Cruise Report for A1-00-SC Southern California Earthquake Hazards Project, Part A

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INTRODUCTION

A three-week cruise to obtain high-resolution boomer and multichannel seismic-reflection profiles supported two project activities of the USGS Coastal and Marine Geology (CMG) Program: (1) evaluating the earthquake and related geologic hazards posed by faults in the near offshore area of southern California and (2) determining the pathways through which sea-water is intruding into aquifers of Los Angeles County in the area of the Long Beach and Los Angeles harbors. The 2000 cruise, A1-00-SC, is the third major data-collection effort in support of the first objective (Normark *et al*., 1999a, b); one more cruise is planned for 2002. This report deals primarily with the shipboard operations related to the earthquake-hazard activity. The sea-water intrusion survey is confined to shallow water and the techniques used are somewhat different from that of the hazards survey (see Edwards *et al*., in preparation).

Project objectives

The Southern California Earthquake Hazards project activity is supported through the Coastal and Marine Geology Program of the Geologic Division and is a component of the Geologic Division's Science Strategy under Goal 1 --- Conduct Geologic Hazard Assessments for Mitigation Planning (Bohlen *et al*., 1998). The southern California urban areas, which form the most populated urban corridor along the U.S. Pacific margin, are among a few specifically designated for special emphasis under the Division's science strategy (Bohlen *et al*., 1998). The focus of the Southern California Earthquake Hazards project is to identify the landslide, earthquake, and tsunami hazards and related ground-deformation processes occurring in the offshore areas that have significant potential to impact the inhabitants of the southern California coastal region.

The primary objective of the project field activity is to help mitigate the earthquake hazards for the southern California region by improving our understanding of how deformation is distributed (spatially and temporally) in the offshore with respect to the onshore region. To meet this objective, we are investigating the distribution, character, and age (including evidence for recurrence of displacement) of deformation within the basins and along the shelf adjacent to the most highly populated areas (**Fig. 1**). The initial results from the field mapping under this project will be used to identify possible sites for deployment of acoustic geodetic instruments to monitor strain in the offshore region.

Study area

The priorities for the field-mapping program are keyed to those areas with the greatest potential for impact on the southern California populace. Cruises in 1997-1999 concentrated on offshore areas near the Los Angeles metropolitan area and reconnaissance lines south to San Diego. For the 2000 seismic-reflection cruise, the main work areas were designed to complete mapping of 1) the coastal strip between Pt. Dume, north of Los Angeles, and San Diego (especially 0-3 n. mi.), where much of the hazard appears to be associated with strike-slip or oblique-slip faults; and 2) the active faults within the Santa Monica, San Pedro, and San Diego Trough basins, where more extensive sedimentation has left a sufficient stratigraphic record to aid in dating the recent faulting (see **Fig. 1**). The final project cruise planned for 2002 will focus on the offshore extension of the fold and thrust belt of the Western Transverse Range into the Santa Barbara Channel, and the boundary in the Channel Islands region between the strike-slip dominated deformation of the inner California Borderland and the thrust and fold deformation of the Santa Barbara Channel.

Figure 2 shows a generalized depiction of faults in the southern California region (adapted from Greene and Kennedy, 1986). Further interpretation of the key structures of the inner California borderland are available from site-specific studies and regional tectonic syntheses (e.g., see Clarke *et al*., 1985; Ziony and Yerkes; 1985; Vedder *et al*., 1986; Vedder, 1987; Wallace, 1990; Legg, 1991; Crouch and Suppe; 1993, Klitgord and Brocher; 1996, Clarke and Kennedy, 1997; Dolan *et al*., 1997; Pinter *et al*., 1998; Bohannon and Geist, 1998; Normark and Piper, 1998; Marlow *et al*., 2000; and Rivero *et al*., 2000). A major goal of mapping under this project is to provide detailed geologic and geophysical information in GIS data bases that build on the earlier studies and use new data to precisely locate active faults, to map recent submarine landslide deposits (e.g., Bohannon and Gardner, 2001), and to identify potential fault and landslide tsunamigenic sources.

The planned trackline survey for the cruise A1-00-SC was intended to both fill in gaps in survey coverage resulting from equipment problems during cruise A1-98-SC (Normark *et al.*, 1999a) and to extend existing profiles from their termination at the three-mile limit as far as possible toward the shore. The nature and extent of the data gaps are illustrated by the compilation of existing trackline data (**Fig. 3**). The distribution of survey time between priorities 1 and 2 as noted above was intended to complete, as a minimum, a grid at two-kilometer spacings from the shore out to 40-50 km (see Fig. 3B in Normark *et al.*, 1999b). **Figure 4** shows the tracklines for A1-00-SC; note the work was concentrated inside the three-mile limit, with additional profiles collected from offshore Long Beach and the area within 30 miles north of San Diego.

OPERATIONS

This section gives an overview of the restrictions on sound sources, and information about the vessel, personnel, key operational events during the cruise, and equipment used. See **Table 1** for a list of personnel and **Table 2** for a more complete listing of general cruise operational information.

Restrictions on use of the acoustic sound sources

During the surveys in 1998 and 1999 using the multichannel seismic-reflection and Huntec systems offshore southern California, the project contracted with Cascadia Research to provide personnel for observing and recording marine mammal sightings (Normark *et al.*, 1999a, b); we did again in 2000. The mammal observers were to notify USGS personnel on watch to shut off the sound sources, other than echosounder, when marine mammals came within a specified radius of the source. The purpose was to observe restrictions resulting from the Marine Mammal Protection Act (MMPA; see below). The protocols for shutdown of the sound sources were established prior to sailing, and the decision to shutdown was vested solely with the marine-mammal observers and was not subject to veto by the chief scientist. The preclusion zone is a function of the power of the source and mammal sighted. For example, in 1999 we used both air-gun and Huntec sound sources and shutdown was required when whales approached within the specified 250-m-radius preclusion zone around either source. However, the preclusion zone radius was only 100 m for odontocetes (e.g., dolphins) or pinnipeds (e.g., seals). In 2000 we used a lower-power minisparker sound source in addition to the boomer and were allowed an exclusion zone radius of 30 m for odontocetes and pinnipeds, and 250 m for all whales. In all 3 years the radius of the whale exclusion zone exceeded the ship length + tow distance of the sound source, so observers had to look forward, to the sides and aft.

Following is a brief recounting of the permit process. The procedures for acquiring necessary permits to conduct seismic-reflection surveys off California using small sound sources are described in full by Childs *et al.* (1999).

For the 2000 field operation, the National Marine Fisheries Service (NMFS), which is the agency empowered to enforce the MMPA, again required that the U.S. Geological Survey apply for an Incidental Harassment Authorization (IHA). The IHA request process nominally takes 120 days and the request was submitted to NMFS in mid-January 2000. One part of the IHA process requires NMFS to make the application available for public comment, which is done through notification in the Federal Register.

In addition, the California Coastal Commission (CCC), under authorization granted by provisions of the Coastal Zone Management Act, required the USGS to submit a ‘consistency determination,’ which documents that a federal activity (in this case the geophysical survey) will be conducted (1) in a manner consistent with the state’s coastal-zone management program and (2) in such a way that there will be no effect on coastal zone resources. The process of application to the CCC included discussion and review at a monthly meeting of the CCC, and for the 2000 cruise, the hearing was in early April. On 12 April, the USGS received unanimous approval from the CCC for operations as specified in the IHA permit application provided that the USGS agreed to modify its application such that the same preclusion area for marine mammals (30-m radius) be used for both shallow and deep water operations.

After responding to questions from other parties (in addition to the CCC) raised as a result of the public comment period, there were followup discussions between the USGS and NMFS, and the USGS received the IHA permit on 5 June 2000. The IHA specified, among other restrictions, that:

(1) the USGS would have a minimum of three properly trained mammal observers approved in advance by NMFS;

(2) there would be a minimum of two mammal observers on watch during any period when any seismic sound source was being used; this requirement meant that the USGS had to provide a total of five marine mammal observers on the vessel to cover 24 hours of operation per day;

(3) the observers would record and report to NMFS "the estimated number of marine mammals (by species) that may have been harassed as a result of the seismic sources through noted behavioral change" and "any behavioral responses or modifications of these behavioral indicators due either to the seismic-reflection sources or to the vessel's noise";

(4) the protocol for shutdown of the minisparker sound source would be 30 m for dolphins, seals, and sea lions and 250 m for whales;

(5) at "all times, but specifically during nighttime surveys, the [ship's]crew must be instructed to keep watch for marine mammals [and that] if any are sighted, the watch-stander must immediately notify one of the biological observers;"

(6) "observations ……..on marine mammal presence and activity will begin a minimum of 30 minutes prior to the time that the seismic source will be turned on…." ; and

(7) the results of the monitoring will be reported to the Southwest Region, NMFS, and the Office of Protected Resources within 160 days from the end of the geophysical survey cruise.

Other restrictions included: in the event of observation of whales during daylight hours in shallow-water areas where nighttime surveying was planned, then surveying in water depths of less than 50 m was precluded. Although operating in deeper water was permitted, the vessel had to transit to the deeper water area with a minimum of 30 minutes of daylight to allow the observers to note if whales were present.

The program cost for meeting the requirements of the IHA are three fold: (1) the number of pay periods of CMG personnel required for the permitting process, which lasted from mid-December to early June, (2) the loss of seismic-reflection data collection during 41 shutdowns plus 2 transits to deeper water triggered by whale sightings by the marine mammal observers, and (3) the costs of the contract for the marine mammal observers and production of the required report for NMFS.

In addition to the restrictions on the survey resulting from the oversight responsibilities of the NMFS and CCC, the California State Lands Commission (SLC) has regulatory authority over waters within three miles of the coast. At the present time, the SLC prohibits all compressed-air seismic sound-sources (specifically air guns and water guns) regardless of size and regardless of the intended use, e.g., scientific research to define earthquake hazards is not sufficient to obtain an exemption to the ban. As a result, previous surveys with air-gun sources could not approach within three miles of the coast (e.g., note the data gap along the coast depicted in the trackline map of **Fig. 3**). The SLC also has restrictions on power of non air-gun sources such as sparker and boomer systems, but does allow small ones within the three-mile limit. As a result, the 2000 survey attempted to use a minisparker source of $\leq$2kJ for the multichannel seismic-reflection work.

All communication between the mammal team and the geophysical watchstanders was by radio. All conditions stated in the protocol were followed throughout the cruise. **Appendix 1** is the report provided by Cascadia Research detailing the recordings of the marine-mammal observers as required by the IHA.

Research platform

The FY 2000 field program was conducted using a leased vessel, the 176-ft-long *M/V Auriga*, owned and operated by F/V North Wind, Inc. The *M/V Auriga*, which was initially designed as an offshore oilfield supply vessel, is currently outfitted as an Alaskan crab-fishing boat. There are no laboratory compartments on the *M/V Auriga*, but the large open fantail area is amenable to installation of standard container shipping vans, each of which was outfitted for specific scientific function (**Fig. 5**).

For the cruise A1-00-SC, three of the four vans installed on the *M/V Auriga* were the mainstay of the survey activities: (1) an electronics lab/underway-watch van for operating the navigation system and primary geophysical instruments, (2) a mechanical shop used for maintaining the tow sleds for the seismic-reflection sound sources, the winches and davits used for launch and recovery of both the boomer systems, and the streamer and sound source for the high-resolution reflection profiling system; and (3) an office van that also contained power supply systems for the acoustic sound sources. In addition to the science vans, a smaller van that was outfitted as quarters for two of the scientific party was placed on the after side of the 01 deck. **Figure 5** shows the layout of science vans and equipment on the work deck of the vessel. The four vans and all associated deck equipment, including winches and davits, were loaded during a two-day mobilization period at Redwood City, CA.

Scientific Party

The scientific party for A1-00-SC included three scientists from the Southern California Earthquake Hazards project, five geophysical watchstanders, and six technical-support personnel from the Western Region CMG Marine Facilities staff (**Table 1**). In addition, there were seven contract personnel, one to oversee operation of the deep-tow boomer, one to effect repairs to the minisparker sound source, and five to provide a two-person, 24-hour watch for marine mammals whenever the seismic-reflection systems were in use. Personnel transfers on the 7th, 20th, 23rd, and 25th of June maintained the total scientific staff on the vessel at no more than 16 at any time.

General Operations

The geophysical survey was set for 7 to 27 June, 2000, departing and returning to the port of Redwood City, California, on 5 and 29 June, respectively. The ship departed in mid-morning on 5 June 2000 (**Table 2**). Following the 34-hour transit to the western boundary of the work area, the ship arrived at Port Hueneme for repairs to the vessel's gyro compass. Following repairs and the first exchange of scientific personnel, the ship departed Port Hueneme to rendezvous with a small boat, *Blue Skies*, from which Greenridge Associates conducted measurements of acoustic sound-source parameters for the seismic-reflection systems to be used during the surveys. The acoustic measurements were conducted early on 7 June, and by mid-afternoon were completed. At that time, the seismic-reflection systems were deployed to begin the planned survey. The geophysical survey took place between late on the 7th to mid-day on the 27th of June, 2000, including the work in and around the ports of Long Beach and Los Angeles that is reported elsewhere (Edwards *et al.*, in preparation).

The general plan for survey lines during the cruise and the final survey tracklines (**Fig. 4**) differ considerably. There was significant loss of survey time as a result of equipment malfunctions. Specifically, the problems with the power supplies for the minisparker sound-source for the multichannel system resulted in multiple breaks in tracklines lines for testing. In addition, the minisparker could not be operated simultaneously with the boomer sound sources (either the Geopulse or Huntec) because of interference resulting from similar range of frequencies generated by the sources. This resulted in only one type of data, rather than both, being collected along each trackline. **Table 2** shows the milestones for the main operational activities and primarily shows those events that affected the collection of data; the table includes annotations for equipment failures and maintenance periods, personnel transfer periods, and interruptions in the collection of seismic-reflection data as a result of encounters with marine mammals.

Equipment Review

A brief description of the survey equipment used during the cruise is given below. For specific times of data collection for the different systems used during the survey, navigate from this website:

http://walrus.wr.usgs.gov/docs/infobank/lion/a/a100sc/html/a-1-00-sc.meta.html

Shipboard positioning system

Position data were collected with the USGS-designed YoNav Navigation system (Gann, 1992), with input from a CSI MBX3 GPS receiver operating in differential mode. The YoNav system is a PC-based data-acquisition and display program written in Microsoft C/C++ designed to provide navigation services on Windows NT platforms. The YoNav system incorporates a real-time trackline display and line-generating software for both the vessel's bridge watch and the scientific personnel. The display shows the ship's position relative to the desired survey line; enabling the bridge watch to keep the vessel within defined line parameters. An added advantage of the YoNav system is that the display could also be set to show one or more reference-data layers including bathymetric contours, shaded-relief images from multibeam-sounding data, tracklines of previous surveys, and compilations of seafloor structural features.

Overall the YoNav system worked well, using GPS input to provide position data every ten seconds for 24 hrs/day. Differential GPS positioning provides navigational accuracy of approximately 5m. Minimal problems with the shore-based reference stations were encountered during the survey; periods without differential GPS were limited to a few minutes, resulting in the occasional inaccurate fix that was off by several degrees of longitude, suggesting both bad data input and failure of YoNav to filter out bad data.

The most vexing problem involved shipboard post-processing of the navigation data. The YoNav system was unable to assign the correct UTM zone to position data collected during previous survey days. This, plus the lack of space to plot fixes by hand, made it very difficult to compare completed survey lines with either current or planned tracklines while at sea. A fix for this problem was prepared and delivered to the vessel during an unscheduled, mid-cruise port call at Scripps Institution of Oceanography (San Diego) to pick up a new power supply for the minisparker. The correction worked well, but needs further testing to ensure that it will work in UTM zones outside the southern California survey area as well as during future project surveys when tracklines will cross UTM zone boundaries.

Multichannel seismic-reflection system

The sound source for multichannel seismic-reflection (MCS) profiling during the cruise was a 1.5 kJoule (kJ) "SQUID 2000" minisparker system manufactured by Applied Acoustic Engineering, Inc. This minisparker consists of eight sets of discharge electrodes, in two banks, mounted on a small pontoon sled (**Fig. 5D**). The pontoon sled that supports the minisparker is towed on the sea surface, generally about 5 meters behind the ship. The position of the tow cable for the minisparker sled is shown in **Figure 5A**. A total of approximately 85 km of minisparker data were collected with the MCS system and 15 km with the single-channel streamer alone, not including the 370-km survey, during Leg 2, in support of the aquifer study reported elsewhere (Edwards *et al.*, in preparation).

Source characteristics of the SQUID 2000™ provided by the manufacturer show a sound-pressure level (SPL) of 209 dB re 1 μPa-m RMS. The amplitude spectrum of this pulse indicates that most of the sound energy lies between 150 Hz and 1700 Hz, and the peak amplitude is at 900 Hz. The output sound pulse of the minisparker has a duration of about 0.8 ms. For the multichannel seismic-reflection survey, the minisparker was discharged every 2 seconds, and when used with a single-channel streamer, at 400 J, the fire rate varied from 300-750 ms, depending on water depth.

The streamer for the MCS operation was a 24-channel solid-core ITI streamer with 10-m-long groups and 3 hydrophones per group. Data were collected using a Geometrics STRATAVIEW seismograph. Shots were triggered by an in-house controller. Data were recorded in SEG-D format on 4-gbyte DAT tapes using a 0.125 msec sample rate and a record length that varied from 0.75 to 1.5 seconds. A 70-Hz low-cut filter was used; otherwise all frequency bands were passed.

A 5-m-long SIG streamer with 8 hydrophones at 0.5-m spacing was also used for all minisparker lines. Data were collected using Triton-Elics International 'Delph Seismic' software. Data were recorded in SEG-Y format on the Delph system hard disc using sample frequencies between 250 Hz and 49 kHz, (usually 16 kHz) and up to 1 second record length. The data were recorded raw, e.g., without using bandpass filters or gain algorithms, and then backed up on CD-ROM during the cruise. The single channel minisparker data were also displayed in real time on thermal film using an EPC 9802 recorder.

The minisparker source did not function properly during most of the cruise. The primary problem involved the 1 kJ power-supply units, which repeatedly failed catastrophically after a relatively few minutes to several hours of operation (**Table 2**). About midway through the cruise, a new 2-kJ power supply provided by Applied Acoustic Engineering, Inc. was shipped to San Diego. Problems persisted, however, and near the end of the cruise, an engineer from the company flew to Los Angeles and boarded the vessel on the 22nd of June. Even with the engineer's assistance, the 1kJ power supplies continued to fail during the remainder of the cruise, except when used singly at low power (400-700 J). During the last three days of the survey, the new minisparker power supply provided fairly stable firing of one bank of 4 electrodes at 1.5 kJ.

During the cruise, attempts to operate the multichannel system and the Huntec boomer system together proved unsatisfactory. Asynchronous firing of the boomer system in the time interval between the end of the recording window for the multichannel data and the succeeding trigger was unsatisfactory, especially in deeper water, as a result of the required uneven spacing of shots on the Huntec that produced gaps in the data. Simultaneous triggering of the multichannel and the Huntec system was likewise unsuccessful because the frequency ranges generated by the sound sources are similar enough to cause extensive cross-talk and resulting degradation of both minisparker and boomer data.

Huntec

A high-resolution Huntec DTS (Deep-Towed Seismic) boomer system (**Fig. 5F**) towed between 20 m and 137 m below the sea surface (depending upon the water depth) was used to image the upper few tens of milliseconds of strata with a resolution of better than 0.5 ms (0.4 m). The Huntec system was operated primarily in areas of deeper water (>300 m) throughout the cruise. About 1400 km of Huntec survey data were obtained during the cruise, of which 1300 km were in support of the seismic hazards work.

The SPL for this source is 205 dB re 1 µPa-m RMS. Power output was 375 Joules, with a firing rate that was also dependent on water depth, ranging from 0.5 sec over the shelf and upper basin slopes to 1.67 sec over the deeper parts of the basins. Returning signals were received with a 7.6 m (25 ft) long Geoforce GF25/25P streamer, with a 25-element hydrophone array. Data were collected using Triton-Elics International 'Delph Seismic' software and an in-house controller for triggering. Data were recorded in SEG-Y format on the Delph system hard disc using sample frequencies between 250Hz and 49 kHz, (usually 16 kHz) and a 200 to 300 millisecond record length. The data were recorded raw, e.g., without using bandpass filters or gain algorithms. The data were then backed up on CD-ROM during the cruise. The Huntec data were also filtered at 640-4000 Hz and displayed in real time on thermal film using an EPC 9802 recorder. The average survey speed of about 4 kt (7.4 km/hr) resulted in a shot spacing between 1.0 and 3.4 m for the deep-tow boomer profiles. The position of the tow cable for the Huntec vehicle is shown in **Figure 5A**.

The data quality provided by the Huntec system is excellent, and appeared comparable to the 1998 results (Normark *et al*., 1999a). The only shutdowns were for mammal sightings (**Table 2**).

Geopulse

The surface-towed Geopulse boomer system was used in the shallow water parts of the survey area, typically in water depths from 20 m to 300 m (**Fig. 4**). The sound source consists of two ORE Geopulse 5813A boomer plates mounted on a catamaran sled built in-house (**Fig. 5C**). The catamaran was towed from the same deck area as the multichannel sound source, while the short hydrophone streamer was towed from a boom on the starboard side of the vessel (**Fig. 5A**). About 1200 km of Geopulse data were obtained during the cruise, of which some 960 km were collected for the seismic hazards study.

The source level suggested by the manufacturer is 220 dB re 1 µPa-m RMS. Power input was 350 Joules, with a firing rate that was also dependent on water depth: 0.5 or 1.0 second for the geologic hazard part of the survey and 0.25 second in the harbor areas. Returning signals were received with a 5-meter-long SIG streamer, with eight hydrophones at 0.5 m spacing. The effective bandwidth of the Geopulse system is about 750 to 3500 Hz. The data were displayed in real time on thermal film using the same EPC 9802 recorder that was used for the Huntec data. As with the Huntec system, data were also recorded using the Triton-Elics International 'Delph Seismic' software in SEG-Y format generally using 16Hz sample frequency and a 200 to 300 millisecond record length. The data were recorded raw, e.g., without using bandpass filters or gain algorithms, and were then backed up to CD-ROM during the cruise. The survey speed of 4 to 5 kt (7.4 to 9.2 km/hr) and the variable firing rate resulted in shot spacings generally between 1.0 and 2.5 m for the hazard profiles and 0.5 m spacing for the work in the Long Beach shelf and harbor areas (Edwards *et al*., in preparation).

The Geopulse system was trouble-free, except for its ability to capture kelp.

Bathymetry (12 kHz)

A Knudsen Engineering, Ltd. 320 BR towed 12-kHz echosounder system was installed on the *M/V Auriga* to provide a continuous water-depth profile primarily to ensure proper tow depth for the Huntec system. The position of the davit for towing the 12-kHz fish, which maintained a depth of 5 or 10 m, is shown in **Figure 5A**. During transects across the basin slopes, when the water depth would change rapidly, the Huntec recording system required frequent time-delay (scale) changes. An independent measure of the water depth was desirable to avoid using the Huntec as a seafloor-sampling instrument.

Digitized data were logged on the YoNav system, and the bathymetric profiles displayed on a Raytheon TDU 850 recorder. The echo-sounding system performed without interruption in data collection except over steep terrain when the automatic tracking gate lost the signal returning from the seafloor, and during inspection of the tow vehicle, primarily to remove kelp snagged by the tow cable (**Fig. 5E; Table 2**). Regular observations of the 12-kHz display monitor suggests that there were few problems with the digital depth data.

OVERVIEW OF SEISMIC-REFLECTION DATA

This section briefly reviews the quality of the seismic-reflection data collected on A1-00-SC. Profile locations for **Figures 7-12** are shown in **Figure 6**. Huntec and Geopulse profiles are compared in **Figures 7 to 10**. The selected examples of multichannel seismic-reflection profiles illustrate the effectiveness of the minisparker sound source when it was functioning normally (**Fig. 11 and 12**).

The Huntec data contain an acoustic artifact, the sea-surface ghost, resulting from reflection of the outgoing pulse by the sea surface. This sea-surface ghost looks like a subbottom profile that mimics the seafloor shape and swamps real data. It is especially a problem in shallow water where, if the Huntec is towed at 20 m depth for example, the ghost shows up in the data 20 m below the seafloor return. In deep water the Huntec is towed deeper, and that pushes the appearance of the sea-surface ghost below most real subbottom returns. For that reason the Huntec is used primarily in water deeper than 300 m. The Geopulse often has superior results in water shallower than 300 m, but loses effectiveness in deeper water.

The segments of high-resolution boomer profiles in **Figures 7 and 8** compare data obtained during separate passes along the same test line near the edge of the shelf south of Long Beach, California (**Fig. 6**). In these examples, both the advantages and disadvantages of the Huntec and Geopulse systems are well illustrated. In shallow water on the shelf, both systems have a pronounced seafloor multiple (seen in the lower left-hand corner of **Fig. 7A and B** and the lower right-hand corner of **Fig. 8A and B**) that generally obscures deeper horizons. The Huntec system, which along this line was towed about 20 m below the sea surface, has a prominent sea-surface ghost which blocks out deeper reflections from the primary pulse (**Fig. 7B and 8B**). The Geopulse system is better for shallow water applications even though it lacks the resolution of reflectors compared to the Huntec (compare reflections in areas labeled 'D' in **Fig. 7A, B and 8A, B)**. In shallow water acoustic penetration on both systems tends to be limited by the seafloor multiple.

As noted above, the trade-off in data quality between using the two boomer-source systems is at about 300 m water depth. This trade-off is well illustrated in **Figure 9**, which compares data from subparallel tracklines that show the transition from basin slope to basin floor at about 300 m water depth. The two profiles cross near the edge of a turbidite channel on the basin floor (see **Fig. 6** for location). Neither system obtained stellar data from the slope area, but there are marked differences over the basin floor. The vertical movement of the Geopulse catamaran in the ocean swells results in a wavy seafloor return and a loss of resolution of the closely spaced reflections in the overbank areas adjacent to the channel. The Huntec system shows a high degree of detail in the overbank sequences (compare areas labeled 'D' in **Fig. 9A, B**). In deeper water such as along this profile, the Huntec is towed at a greater depth, which not only reduces interference by the sea-surface ghost, the longer tow length creates a catenary in the cable that helps damp out any vertical motion of the ship.

Although the Huntec boomer system is rarely towed deeper than 140 m, excellent subbottom penetration can be achieved in the deeper basin areas. **Figures 10A and 10B** show two examples obtained from the Gulf of Santa Catalina (**Fig. 6**) in more than 800 m water depth. Both profile examples show about 100 m of acoustic penetration and in both cases the penetration is limited by the sea-surface ghost. The sea-surface ghost does not exactly mimic the seafloor shape in these profile segments indicating changes in the length of the tow cable to adjust the depth of the Huntec vehicle. The resolution obtained with the Huntec system shows progressive deformation of deeper reflectors caused by growth faults that do not show much relief at the seafloor. Much of the deformation observed below 850 m in **Figure 10B** is masked near the seafloor surface by recent turbidite sedimentation.

As noted earlier, the minisparker source for the multichannel system did not work much of the time. The multichannel lines shown in **Figures 11 and 12** are from the northern slope of the Santa Monica Basin near Point Dume (**Fig. 6**). In **Figure 11**, the acoustic penetration is limited to about 0.4 sec (~300 m) over the basin floor but with good resolution within the turbidite sequence. This profile can be correlated with the core recovered at ODP Site 1015 thus providing some age control on the fold developed at the base of the slope (Normark and Piper, 1998; Piper *et al*., 1999). The profile in **Figure 12** extends to the shelf edge and is more typical of the lesser quality of data obtained with the minisparker system when it was working. There are no tracklines on which to directly compare the Huntec and multichannel minisparker data quality. However, in areas of similar water depth and subbottom type, the minisparker resolved about 300 m subbottom, while the Huntec resolved about 100 m.

SUMMARY

As shown in the examples discussed above, the Geopulse and Huntec boomer-source seismic-reflection systems deployed for the 2000 earthquake-hazard survey generally provided satisfactory information for defining structures in the upper 50 m to 100 m within the seafloor sediment and sedimentary rock. In general, the Geopulse system was preferred for work in water depths less than 300 m. Because the multichannel system did not function properly during the first two weeks of the survey, the operation focused on working inside the state three-mile limit, which had been off limits in the 1998 and 1999 surveys when air gun sources were used for the multichannel work. Operations in deeper water with the Huntec system were limited to filling in the gaps in earlier surveys, especially in the area between Dana Point and La Jolla.

Even with the survey generally limited to the boomer systems, the specified 30-m preclusion zone for marine mammals was applied. During the operation, 41 shutdowns were called, and two major transits to deep water after whale sightings near dusk, resulting in a total loss of survey time of about one-half day (11 hr, 6 min).

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We thank the captains and crew of the *Auriga* for their tremendous support of our cruise, from mobilization through demobilization. We are in debt to our own Marine Facility personnel who transformed the *Auriga* from crab boat to research vessel -- and back -- in record time. Larry Kooker’s persistence and labor, aided by Dave Gonzales, were outstanding in the struggle with the minisparker power supplies. We enjoyed working with the mammal observers, who were always willing to share their knowledge. We appreciate Holly Ryan’s timely and helpful review of this report.

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Table 1. Scientific Personnel

Crew Person (dates embark and disembark)	Crew Affiliation	Crew Responsibilities
Chris Gutmacher (1)	USGS	Co-Chief, watchstander
Stephanie Ross (3)	USGS	Co-Chief, watchstander
Brian Edwards (4)	USGS	Co-Chief Scientist
Larry Kooker (1)	USGS	ET
Kevin O'Toole (2)	USGS	MT
Ray Sliter (1)	USGS	MCS Watchstander
Becky Cooper (1)	USGS	Watchstander, Navigation
Pat Hart (3)	USGS	MCS Watchstander
Jon Childs (4)	USGS	MCS Watchstander
Dave Gonzales (2)	USGS	ET
Jane Reid (5)	USGS	Watchstander
Dave Hogg (4)	USGS	ET
Tim Elfers (4)	USGS	MT
Walt Olson (4)	USGS	MT
Martin Uyesugi (1)	Geoforce Consultants	Huntec engineer, watchstander
Annie Douglas (1)	Cascadia Research	Mammal Observer
Lisa Baraff (1)	Cascadia Research	Mammal Observer
Dave Ellifrit (1)	Cascadia Research	Mammal Observer
Todd Chandler (1)	Cascadia Research	Lead, Mammal Observer Team
JR Veldink (1)	Cascadia Research	Mammal Observer
Dick Corrigan (2)	Northwind Shipyards	Captain
Ted Blinkers (4)	Northwind Shipyards	Captain
Jeffrey "Striker" Stringer (1)	Northwind Shipyards	Mate
James "Sparky" Stacey (1)	Northwind Shipyards	Engineer
Ricky Labrador (1)	Northwind Shipyards	Cook
Rich Soderblom (1)	Northwind Shipyards	Deck Hand, everything else
Brad Scarrott (6)	Applied Acoustic Eng.	Minisparker doctor

(1) 5-29 June
(2) 5-20 June
(3) 7-20 June
(4) 20-29 June
(5) 5-7 June
(6) 22-25 June

Table 2. Operational Log

Local time is 7 hours behind Julian Day (JD) and Greenwich Mean Time (GMT)
June 5, 2000 = JD 157
Dawn about 0530 local = 1230z
Dark about 2030 local = 0330z next JD

DATE/TIME JD/GMT	ACTIVITY
157/1700	Depart USGS Marine Facility, Port of Redwood City
159/0345-1630	At Port Hueneme for repair of ship's gyro and personnel transfer. Test minisparker over the side, smoke the power supplies, repair them
159/1726-2006	Rendezvous with *Blue Skies* and participate in sound-source calibration experiments conducted by Greenridge Associates
159/2339	Begin Leg 1 survey with Huntec, minisparker, and 12kHz
160/0200	Approx. time minisparker power supplies fail, continue with Huntec
160/1607-1646	**Shutdown of acoustic sources called by "mammal team"**
160/1825	Huntec off for minisparker test
160/1830-2025	Minisparker test, power supplies fail again
160/2030	Huntec on
160/2110-2210	Huntec off, switch gear, Geopulse on
162/0244-0320	Geopulse off; replace multichannel (MC) streamer tail buoy destroyed by pleasure boat
162/1007-1009	**Shutdown called by "mammal team"**
162/1140-1146	**Shutdown called by "mammal team"**
162/1915-1922	**Shutdown called by "mammal team"**
162/2126	Geopulse off for minisparker test
162/2130-2155	Minisparker test; terminated when one power supply smoked
162/2245	Geopulse on
162/2344-2353	**Shutdown called by "mammal team"**
163/1526-1646	Geopulse off to remove kelp, vet geopulse sled, replace tail buoy again
163/1946-1948	Geopulse off, switch gear, Huntec on
163/2234-2305	**Shutdown called by "mammal team"**
164/0301-0312	Huntec off, switch gear, Geopulse on
164/0524	Geopulse off for minisparker test
164/0530-0558	Minisparker test using 220 power from ship—power supplies smoked again, running out of spares and ideas

164/0623	Geopulse on
164/0701-0732	Geopulse off while removing crab pots from 12kHz
164/1217-1259	12-kHz system off (too shallow to tow safely, use bridge's fathometer)
164/1642-1702	Geopulse off for kelp removal
164/1827-1900	Geopulse off to remove kelp from it and from MC streamer tail buoy
164/2107-2126	12-kHz system off (too shallow to tow safely, use bridge's fathometer)
164/2216-2230	**Shutdown called by "mammal team". Whale sighted,** so night ops (0330-1230) will stay in water deeper than 50m.
165/0009	Geopulse off; retrieve gear, send skiff to Seaside harbor for gyro repair man
165/0253	Resume survey with Geopulse and 12Khz systems.
165/0432	Geopulse off; retrieve gear, and after lengthy delay to work on auto-pilot, send skiff to deliver repair man. **Whale sighting** results in plan to Huntec in water >50m this night
165/0847	Resume survey with Huntec and 12Khz systems
165/2339-2345	**Shutdown called by "mammal team". Whale sighted,** so night ops (0330-1230) will stay in water deeper than 50m.
166/0130-0155	Huntec off, switch gear, Geopulse on
166/0540-0556	**Shutdown called by "mammal team"**
166/0735-0828	**Shutdown called by "mammal team"**
166/1135-1204	Geopulse off, switch gear, Huntec on
166/2000-2021	Huntec off, switch gear, Geopulse on
166/2041-2338	Power down; spiking voltage, check generator, eventually switch gen.
166/2340	Resume survey with Geopulse and 12 kHz
167/0306-0310	**Shutdown called by "mammal team"**
167/0841-0858	Geopulse off, switch gear, Huntec on
167/1159-1206	**Shutdown called by "mammal team"**
167/1258-1303	**Shutdown called by "mammal team"**
167/1334-1336	**Shutdown called by "mammal team"**
167/1615-1618	**Shutdown called by "mammal team"**
167/1737-1742	**Shutdown called by "mammal team"**
167/2246-2309	Huntec off; trigger problems
168/0030-0052	Huntec off, switch gear, Geopulse on
168/0628-0635	**Shutdown called by "mammal team"**
168/0726-0734	**Shutdown called by "mammal team"**
168/1347	Geopulse off; recover gear for transit to San Diego

168/1545-1715	Port call in San Diego (use Scripps Institution of Oceanography Marine Facility pier) to pick up new power supply (built in England) and cable for the minisparker system
168/1932	Resume survey with Geopulse and 12 kHz
169/0405	Geopulse off; prepare for test of new power supply for minisparker
169/0430-0453	Minisparker test
169/0453-0459	**Shutdown called by "mammal team"**
169/0459-0722	Continue minisparker testing
169/0752-0913	Test simultaneous and asynchronous firing of minisparker with Huntec
169/0926	Huntec off
169/0934-1006	Minisparker alone on comparison line
169/1013-1032	Huntec alone on comparison line
169/1037-1203	Use minisparker alone until power supply dies
169/1208	Huntec on
169/1340-1357	Huntec off, switch gear, Geopulse on
169/1433	Huge kelp crisis, must recover, clear kelp from all gear incl. MC streamer
169/1650	Resume survey with Huntec and 12 kHz
170/0325-0329	**Shutdown called by "mammal team"**
170/0417-0422	**Shutdown called by "mammal team"**
170/0445-0455	**Shutdown called by "mammal team"**
170/1153-1159	**Shutdown called by "mammal team"**
170/1636-1639	**Shutdown called by "mammal team"**
170/1750-1850	Marty running Huntec tests while ship's engine oil changed (noisy record while using only one engine)
171/0200	Huntec off for test of minisparker system
171/0223-0235	Minisparker test
171/0235-0252	**Shutdown called by "mammal team"**
171/0252-0327	Huntec on between minisparker tests
171/0328-0355	Minisparker test with new cable and "real" 220 from transformer--blue flame shoots out--decide to wait for engineer and spares
171/0413	Huntec on
171/1953-2011	Huntec off, switch gear, Geopulse on
171/2159	Geopulse and 12 kHz off; retrieve gear for transit to Newport area
172/0221	Huntec and 12 kHz on
172/0534-0539	**Shutdown called by "mammal team"**
172/0803-0807	**Shutdown called by "mammal team"**

172/1203-1204	Huntec off, switch gear, Geopulse on
172/1342-1344	Geopulse off, switch gear, Huntec on
172/1350-1354	**Shutdown called by "mammal team"**
172/1702	Huntec and 12 kHz off; retrieve gear, transit to San Pedro for personnel transfer before starting survey for salt water intrusion of aquifers on Long Beach shelf and harbor area
172/1915-173/0150	Port call at San Pedro berth 93B. Repair 1 generator, get groceries, swap out several science crew and ship's captain (see Table 1).
	Leg 2
173/0413	Begin Leg 2, aquifer study; Huntec and 12 kHz on
173/0632-0636	**Shutdown called by "mammal team"**
173/0658-0702	**Shutdown called by "mammal team"**
173/0714-0720	**Shutdown called by "mammal team"**
173/1549	Huntec off, prepare to test Uniboom along same line
173/1622-1747	Uniboom system on along test line
173/1816	Geopulse on along test line, like it best so continue
174/0456	12 kHz off; retrieve tow fish for very shallow shelf and harbor work
174/1852	Geopulse off, retrieve all gear for U-turn in narrow harbor channel
174/1942	Geopulse on, collect data while underway in harbor channel
174/2325-2355	Geopulse off; port touch and go to pick up engineer and spare parts from Applied Acoustics to work on minisparker power-supply problems
175/0218	Geopulse on, resume survey
175/0317	**Whale sighted**, must change plans and move to deeper-water (>50m) area for night ops, Geopulse off for transit
175/0539	Huntec and 12 kHz on, resume survey
175/0821-0823	**Shutdown called by "mammal team"**
175/1326-1346	Huntec off, retrieve 12 kHz for harbor work, switch gear, Geopulse on
175/1829	Geopulse off for minisparker tests
175/1855-2306	Minisparker on
175/2312-2322	Port touch and go to get last box of minisparker spares
175/2327	Continue minisparker lines
176/1317	Minisparker off to deploy MC streamer
176/1317-1318	**Shutdown called by "mammal team"**
176/1350	Continue minisparker, breaking, repairing, retesting power supplies
177/1900	Minisparker off to drop off Brad (engineer). New power supply stable
177/2000-2010	Port touch and go to let Brad off

177/2055	Minisparker on
177/2109	Launch 12 kHz on shelf
177/2241	12 kHz off for more shallow water ops
178/0255	**Whale sighted**, must change plans and move to deeper-water area for night; minisparker off and retrieve gear for transit
178/0552	Huntec and 12 kHz on in deeper water
178/0605-0607	**Shutdown called by “mammal team”**
178/0945	Huntec and 12 kHz off; retrieve gear for transit to N. Santa Monica Bay
178/1246	Minisparker and 12 kHz on
179/0130	Minisparker off, problem with MC streamer; switch gear
179/0155	Huntec on
179/1158-1203	**Shutdown called by “mammal team”**
179/1304-1307	**Shutdown called by “mammal team”**
179/1658-1716	**Shutdown called by “mammal team”**
179/1659	12 kHz off for calibrated hydrophone listening tests
179/1716	Begin listening test with Huntec
179/1729-1739	Huntec off; switch gear, Geopulse on
179/1751	Geopulse off; sound test over, deploy MC streamer
179/1805	Minisparker on, test streamer
179/1830-1833	**Shutdown called by “mammal team”**
179/1847-1854	**Shutdown called by “mammal team”**
179/1854	Huntec and 12 kHz on for last line (done with MC streamer test)
179/1859-1906	**Shutdown called by “mammal team”**
179/1920-1922	**Shutdown called by “mammal team”**
179/2045	End of survey; retrieve all gear; prepare to head to Redwood City
181/0645	Arrive Port of Redwood City after fast, smooth 34-hr transit "up hill"

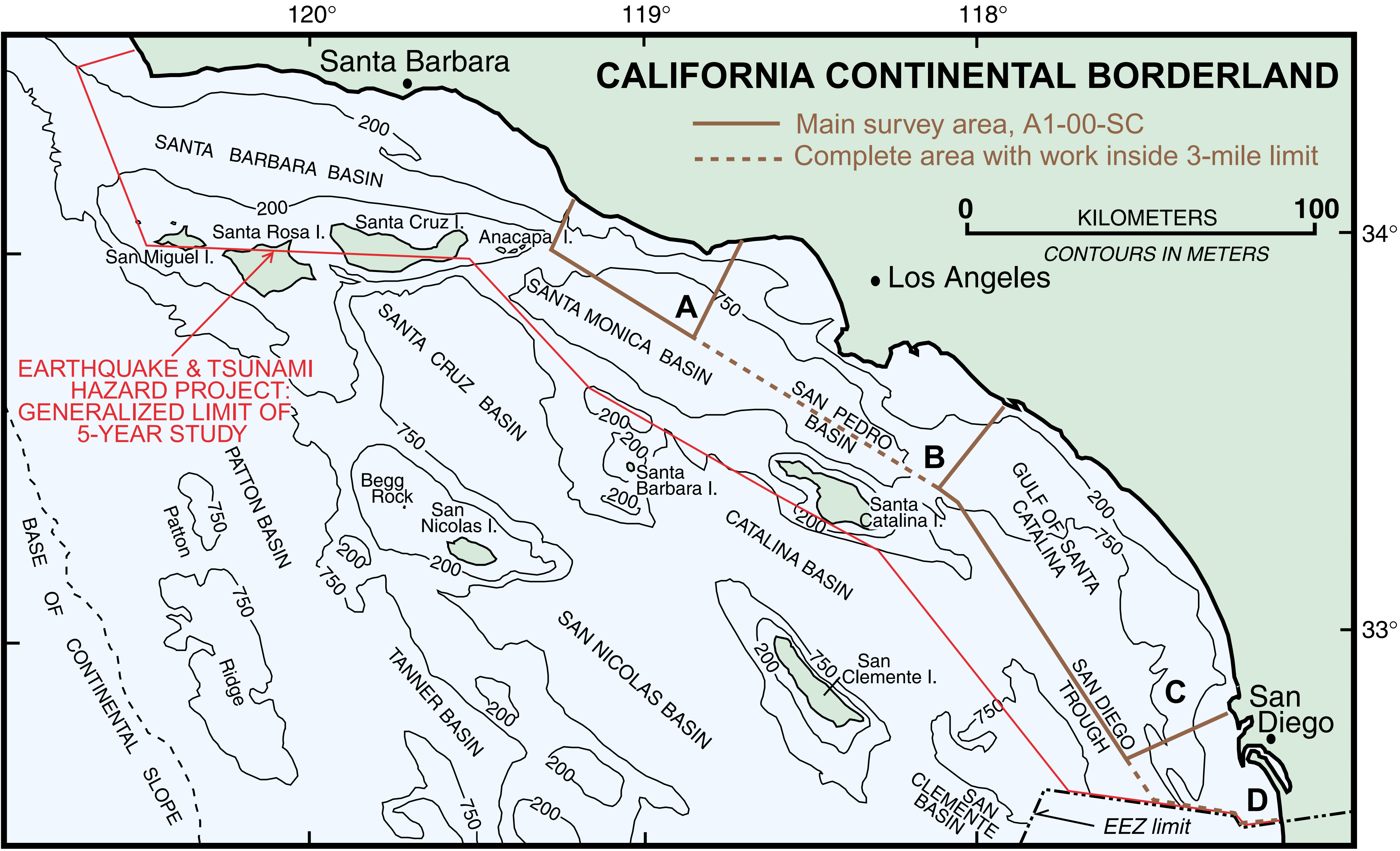


FIGURE 1

Physiography of the southern California borderland showing the major basins and islands. The study area for the offshore earthquake hazards project includes the innermost basins and islands and extends from the western margin of Santa Barbara Basin to the Mexican-U.S. EEZ boundary southwest of San Diego. The main survey areas of the A1-00-SC seismic-reflection cruise are also shown: A is a new area not previously surveyed, area C needed additional lines to complete a grid of tracklines, and in B-D the 0-3 mile coastal strip was surveyed.

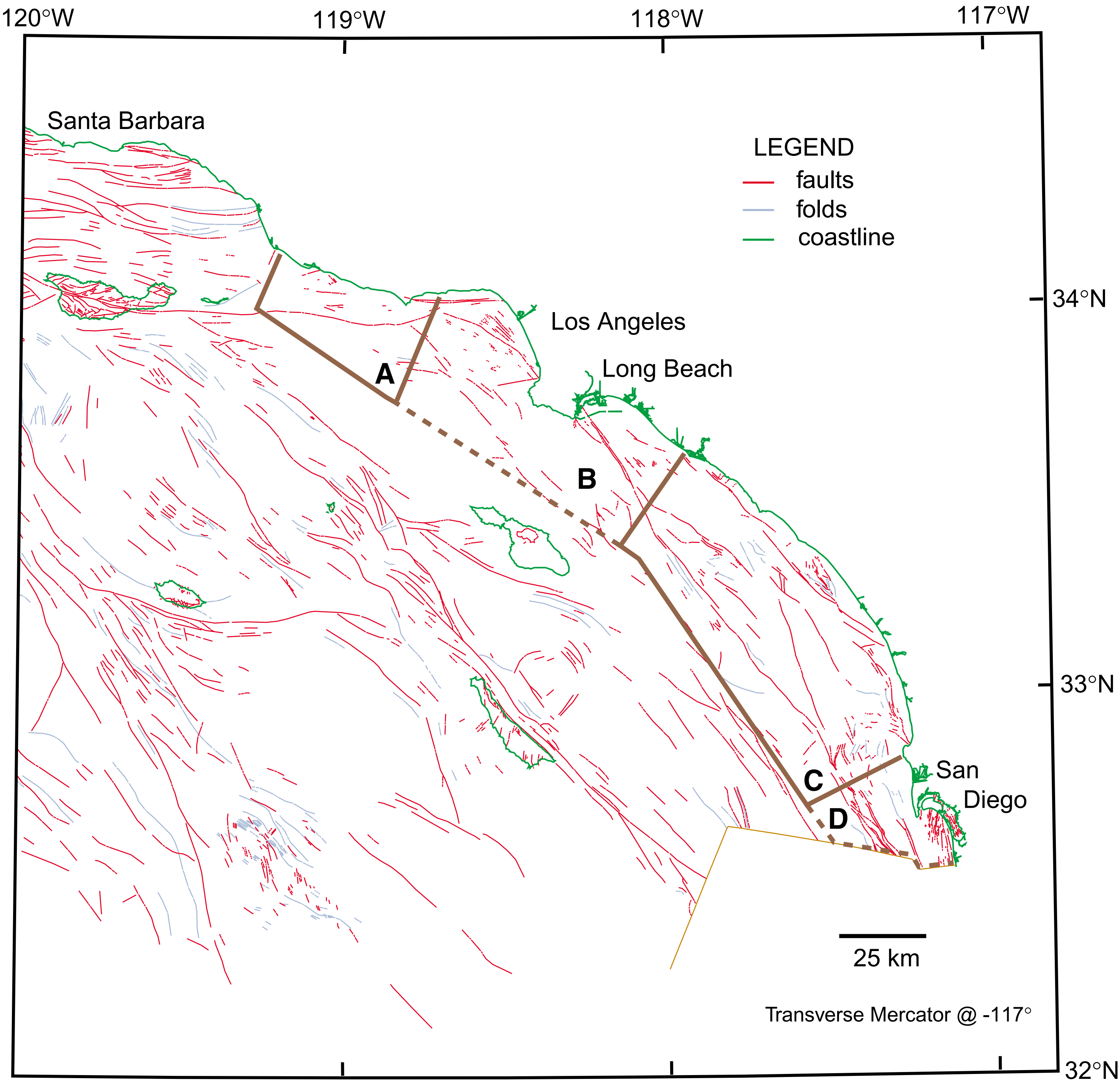


FIGURE 2
Generalized fault pattern for the inner southern California borderland modified from Greene and Kennedy, 1986. The main survey areas of the 2000 seismic-reflection cruise that is the subject of this report are also shown (see Figure 1 for explanation).

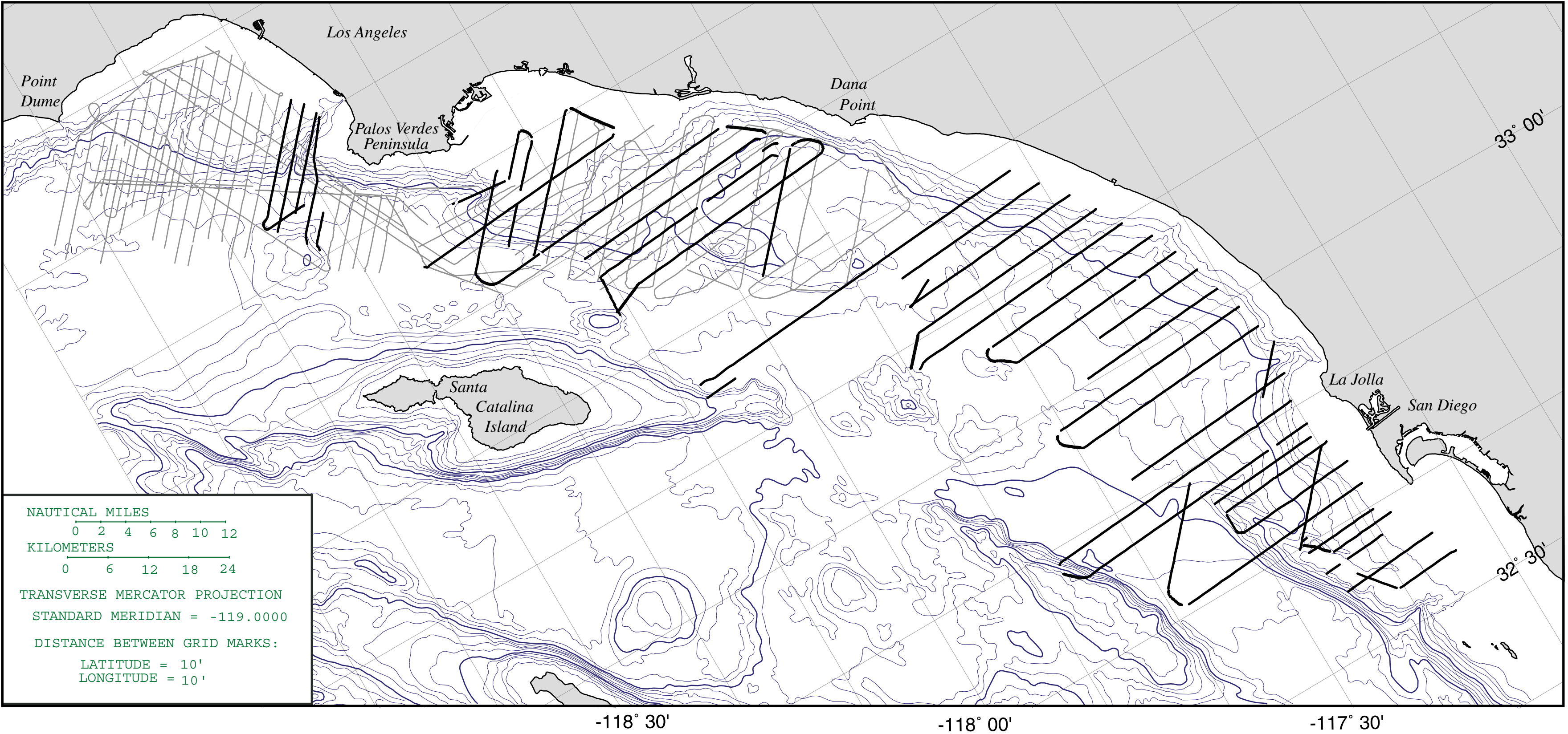


FIGURE 3

Trackline map showing multichannel seismic-reflection (MCS) data obtained during previous field data acquisition under this project. Tracklines for the 1999 survey are shown in thick bold lines; tracklines for previous years, primarily 1998, are shown in thin gray lines (from Normark *et al.*, 1999b). The survey priorities for 2000 included filling parts of the previous survey grid in areas, especially within the three-mile limit and the basin areas between Dana Point and La Jolla.

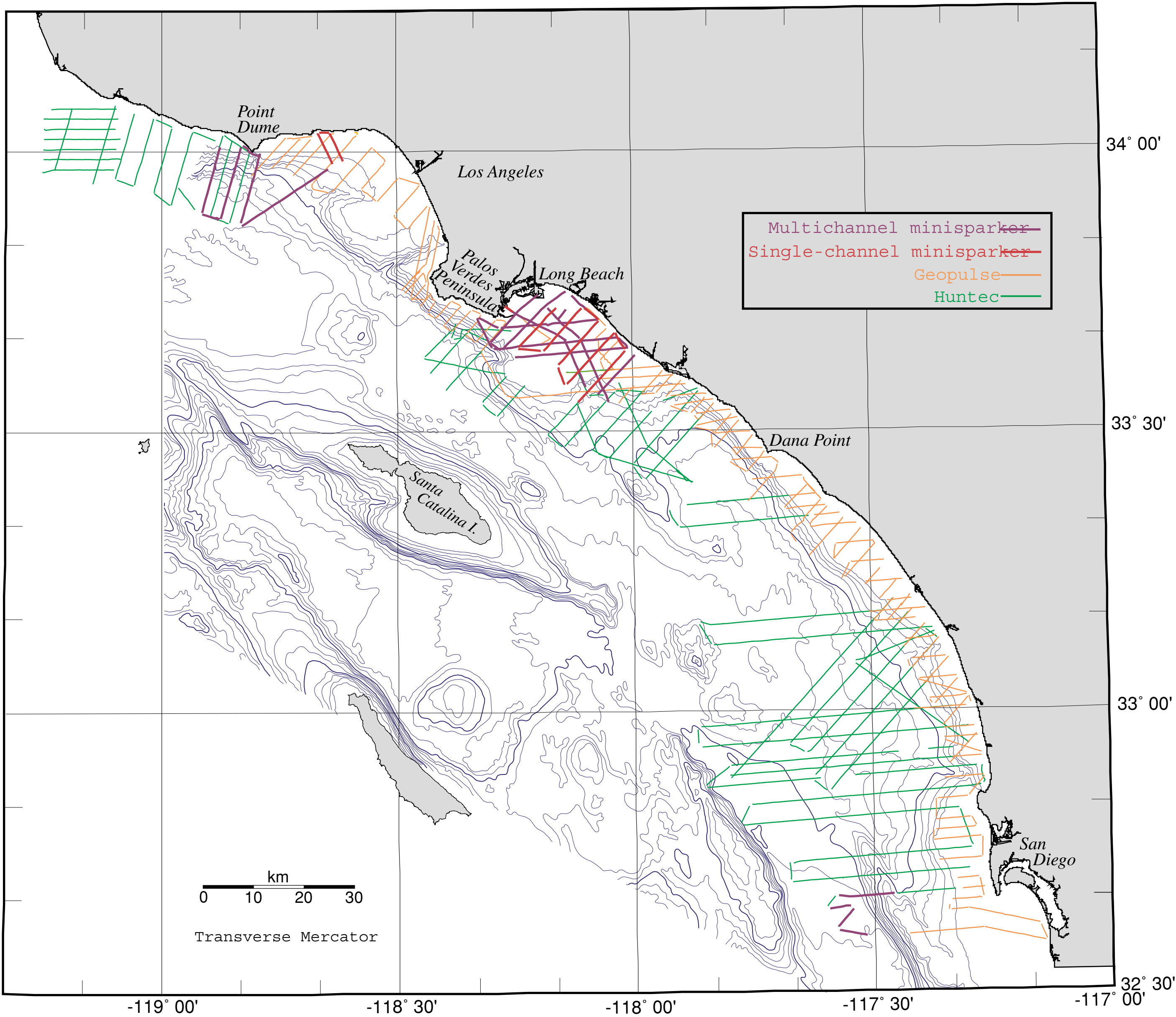
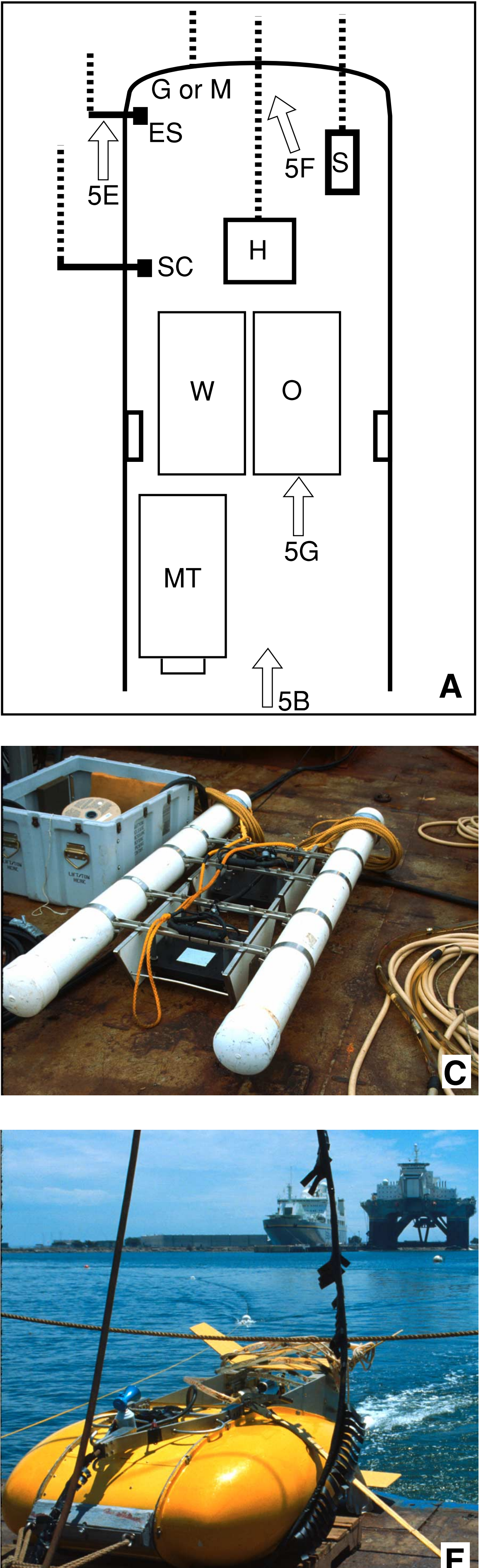


FIGURE 4
Trackline plot for A1-00-SC. Closely spaced lines from Leg 2 collected in Los Angeles and Long Beach harbors are not shown (see Edwards *et al.*, in preparation). The different types of seismic-reflection systems used during the survey are depicted with different color tracklines.



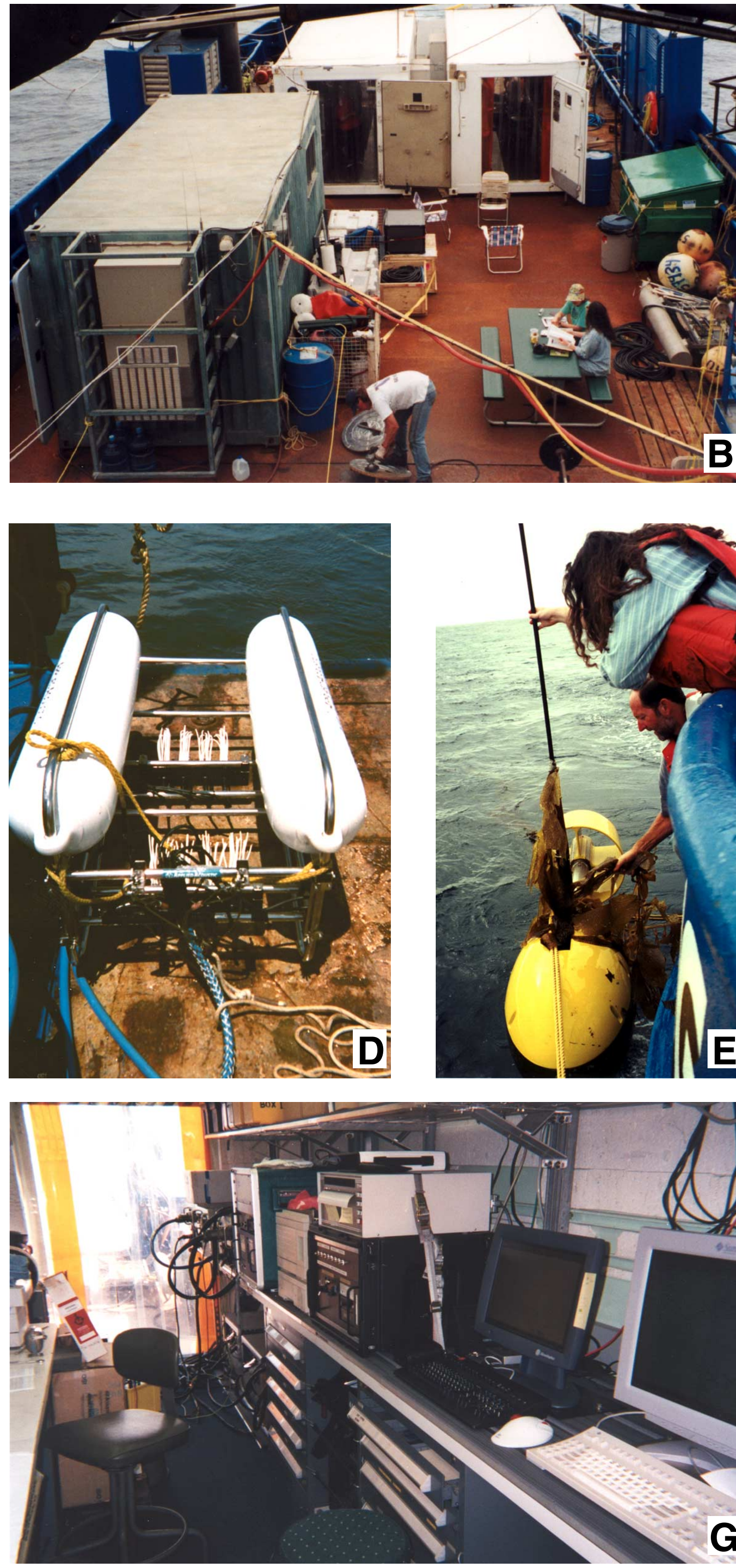


FIGURE 5

Photos and schematic of equipment placement on the *M/V Auriga*. (**A**) Schematic of working deck showing placement of equipment. MT, mechanical workshop van; W, watchstanding lab van; O, office van; H, Huntec winch (dashed line shows tow configuration through sheave on A frame); SC, boom from which single-channel hydrophone streamer for Geopulse and minisparker was towed; ES, davit from which the 12 kHz echo sounder was towed; S, reel for multichannel streamer; G or M, tow point of sleds for Geopulse or minisparker sound sources, which could not be operated simultaneously (see text). Open arrows show direction of view for photos shown in **B**, **E**, **F**, and **G**.

(**B**) view aft of the work deck showing placement of the vans.
(**C**) tow sled for the Geopulse boomer sound source.
(**D**) tow sled for the minisparker sound source.
(**E**) 12kHz tow fish with snagged kelp being removed.
(**F**) Huntec tow fish. (**G**) view inside the office van.

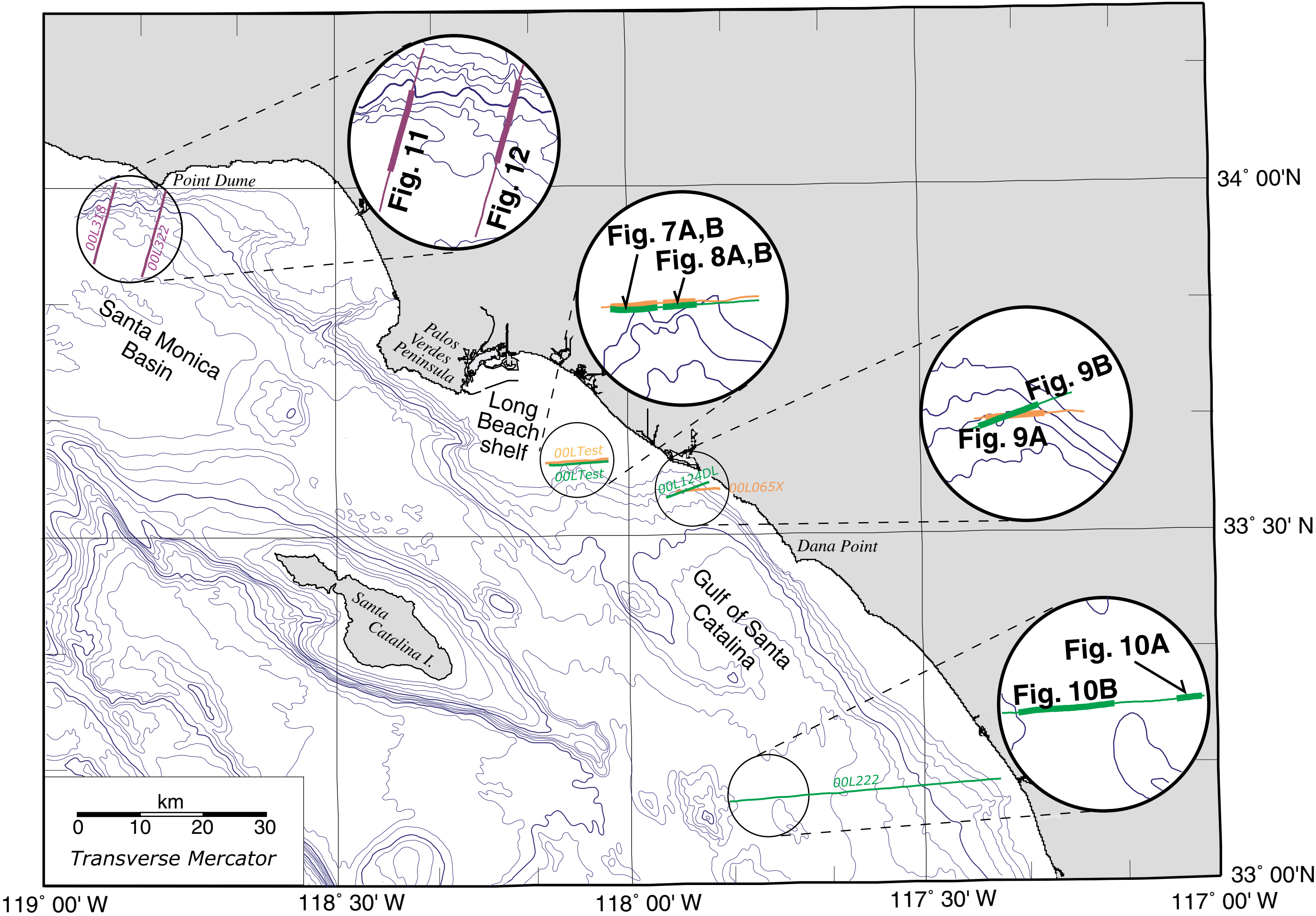


FIGURE 6

Location of profiles shown in Figures 7 to 12. The colors of the tracklines are as presented in the legend of Figure 4 and the original survey line numbers are given. In the insets, which are expanded views of the tracklines, the thick line segments represent the data shown in the profiles of Figures 7 to 12.

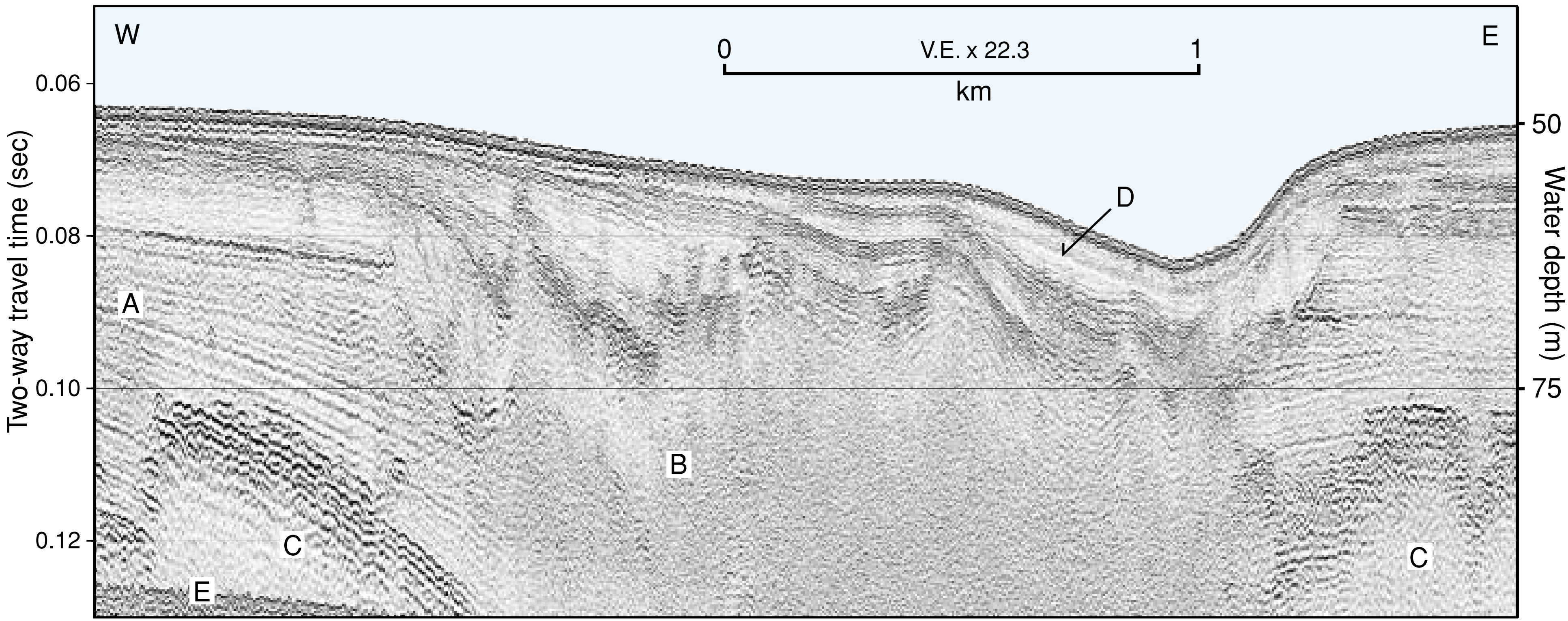


FIGURE 7**A** Geopulse

Geopulse (7**A**) and Huntec deep-tow (7**B**) boomer profiles obtained along the same survey line during system tests showing the advantages of, and problems with, both systems. The profiles have been prepared at the same vertical and horizontal scales and have the same annotation (letters A through E) to aid comparison. The letter A in Figure 7**B** denotes the sea-surface ghost, resulting from the sea-surface reflection of the out-going pulse from the Huntec system, which was being towed about 20 m depth. The Geopulse sound source, which is towed at the sea surface, does not produce a sea-surface ghost. The letters B and C denote areas of ambiguous reflections where the sea-surface ghost overlaps with 'real' data in the Huntec profile. The Geopulse does not produce such an artifact in the record and shows better depth of penetration when operated at shelf depth. The Huntec profile, however, shows better definition of reflections where there is not interference of the sea-surface ghost, e.g., at D in the profiles. The seafloor multiple is at E. Profile locations in Figure 6.

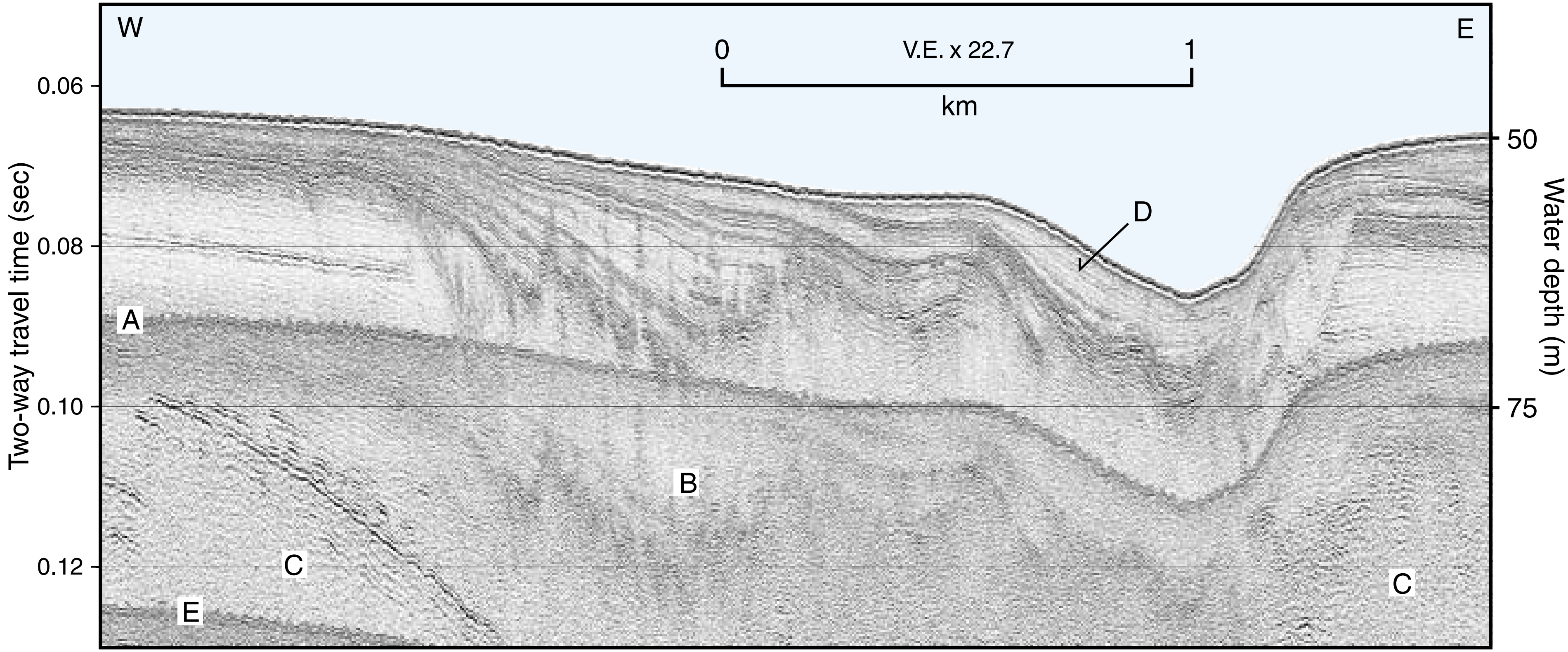


FIGURE 7**B** Huntec

Geopulse (7**A**) and Huntec deep-tow (7**B**) boomer profiles obtained along the same survey line during system tests showing the advantages of, and problems with, both systems. The profiles have been prepared at the same vertical and horizontal scales and have the same annotation (letters A through E) to aid comparison. The letter A in Figure 7**B** denotes the sea-surface ghost, resulting from the sea-surface reflection of the out-going pulse from the Huntec system, which was being towed about 20 m depth. The Geopulse sound source, which is towed at the sea surface, does not produce a sea-surface ghost. The letters B and C denote areas of ambiguous reflections where the sea-surface ghost overlaps with 'real' data in the Huntec profile. The Geopulse does not produce such an artifact in the record and shows better depth of penetration when operated at shelf depth. The Huntec profile, however, shows better definition of reflections where there is not interference of the sea-surface ghost, e.g., at D in the profiles. The seafloor multiple is at E. Profile locations in Figure 6.

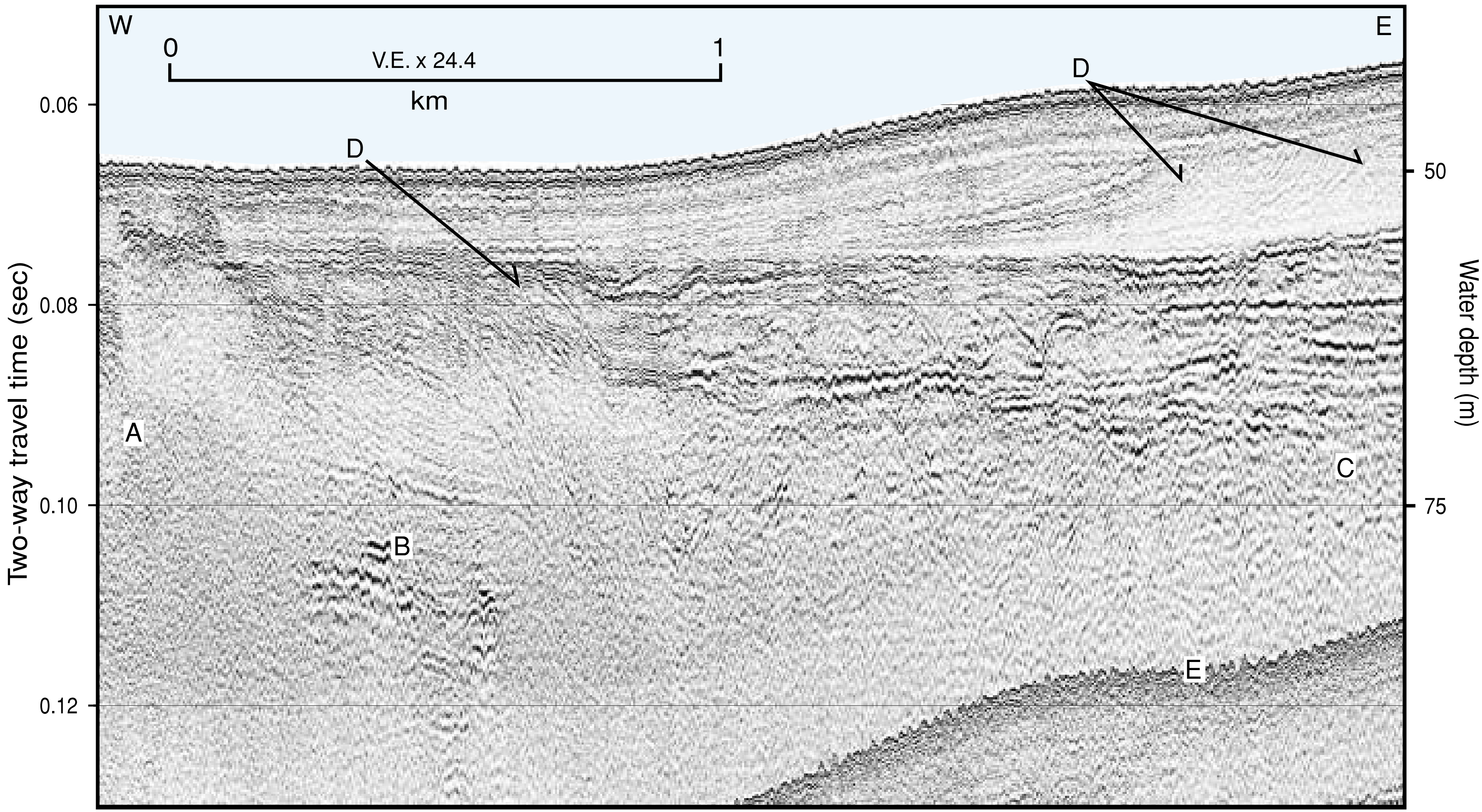


FIGURE 8**A** Geopulse

Geopulse (8**A**) and Huntec deep-tow (8**B**) boomer profiles obtained along the same test line presented at the same vertical and horizontal scales, and with identical annotation (letters A through E) to aid comparison. The letter A in Figure 8**B** denotes the sea-surface ghost in the Huntec profile that makes it difficult to interpret the subbottom returns in the areas denoted by letters B and C. The better resolution reflectors, however, are shown in the Huntec record (at D) along the margins of buried channels. Both systems show the seafloor multiple at E. Profile locations in Figure 6.

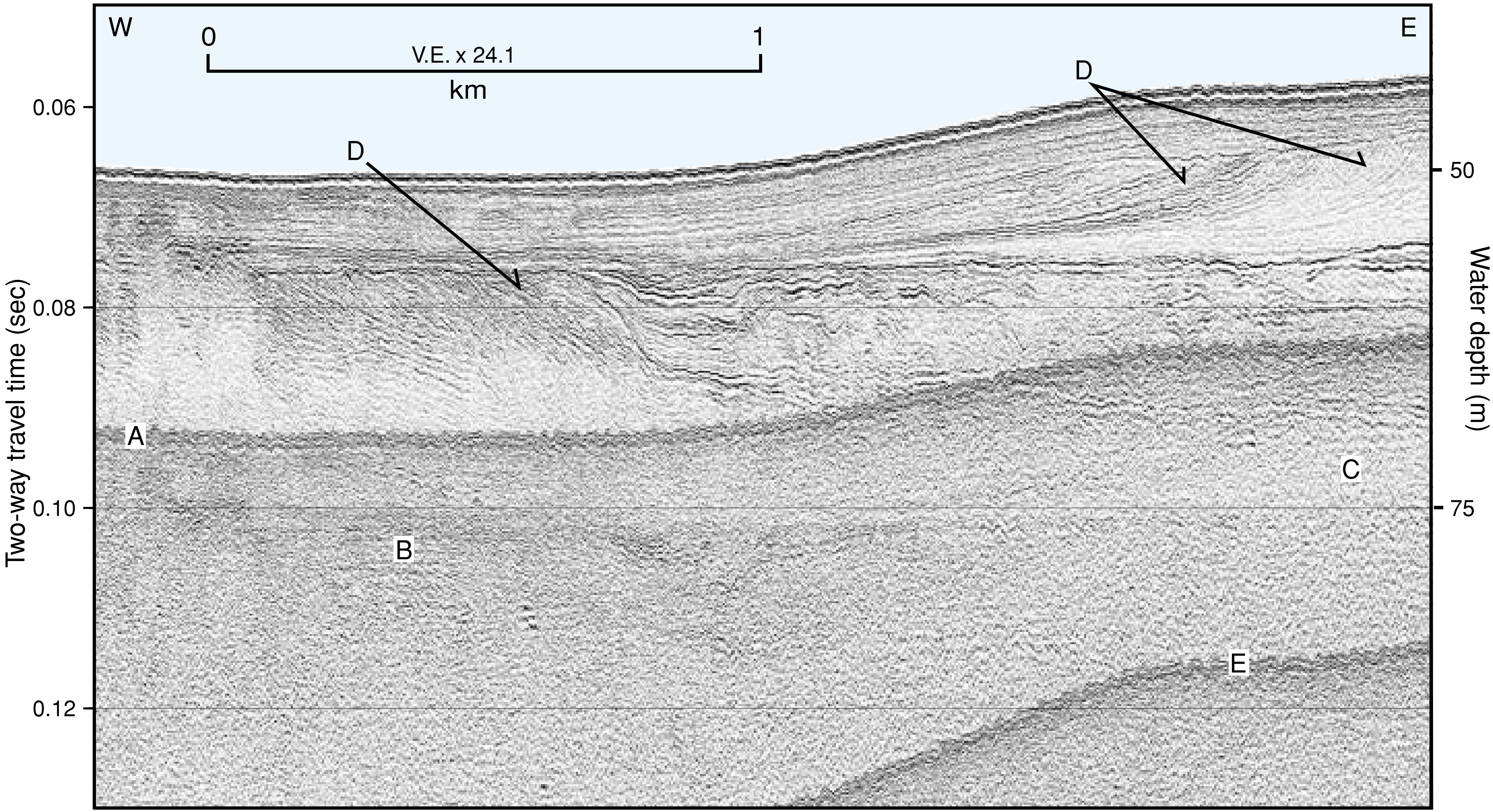


FIGURE 8**B** Huntec

Geopulse (8**A**) and Huntec deep-tow (8**B**) boomer profiles obtained along the same test line presented at the same vertical and horizontal scales, and with identical annotation (letters A through E) to aid comparison. The letter A in Figure 8**B** denotes the sea-surface ghost in the Huntec profile that makes it difficult to interpret the subbottom returns in the areas denoted by letters B and C. The better resolution reflectors, however, are shown in the Huntec record (at D) along the margins of buried channels. Both systems show the seafloor multiple at E. Profile locations in Figure 6.

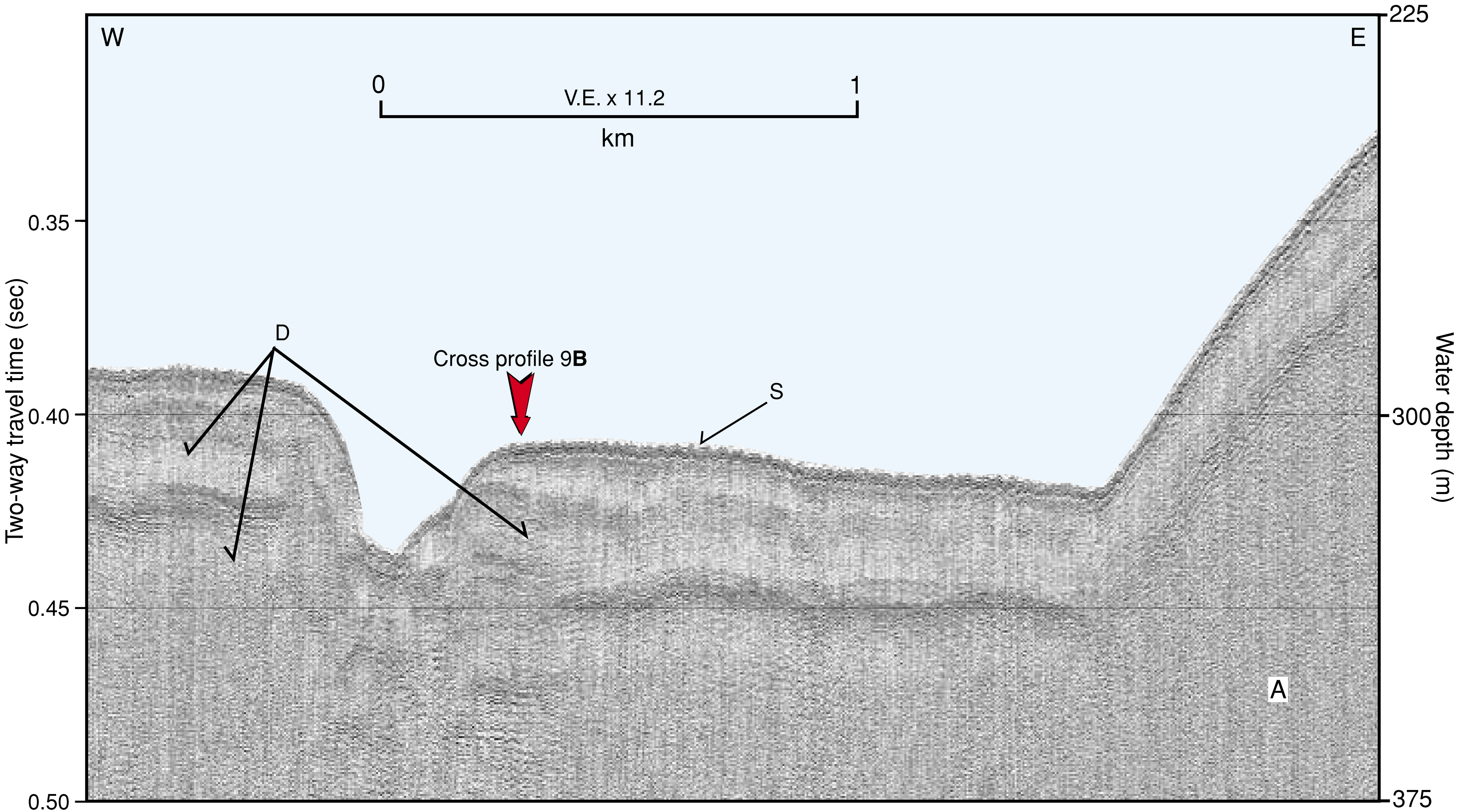


FIGURE 9**A** Geopulse

Geopulse (9**A**) and Huntec deep-tow (9**B**) boomer profiles obtained along crossing subparallel lines from the lower slope and edge of the shallow basin floor. The records are shown at the same vertical and horizontal scales. In higher sea states, the surface-towed Geopulse produces records that have a wavy seafloor return, e.g., at letter S. The vertical motion of the Geopulse in the swells also results in loss of reflector resolution whereas the deep-towed Huntec clearly shows the bedding details within the overbank deposits (letter D). Because the water depth allowed for towing the Huntec at >100 m, the sea-surface ghost (A) is not a problem in this profile. Profile locations in Figure 6.

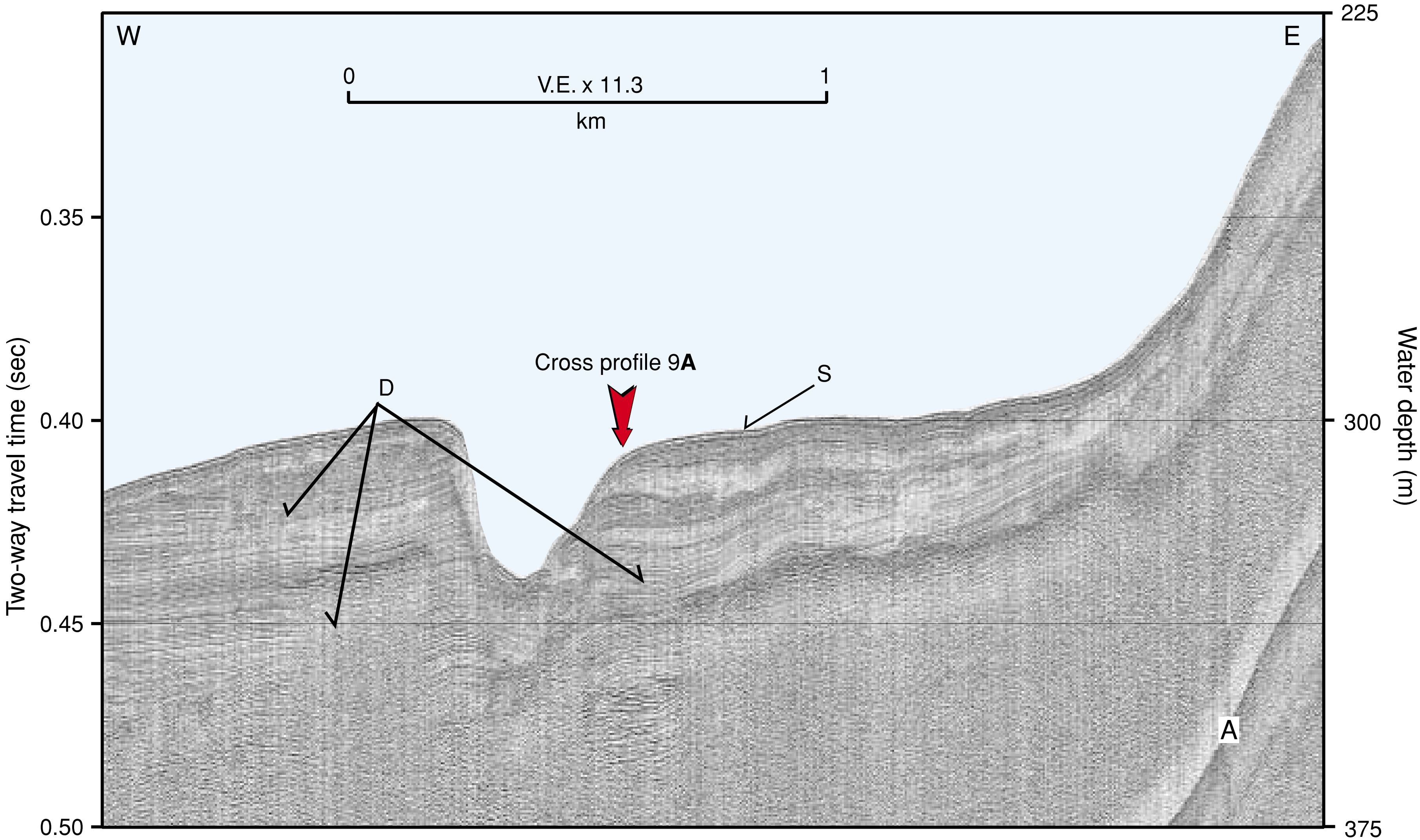


FIGURE 9**B** Huntec

Geopulse (9**A**) and Huntec deep-tow (9**B**) boomer profiles obtained along crossing subparallel lines from the lower slope and edge of the shallow basin floor. The records are shown at the same vertical and horizontal scales. In higher sea states, the surface-towed Geopulse produces records that have a wavy seafloor return, e.g., at letter S. The vertical motion of the Geopulse in the swells also results in loss of reflector resolution whereas the deep-towed Huntec clearly shows the bedding details within the overbank deposits (letter D). Because the water depth allowed for towing the Huntec at >100 m, the sea-surface ghost (A) is not a problem in this profile. Profile locations in Figure 6.

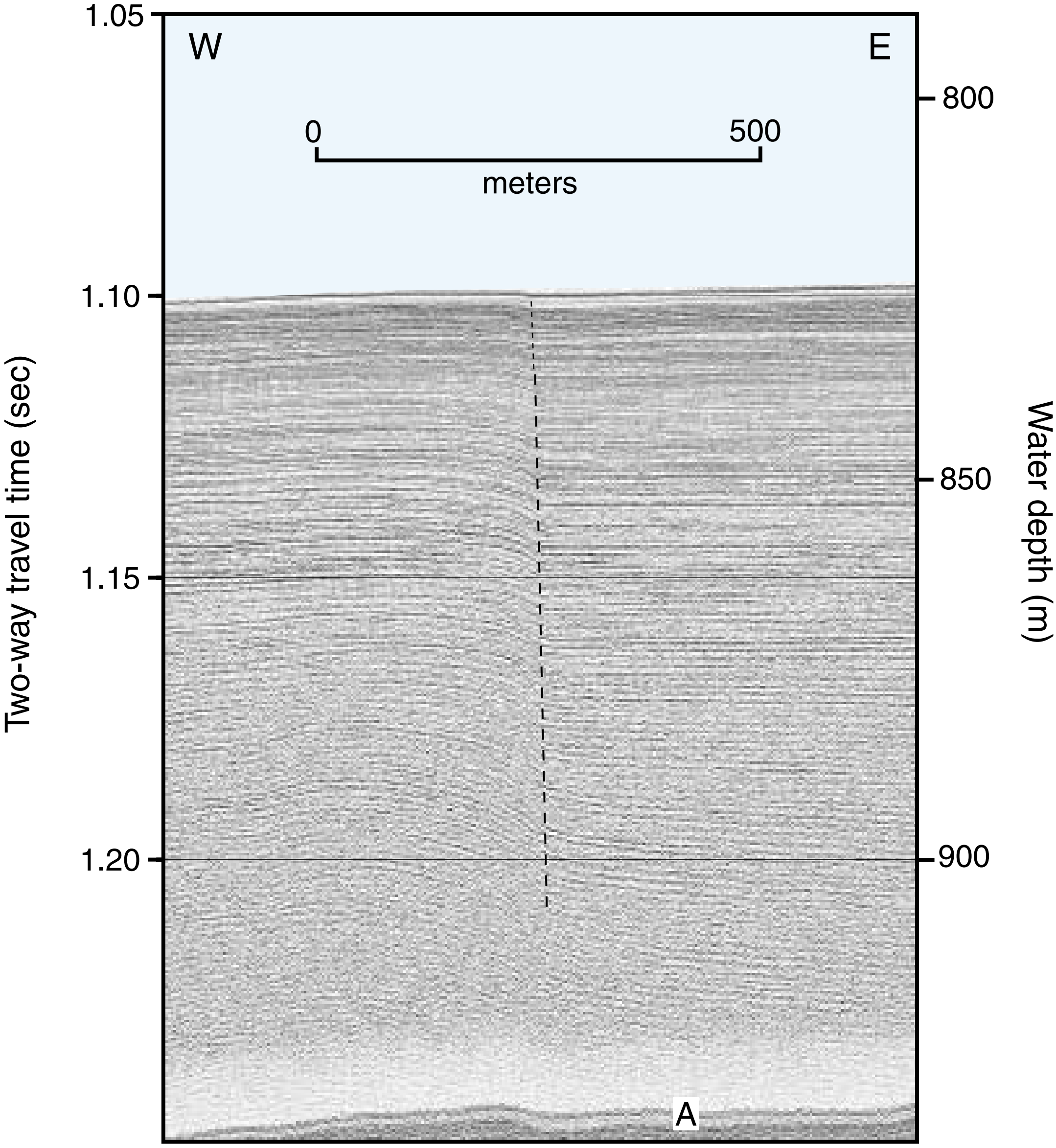


FIGURE 10**A** Huntec

Huntec deep-tow boomer profiles 10**A** and 10**B,** obtained along line 222 that crosses the Gulf of Santa Catalina at basin depths greater than 800 m. At these depths, the Huntec system is capable of as much as 100 m acoustic penetration in the turbidite fill. In deeper water areas, the Huntec is towed deeply enough that the sea-surface ghost (A) does not greatly interfere with the primary data returns. (10**A**) Dashed line shows where the turbidite-smoothed floor of the basin obscures view of a major near-vertical fault that shows progressively greater offset of reflectors with depth. (10**B**) Dashed line indicates where folded and faulted turbidites near the western margin of the basin show greater deformation in increasing depth. Lump in sea-surface ghost at letter A is caused by adjustment of the Huntec tow depth. Profile locations in Figure 6.

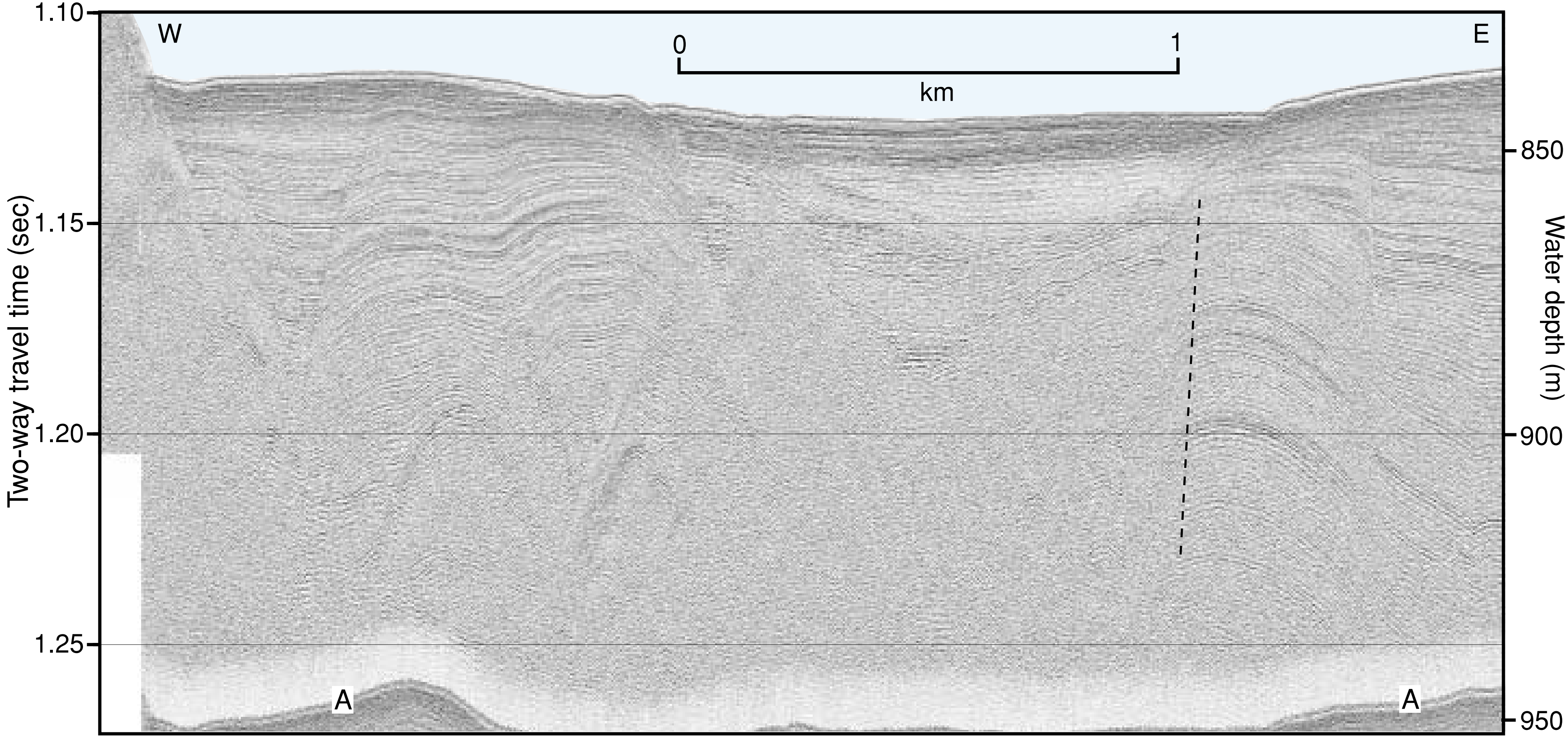


FIGURE 10**B** Huntec

Huntec deep-tow boomer profiles 10**A** and 10**B,** obtained along line 222 that crosses the Gulf of Santa Catalina at basin depths greater than 800 m. At these depths, the Huntec system is capable of as much as 100 m acoustic penetration in the turbidite fill. In deeper water areas, the Huntec is towed deeply enough that the sea-surface ghost (A) does not greatly interfere with the primary data returns. (10**A**) Dashed line shows where the turbidite-smoothed floor of the basin obscures view of a major near-vertical fault that shows progressively greater offset of reflectors with depth. (10**B**) Dashed line indicates where folded and faulted turbidites near the western margin of the basin show greater deformation in increasing depth. Lump in sea-surface ghost at letter A is caused by adjustment of the Huntec tow depth. Profile locations in Figure 6.

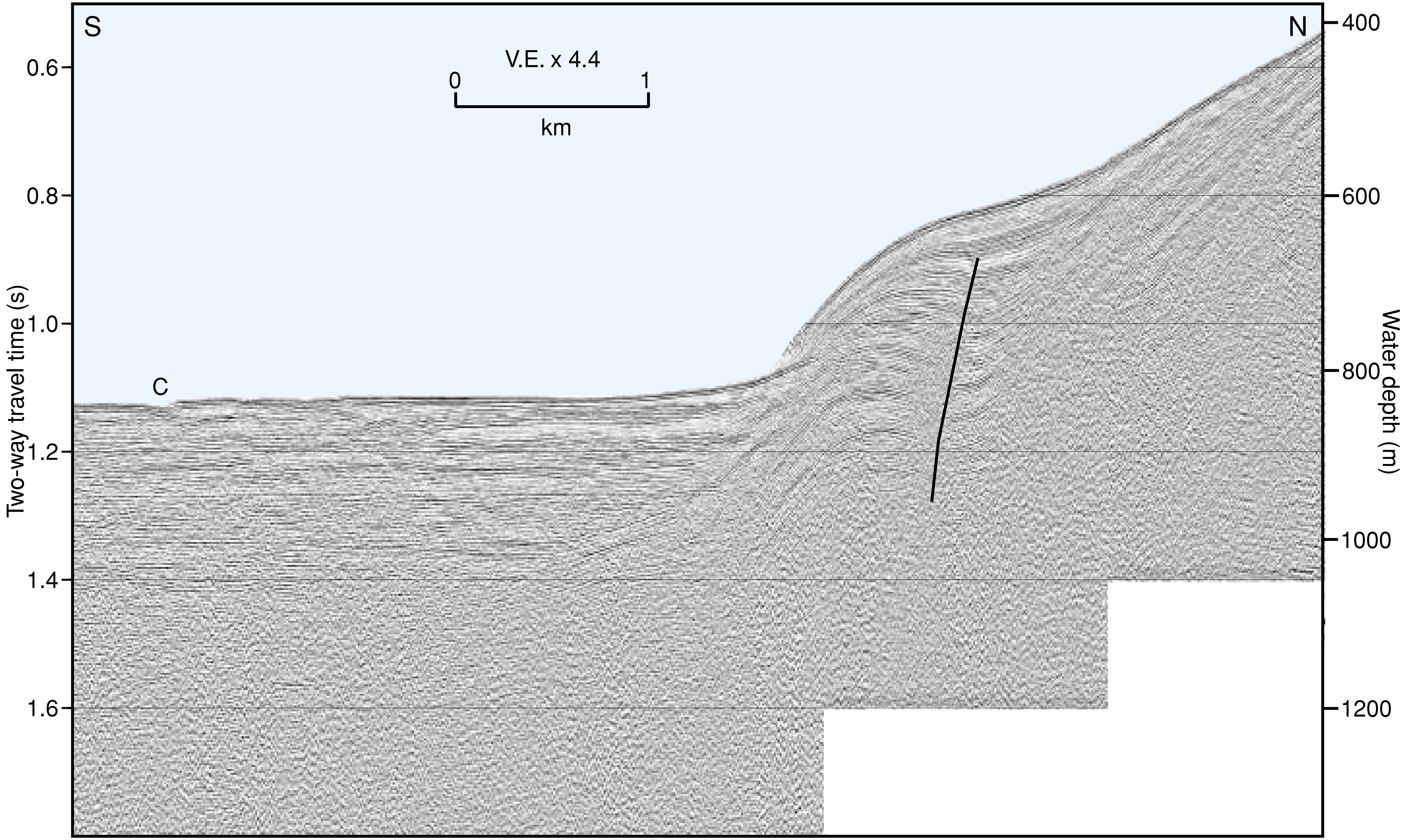


FIGURE 11 (Minisparker): Multichannel seismic-reflection profile from the lower slope and floor of Santa Monica Basin offshore Point Dume, California, illustrating the resolution and acoustic penetration obtained with a 1.5-kJoule minisparker sound source for the high-resolution multichannel system. Effective acoustic penetration is limited to about 0.4 sec (~300 m). A growth fold (indicated by solid line) at the base of slope, the flank of which is onlapped by turbidite sediment at the edge of the basin, is an example of the type of structural features for which the timing of development might be determined from the age of the onlapped sediment. C denotes a turbidite channel on the basin floor. Profile location in Figure 6.

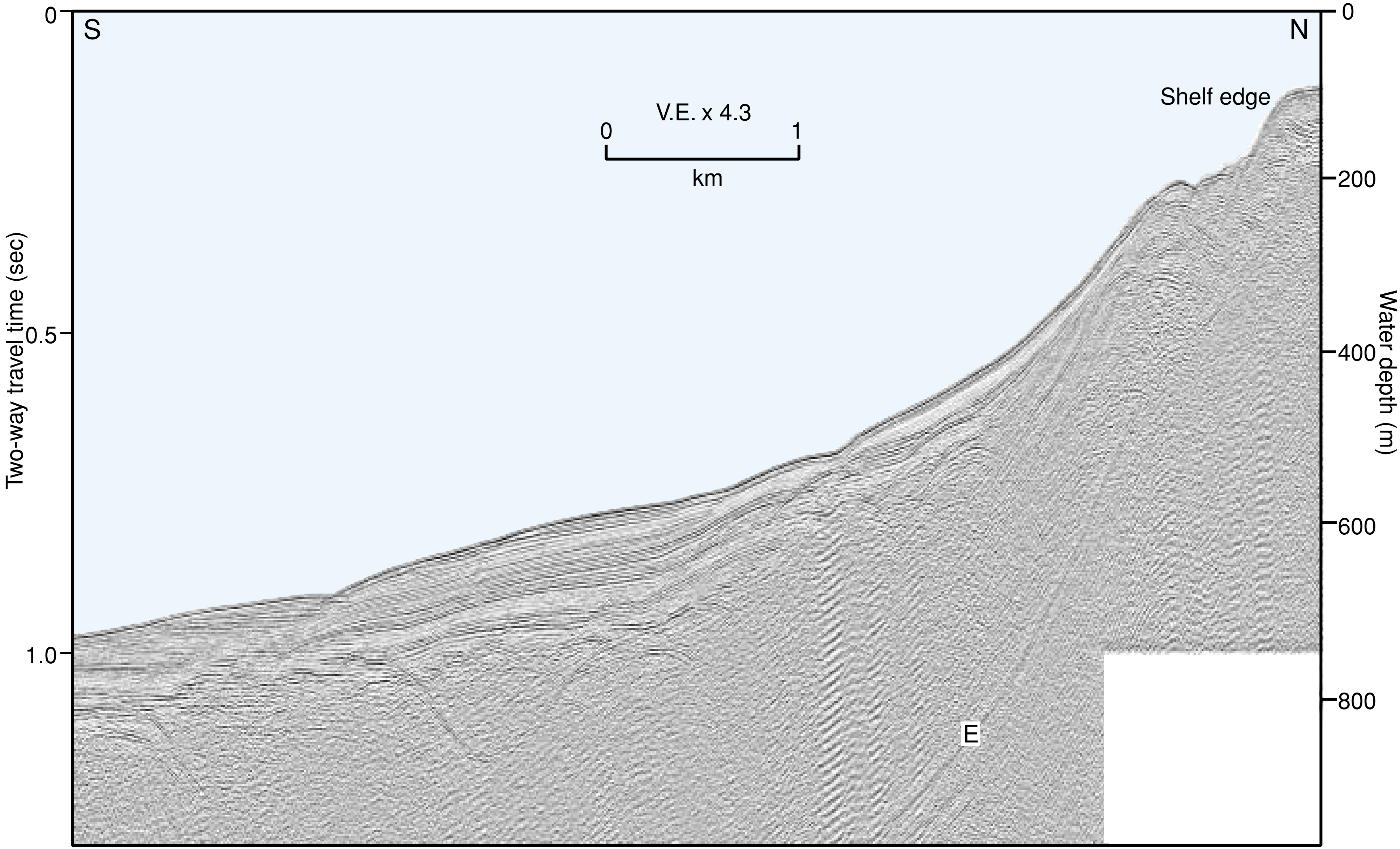


FIGURE 12 Minisparker
Example of multichannel seismic-reflection profile from the shelf edge and northern slope of Santa Monica Basin showing more limited penetration (~200 m) than on the profile from the basin floor (Fig. 11). E denotes seafloor multiple. Profile location in Figure 6.

Appendix 1

USGS OF 00-516

Report prepared by

Cascadia Research

Under contract to the USGS in support of

Cruise A1-00-SC

(The following report has been formatted to fit on fewer pages than the original, and paginated as a continuation of OF 00-516. No text or content changes were made.)

FINAL REPORT

MARINE MAMMAL OBSERVATIONS AND MITIGATION ASSOCIATED WITH USGS SEISMIC SURVEYS IN THE SOUTHERN CALIFORNIA BIGHT IN 2000

Prepared for

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December 2000

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INTRODUCTION

From 7 to 27 June 2000, the U.S. Geological Survey conducted seismic surveys in the coastal waters of the Pacific Ocean, in the southern California Bight, to investigate earthquake hazards. As a part of this project, Cascadia Research was contracted by the USGS to monitor marine mammals from the survey platform and provide mitigation on impacts on marine mammals by requesting shutdown of the sound sources when marine mammals were close to the operations.

This report summarizes the results of a marine mammal mitigation and monitoring program conducted in conjunction with these USGS surveys and adds information to similar work conducted by Cascadia Research in 1998 and 1999 (Calambokidis et al 1998, Quan and Calambokidis 1999). There were several modifications to observations and mitigation operations in 2000 compared to 1999 and 1998: 1) five observers were on board with at least two on duty during all daylight and nighttime operations, 2) the mitigation safety zone was slightly more complicated and involved multiple sound sources, and 3) airgun operations were conducted during the night time hours if baleen whales had not been seen in the area during the day.

BACKGROUND ON PROJECT AND SOUND SOURCE DESCRIPTION

The following background on the overall project and sound source description was provided by the USGS.

The focus of this project is to identify the landslide and earthquake hazards, as well as related deformation processes, that have great potential to impact the social and economic well being of the inhabitants of the Southern California coastal region--the most heavily populated urban corridor along the U.S. Pacific margin. We are studying Pleistocene-Holocene sedimentation and deformation patterns and related seismicity and strain within the coastal zone and adjacent continental borderland basins. Our findings will help us evaluate the hazard potential for large, destructive earthquakes and identify how deformation is distributed in space and time between onshore and offshore regions. The results of this project will contribute to decisions involving land use, hazard zonation, and building codes in the area.

The FY 2000 field program was conducted using a leased vessel, the 156-ft-long M/V *Auriga*, owned and operated by F/V North Wind, Inc. Three sound sources were used:

<u>Minisparker:</u> The sound source for the multi-channel seismic-reflection (MCS) profiling during the cruise was a 1.5 kJoule (kJ) "SQUID 2000" minisparker system manufactured by Applied Acoustic Engineering, Inc. This minisparker consists of eight sets of discharge electrodes, in two banks, mounted on a small pontoon sled. The pontoon sled that supports the minisparker is towed on the sea surface, generally about 3 meters behind the ship. Source characteristics of the SQUID 2000™ provided by the manufacturer show a sound-pressure level (SPL) of 209 dB re 1 Pa-m RMS. The amplitude spectrum of this pulse indicates that most of the sound energy lies between 150 Hz and 1700 Hz, and the peak amplitude is at 900 Hz. The output sound pulse of the mini-sparker has a duration of about 0.8 ms. For the multichannel seismic-reflection survey, the minisparker was discharged every 2 seconds, and when used with a single-channel streamer, at 400 J, the fire rate varied from 300-750 ms, depending on water depth.

<u>Huntec:</u> A high-resolution Huntec DTS boomer system towed between 20 m and 137 m below the sea surface (depending upon the water depth) was used to image the upper few tens of milliseconds of strata with a resolution of better than 0.5 ms (0.4 m). The SPL for this source is 210 dB re 1 Pa-m RMS. Power output was 375 Joules, with a firing rate that was also dependent on water depth, ranging from 0.5 sec over the shelf and upper basin slopes to 1.67 sec over the deeper parts of the basins.

<u>Geopulse:</u> The sound source consists of two ORE Geopulse 5813A boomer plates mounted on a catamaran sled built in-house. The catamaran was towed from the same deck area as the multichannel sound source, while the short hydrophone streamer was towed from a boom on the starboard side of the vessel. The source level suggested by the manufacturer is 220 dB re 1 Pa-m RMS. Power input was 350 Joules, with a firing rate that was also dependent on water depth: 0.5 or 1.0 second for the geologic hazard part of the survey and 0.25 second in the harbor areas.

OBJECTIVES

The objectives of the marine mammal study were as follows:

1. Mitigate impacts on marine mammals by monitoring the presence of these species from the survey ship and requesting shut-down of the sound source when marine mammals were seen within specified safety zones representing distances close enough to potentially cause physical injury.

2. Document the number of animals of each species present in the vicinity of sound transmissions.

3. Evaluate the reactions of marine mammals to the sound transmissions at different distances from the sound source.

METHODS

General Approach

The research effort consisted of observations made directly from the seismic vessel (*Auriga*) to provide mitigation, document marine mammals exposed to the sound sources, and monitor reactions of marine mammals close to the seismic survey vessel. Observations were conducted from several locations. The primary platform utilized by one of the two on-duty observers during both day and night operations was in front of the bridge and put the observer's eye level at 7.6 m above the water. This external platform provided excellent visibility to the front and sides but obscured visibility to the rear. The platform was near the front of the vessel 6.4 m behind the bow and 47 m from the stern of the vessel. During daylight observations, a second observer used a platform immediately behind the bridge that faced aft and put the observer eye level at about 10m above the water. This station was used to view the area to the rear of the bridge and immediately around the sound source. During night observations the second observer roamed the vessel's main external deck just above water level.

Observations were conducted 24 hours a day when seismic operations were underway. Two observers were on watch at all times on rotating shifts among the total of five observers on the boat. Observers shifted every two hours. During daylight observations, observers used *Tasco 7x50* binoculars with internal compasses and reticles to record the horizontal and vertical angle to sightings. Night-time operations used a commercial night vision goggles (see next section). The roaming observer that was responsible for the sides and rear portion of the ship had the benefit of lights that illuminated the rear deck and aft of the ship.

Data on survey effort and sightings were recorded on a datasheet which included observers on duty and weather conditions (Beaufort sea state, wind speed, cloud cover, swell height, precipitation, visibility, etc.). For each sighting the time, bearing and reticle reading to sighting, species, group size, surface behavior and orientation were recorded. A polaris was used to determine the angle to the sighting in relation to the ship's course.

Distances to sightings were calculated using the vertical angle to the animal (based on either the reticle reading through the binoculars or a hand held clinometer for close sightings) and the known elevation above the water.

Mitigation safety zones

Two safety zones were used for this project. These were:

1. For pinnipeds and odontocetes (all toothed cetaceans except sperm whales) seismic operations would be shut down when an animal was seen close to a distance of 30 m or less.

2. For mysticetes (baleen whales) and sperm whales, the safety zone was 250 m.

To allow a quick determination of status, safety zones were calculated in three arcs around the ship and the safety distance was applied using the closest part of the ship or sound source. Three different cut-off distances (based on distance and angle from the observers) were calculated for off the bow (60 degrees to either side of the bow), to either side of the vessel (from 60 to 120 degrees off the bow and off the stern (120 to 180 degrees off the bow).

Observers were instructed to call for a shut-down when a marine mammal was seen inside the safety zone or close enough to the safety zone that given measurement-error, it could be within the safety zone. Shut-down was also considered when animals were ahead of the vessel path outside the safety zone, but it appeared likely that the direction of travel of the vessel would result in the marine mammal being within the safety zone shortly. If possible, marine mammals were tracked until they were outside the safety zone at which time seismic operations resumed. If animals could not be tracked then seismic operations were resumed after there were no resightings of animals within the safety zone for a period adequate to indicate these animals were not any longer near the ship.

For effective mitigation, the observers needed to know very quickly whether a sighting was within the safety zone. We used a polaris (angle board) for the observers to estimate the angle to the sighting. The cut-off vertical angle, which represented each of the safety zones, was also written on the polaris, allowing quick determination of the proximity of a sighting to the safety zone.

Night Observations

Several modifications were made for night observations during seismic operations. Due to the reduced visibility at night, the two observers focused on sightings of marine mammals in the immediate vicinity of the ship. One observer would observe the forward part of the ship from the platform forward of the bridge and the second would roam the sides and aft portion of the shift primarily observing aft near the sound source. Generation-3 night vision goggles (ITT Industries) were used to assist in sightings primarily by the forward observer. Distances to sightings could not easily be determined with clinometers or binoculars and were instead estimated.

As a mitigation to avoid exposure to mysticete (baleen) or large odontocetes (toothed) whales during night operations, additional precautions were taken. Because sightings of these species out at the mitigation distance of 250 m was not possible, night operations were conducted only if no large whales had been seen in the region during the daylight operations.

RESULTS AND DISCUSSION

Marine mammal sightings

There were a total of 241 sightings (not including re-sightings), representing at least 11 species and comprised of 4,792 marine mammals made during observation operations (Table 1). Small cetaceans were the most numerous and common marine mammal species sighted accounting for 54% of the sightings and 96% of the animals. Common dolphins were the most common small cetacean species with 74 sightings of 3,764 animals. Risso's dolphins, bottlenose dolphins, and Dall's porpoise were also seen in smaller numbers. Pinnipeds accounted for 98 sightings and these were predominantly California sea lions. Smaller numbers of harbor seals and a single elephant seal were also sighted. Four species of large cetacean were sighted in small numbers including blue, fin, humpback, and minke whales. Blue whales were the most common with five sightings of single animals.

Sightings of marine mammals were made during a wide variety of operational states for the various sound sources (Table 2). Rates at which marine mammals were sighted were different among the different operational modes likely due to habitat differences. California sea lion sightings were made almost twice as often during operation of the minisparker than they were during other operating modes. Conversely, common dolphin sightings occurred during Huntec operations at more than twice the rate of other operating modes. These differences likely reflect the differences in where these sound sources were used: minisparker on the shelf and near LA/Long Beach Harbor and the Huntec in more offshore waters.

Marine mammal mitigation — Shut-downs

Shut-down of the sound source was requested in 40 instances (22 daylight and 18 night) (Table 3). Shut-downs were called for during a variety of sound source operations including 19 during Huntec and 12 during Geopulse operation. Shut-downs were called in response to five different species (in one case the dolphin species was not determined). Common dolphins were the most common species triggering a shut-down accounting for 29 instances. Risso's and bottlenose dolphins and California sea lions each accounted for three or four shut-downs each. The only shut-down for a large whale was for a sighting of a blue whale which was still outside the 250 m mitigation zone but which prompted a precautionary shut-down.

The high proportion of shut-downs caused by common dolphins was a result both of their being one of the most common species in the area and their tendency to approach the ship. Common dolphins accounted for 31% of the marine mammal sightings but were responsible for 72% of the shut-downs. California sea lions, which accounted for 36% of the sightings were responsible for only 7% of the shut-downs. Although other dolphin species were less common, both Risso's and bottlenose dolphins had shut-down rates that were similar to common dolphins.

Overall, 30% of small cetacean sightings made while sound sources were operational led to shut-downs compared to only 4% of pinniped sightings (Table 4). A low proportion of large whale sightings led to shut downs. The 11 sightings of whales made during sound source operations led to only the single precautionary shut-down (outside the mitigation area) for the blue whale mentioned above. This low rate is partly the result of the much greater distance at which large whales could be sighted.

The proportion of sightings that led to shut-downs did not seem to vary greatly by what sound source was operating (Table 5). About 20% of small cetaceans sightings during daylight observations lead to a shut-down regardless of sound source operating. Similarly, about 4% of daylight sightings of pinnipeds lead to shut-downs regardless of sound source. These findings suggest that there were not large differences in how marine mammals were attracted to or avoided the ship when different sound sources were operating.

Behavior

Marine mammals were observed in a variety of behaviors regardless of sound source operation (Table 6). Primary behavior was slow or fast travel, hauled out, or milling. Fast travel was the most common behavior for common dolphins during both times sound was transmitting and when it was not. Pinnipeds were most commonly seen hauled out or slow traveling. Breaching was seen in two cases for large cetaceans; a minke whale and a group of two humpback whales. Sound transmissions were occurring only for the minke whale sighting.

Orientation of marine mammals in relation to the boat at initial sighting did not appear to vary by sound transmissions (Table 7). Most marine mammals were not judged to be headed toward or away from the survey vessel but on a tangent. This was the case both during transmissions and when there were none. Of those that were judged to be moving toward or away from the vessel, a slightly higher proportion of animals tended to be headed toward the vessel compared to away. This again held true both when sound sources were on or off. Overall, we could not detect differences in orientation of marine mammals in relation to transmissions.

Night Observations

Some aspects of the night operations were discussed above. Overall there were dramatically reduced numbers of sightings of marine mammals at night (Table 5). Sightings at night were primarily of dolphins that approached the boat closely. In all but one case the animals were 100 m or closer from the boat when initially sighted. The close distance at which marine mammals could be seen at night resulted in shut-downs in 18 of 29 cases where small cetaceans were seen at night during sound transmissions. Sightings of both pinnipeds and larger cetaceans were dramatically reduced at night since these species did not approach the boat closely as often. There were no large cetacean sightings at night and only six pinniped sightings at night (compared to 92 in the day).

Despite the difficulty in sighting marine mammals at night, the observers were successful in sighting marine mammals within the safety on 18 occasions resulting in shut-downs. Despite the low sighting rate, the observers were able to provide some mitigation and reduced the potential exposure of bow-riding dolphins to elevated sound levels. Despite the use of a variety of generation 3 night-vision gear, it was not possible to sight marine mammals at distances greater than 100 m. Mitigating exposure through the 250 m safety zone for large cetaceans was therefore not practical. We were not able to evaluate whether the precaution of conducting operations at night only in areas where large cetaceans had not been seen in the day was completely effective as a mitigation strategy.

CONCLUSIONS

Overall marine mammal monitoring and mitigation appeared successful in meeting the objectives of the study. There were more shut-downs in 2000 compared to either 1998 or 1999 and even though these provided effective mitigation, they interrupted the objectives of the seismic survey. Most of the shut-downs were from common dolphins, a species that was sighted more often in 2000 than in 1998 and 1999, but this increased sighting rate was not enough to account for the difference. Additionally, the safety zone for pinnipeds and small cetaceans in 1998 and 1999 was 100 m, greater than the 30 m zone used in 2000. Shut-downs at night were a principal reason for the higher number of total shut-downs in 2000. In 1999 there were no night operations. In 1998 there were night operations but only two shut-downs called at night compared to 18 in 2000. Sighting conditions in 1998 were not as good with only one observer on duty and inferior night vision gear to that used in 2000. That combined with a lower presence of dolphins in the study area likely accounted for the difference between 1998 and 2000.

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Quan, J., and J. Calambokidis. 1999. Marine mammal observations and mitigation associated with USGS seismic surveys in the southern California Bight in 1999. Final Report to U.S. Geological Survey, Menlo Park, California. Cascadia Research, 218-1/2 W Fourth Ave., Olympia, WA 98501. 16pp.

TABLES

1. Summary of sightings and resightings by species
2. Sightings by species and operational state
3. List of shut-downs called during the survey
4. Percent of sightings resulting in shut-downs during sound transmissions
5. Summary of effort, sightings and shutdowns by operational state and day/night
6. Summary of primary behavior by species
7. Summary of orientation by species

Table 1. Summary of sightings and resightings by species in 2000. Resightings represent groups seen more than one time. Does not include sightings outside study area during transit to and from region.

	Sighting		Resighting	
Species	# of Sightings	# of Animals	# of Sightings	# of Animals
Large whales				
Blue whale	5	5	4	4
Fin whale	1	1	2	2
Humpback whale	1	2		
Large Balaenopterid	1	1	2	2
Minke whale	2	3	2	4
Unidentified whale	2	2		
Total whales	12	14	10	12
Small cetaceans				
Common dolphin (short & long-beaked)	74	3764	20	2047
Risso's dolphin	14	120	4	35
Dall's porpoise	2	2		
Bottlenose dolphin	10	82	4	41
Unidentified dolphin	31	627	1	55
Total small cetaceans	131	4595	29	2178
Pinnipeds				
California sea lion	87	171	4	10
Elephant seal	1	1		
Harbor seal	7	8		
Unidentified pinniped	3	3		
Total pinnipeds	98	183	4	10
Grand Total	241	4792	43	2200

Table 2. Summary of sightings by operational condition and species within study area in 2000.

	None		Geopulse		Huntec		Sparker		Uniboom		Geopulse/ Huntec	
Species	# Sit.	# Anim.	# Sit.	# Anim.	# Sit.	# Anim.	# Sit.	# Anim.	# Sit.	# Anim.	# Sit.	# Anim.
Large whales												
Blue whale			3	3	2	2						
Fin whale			1	1								
Humpback whale	1	2										
Large Balaenopterid					1	1						
Minke whale					2	3						
Unidentified whale					1	1	1	1				
Small cetaceans												
Common dolphin (short & long-beaked)	6	795	18	782	41	1,735	4	146	-	-	5	306
Risso's dolphin			3	19	9	80	2	21				
Dall's porpoise					2	2						
Bottlenose dolphin			5	36	3	14	2	32				
Unidentified dolphin	1	5	7	116	18	371	5	135				
Pinnipeds												
California sea lion	18	32	15	28	23	28	30	76	1	7		
Elephant seal					1	1						
Harbor seal			5	6	2	2						
Unidentified pinniped			1	1	1	1	1	1				
Total sightings	26	834	58	992	106	2,241	45	412	1	7	5	306
Summary of effort												
hours on effort	60		166		162		70		2		3	
nmi covered	241		460		660		230		6		11	

Other effort with no sightings:
Total of .9 h covering 2.5 nmi with both Geopulse and Sparker on
Total of 6 h and 14.3 nmi with both Huntec and Sparker on
Also 15 h covering 144 nmi of effort outside study area with no sources not included above (some sightings)

Table 3. List of shut-downs called for based on sightings of marine mammals during 2000 surveys.

			Time							
Date	**Firing**	**Dy/Nt**	**Sight**	**Sht-dn**	**Resume**	**Tot. #**	**Species**	**Sit. #**	**Obs**	**Comments**
08-Jun-00	Huntec	D	0902	0902	0950	1	Common dolphin	7	JRV	Fast traveling
10-Jun-00	Geopulse	N	0306	0306	0308	6	Bottlenose dolphin	14	JRV	Slow traveling
10-Jun-00	Geopulse	N	0440	0440	0446	1	Risso's dolphin?	15	ABD	Slow traveling
10-Jun-00	Geopulse	D	1310	1315	1322	60	Common dolphin	21	ABD	Milling then bowriding
10-Jun-00	Geopulse	D	1645	1645	1654	1	California sea lion	23	TEC	Fast traveling, swam under boat
11-Jun-00	Geop./Hunt.	D	1524	1534	1600	50	Common dolphin	36	TEC	Fast traveling
12-Jun-00	Geopulse	D	1515	1515	1530	1	Blue whale	49	ABD	Slow traveling, outside zone
13-Jun-00	Huntec	D	1631	1632	1639	12	Common dolphin	54	ABD	Bow riding
13-Jun-00	Geopulse	N	2240	2240	2252	30	Common dolphin	57	LSB	Fast traveling
14-Jun-00	Geopulse	N	0034	0034	0129	12	Common dolphin	58	DKE	Fast traveling
14-Jun-00	Geopulse	D	2003	2003	2009	30	Common dolphin	65	TEC	Slow traveling then accelerated
15-Jun-00	Huntec	N	0500	0500	0506	12	Common dolphin	66	LSB	Bow riding
15-Jun-00	Geopulse	D	0558	0558	0603	12	Common dolphin	71	LSB	Bow riding
15-Jun-00	Geopulse	D	0631	0634	0636	75	Common dolphin	74	ABD	Fast traveling, part of group approaches boat
15-Jun-00	Huntec	D	0912	0914	0917	28	Common dolphin	79	ABD	Slow traveling
15-Jun-00	Huntec	D	1035	1036	1040	12	Risso's dolphin	81	LSB	Slow traveling
15-Jun-00	Geopulse	N	2328	2328	2335	3	Unidentified dolphin	83	DKE	Fast traveling
16-Jun-00	Geopulse	N	0025	0025	0032	5	Common dolphin	84	TEC	Slow traveling
16-Jun-00	Minisparker	N	2152	2152	2159	1	Common dolphin	89	JRV	Slow traveling
17-Jun-00	Huntec	D	2025	2025	2028	12	Common dolphin	94	JRV	Fast traveling
17-Jun-00	Huntec	N	2118	2118	2121	2	Common dolphin	95	JRV	Bow riding
17-Jun-00	Huntec	N	2146	2146	2155	40	Common dolphin	96	JRV	Fast traveling
18-Jun-00	Huntec	N	0452	0452	0500	6	Bottlenose dolphin?	97	DKE	Slow traveling
18-Jun-00	Huntec	D	0935	0936	0939	10	Bottlenose and Risso's dolphin	109B	LSB	Fast traveling
18-Jun-00	Minisparker	D	1929	1935	1954	20	Common dolphin	119	ABD	Milling
19-Jun-00	Huntec	N	2234	2234	2239	2	Common dolphin	130	TEC	Slow traveling
20-Jun-00	Huntec	D	0647	0650	0653	120	Common dolphin	134	JRV	Fast traveling
20-Jun-00	Huntec	N	2331	2331	2335	1	Common dolphin	141	TEC	Slow traveling
20-Jun-00	Huntec	N	2357	2357	0002	4	Common dolphin	142	TEC/LSB	Slow traveling
21-Jun-00	Huntec	N	0014	0014	0019	3	Common dolphin	143	JRV	Bow riding
23-Jun-00	Huntec	N	0121	0121	0123	2	Bottlenose dolphin	166	JRV	Fast traveling
24-Jun-00	Minisparker	D	0613	0617	0650	1	California sea lion	184	TEC	Slow traveling
25-Jun-00	Huntec	N	2303	2303	2308	3	Common dolphin	204	JRV	Bow riding
27-Jun-00	Huntec	N	0456	0458	0503	20	Common dolphin	219	JRV	Slow traveling
27-Jun-00	Huntec	D	0605	0605	0606	1	California sea lion	222	ABD	Slow traveling
27-Jun-00	Huntec	D	0956	0957	1016	18	Common dolphin	228	TEC	Slow traveling, testing equip delayed restart
27-Jun-00	Minisparker	D	1124	1130	1134	60	Common dolphin	234	DKE	Slow traveling
27-Jun-00	Minisparker	D	1143	1147	1154	65	Common dolphin	235	DKE	Fast traveling
27-Jun-00	Huntec	D	1159	1159	1205	65	Common dolphin	235	DKE	Fast traveling
27-Jun-00	Huntec	D	1220	1220	1222	700	Common dolphin	239	LSB	Fast traveling

Table 4. Percent of sightings resulting in shut-downs during sound transmissions.

Species	Sightings	Shut-downs	% of sightings
Pinnipeds			
California sea lion	69	3	4%
Other pinniped	3	0	0%
All pinniped	72	3	4%
Small cetaceans			
Common dolphin	68	29	43%
Bottlenose dolphin	10	4	40%
Risso's dolphin	13	3	23%
Dall's porpoise	2	0	0%
Unident. dolphin	30	1	3%
All small cetaceans	123	37	30%
Large cetaceans			
Blue whale	5	1*	20%*
Other whales	6	0	0%
All large cetaceans	11	1	9%

* Single large cetacean shut-down was precautionary (outside safety zone)

Table 5. Summary of effort, sightings, and shut-downs by operational conditions and day/night.

Sound operation	Hours	Large cetaceans		Small cetaceans		Pinnipeds	
		# Sit	# S/D	# Sit	# S/D	# Sit	# S/D
Day							
None	47	1		5		18	
Geopulse	102	4	1	26	4	21	1
Huntec	94	6		52	10	25	1
Sparker	50	1		12	3	27	1
Uniboom	2					1	
Geopulse/Huntec	3			5	1		
Other	4						
All day operations	302	12	1	100	18	92	3
Night							
None	13			2			
Geopulse	64			7	6		
Huntec	69			21	11	2	
Sparker	20			1	1	4	
Uniboom	0						
Geopulse/Huntec	0						
Other	2						
All night operations	168	0	0	31	18	6	0

Table 6. Summary of primary behavior of marine mammals sighted (not including resightings). Number in parenthesis indicates portion seen while no sound source was on.

	Primary behavior									
Species	**Breaching**	**Fast travel**	**Slow travel**	**Bowriding**	**Milling**	**Hauled**	**Stationary**	**Dead**	**Unknown**	**Total**
Blue whale			5						1	6
Fin whale			1							1
Humpback whale	1(1)									1(1)
Minke whale	1		1							2
Unid. large whale									2	2
Common dolphin		35(5)	24	6	9(1)					74(6)
Risso's dolphin		1	12		1					14
Dall's porpoise		2								2
Bottlenose dolphin		3	5		2					10
Unid. dolphin		17	10		4(1)					31(1)
California sea lion		8(2)	27		4(1)	38(8)	8(7)	1	1	87(18)
Elephant seal							1			1
Harbor seal		1	3			1	2			7
Unid. pinniped		1	2							3
All species	2(1)	68(7)	90	6	20(3)	39(8)	11(7)	1	4	241(26)

Table 7. Summary of orientation of marine mammals by operational condition during initial sighting and resightings in 2000.

	None		Geopulse		Huntec		Sparker		Other		All	
Orientation	**# Sit.**	**# Res.**	**# Sit.**	**# Res.**	**# Sit.**	**# Res.**	**# Sit.**	**# Res.**	**# Sit.**	**# Res.**	**# Sit.**	**# Res.**
Away	2	4	9	3	11	3	2				24	10
Left	4		17	2	43	6	7	1	1		72	9
Right	6	1	18	2	28	9	5	1	1	1	58	14
Toward	3	2	6		17		6		1	1	33	3
Variable or not determ.	11	4	8	1	7	2	25		3		54	7
Total	26	11	58	8	106	20	45	2	6	2	241	43
As percent of sightings under that condition												
Away	8%	36%	16%	38%	10%	15%	4%	0%	0%	0%	10%	23%
Left	15%	0%	29%	25%	41%	30%	16%	50%	17%	0%	30%	21%
Right	23%	9%	31%	25%	26%	45%	11%	50%	17%	50%	24%	33%
Toward	12%	18%	10%	0%	16%	0%	13%	0%	17%	50%	14%	7%
Variable or ND	42%	36%	14%	13%	7%	10%	56%	0%	50%	0%	22%	16%