layer) were recorded in that range of offsets. Experiments conducted over different geologic targets may require a different infill criterion, appropriate for the specific imaging objectives. The second 3-D area comprised 14 lines acquired in the southern part of the third racetrack where no infill and reshoots were acquired. Additionally, data were acquired along the ridge axis through the 3-D area and to the south, and a number of individual lines outside the 3-D area also were acquired (Figure 1a).

During the main acquisition phase of the cruise, extended line changes that increased the size of the racetrack loops totaled 44 hours and were used for various maintenance tasks and operational disruptions: air guns, 14 hours, 39 minutes; streamer, 16 hours, 45 minutes; compressors, 11 hours, 10 minutes; recording system, 27 minutes; workboat, 20 minutes; whale sighting, 22 minutes; and ship steering, 21 minutes. Loss of acquisition due to marine mammal sightings (three) was minimal, as expected for the area; however, a significant amount of time was lost during eight turtle sightings, which required air guns to be powered down. Among the nine lines along which gaps in the acquisition arose due to single or multiple power-downs, five were reshot and one was compensated for by an infill. The initial streamer and air gun deployment required 56 hours; the second deployment required about 22 hours. Equipment retrieval took 13 hours the first time and 14 hours the second.

In all, the cruise acquired 3781.95 kilometers of sail line data. These data comprise 111 lines (one partial) acquired perpendicular to the ridge axis (888 CMP lines). However, 10 lines needed to be repeated, and 14 infill lines were required as well. That is, the completion of 111 cross-axis lines suitable for 3-D processing required a total of 135 lines of acquisition. This means that 18% of the total cross-axis acquisition was used for reshoots and infill, less than the 25% multiplier on planned lines that often is used in the seismic industry. Given the modest streamer feathering (average, $0° \pm 5°$) during the survey, 25% is probably a more appropriate figure for planning most academic surveys.

Details of acquisition systems and data quality are available at http://www.ldeo.columbia.edu/3DMCS and in the electronic supplement to this *Eos* issue. A detailed discussion of 3-D cruise planning prepared by John Diebold of the Lamont-Doherty Office of Marine Operations is available at http://www.ldeo.columbia.edu/res/fac/oma/3D_Seismic/3Dcapabilitiesandcruiseplanning.html.

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—JOHN C. MUTTER and SUZANNE CARBOTTE, Lamont-Doherty Earth Observatory (LDEO), Columbia University, Palisades, N.Y.; E-mail: jcm@ldeo.columbia.edu; MLADEN NEDIMOVIC, Dalhousie University, Halifax, Nova Scotia, Canada; JUAN PABLO CANALES, Woods Hole Oceanographic Institution, Woods Hole, Mass.; and HÉLÈNE CARTON, LDEO