Cruise Report for A1-02-SC Southern California CABRILLO project, Earthquake Hazards Task

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Open-File Report 03-110

2003

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

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INTRODUCTION

A two-week marine geophysical survey obtained sidescan-sonar images and multiple sets of high-resolution seismic-reflection profiles in the southern California offshore area between Point Arguello and Point Dume. The data were obtained to support two project activities of the United States Geological Survey (USGS) Coastal and Marine Geology (CMG) Program: (1) the evaluation of the geologic hazards posed by earthquake faults and landslides in the offshore areas of Santa Barbara Channel and western Santa Monica Basin and (2) determine the location of active hydrocarbon seeps in the vicinity of Point Conception as part of a collaborative study with the Minerals Management Service (MMS). The 2002 cruise, A1-02-SC, is the fourth major data-collection effort in support of the first objective (Normark *et al*., 1999a, b; Gutmacher *et al.,* 2000). A cruise to obtain sediment cores to constrain the timing of deformation interpreted from the geophysical records is planned for the summer of 2003.

Project objectives

The evaluation of geologic hazards is part of the CMG Program project on Southern California, and is carried out under the umbrella of Coastal and Marine Geology Regional Investigations (the CABRILLO project). Task 3 of this project is the “Seismic imaging of active fault zones and fault-slip history in the inner borderland and shelf offshore southern California.” The primary objective of this task is to help mitigate the earthquake hazards for the Southern California region by improving our understanding of how deformation is distributed (spatially and temporally) across the offshore as well as the onshore regions. To meet this objective, field activities are focused to identify the active fault systems in the southern California coastal zone, including the shelf and slope areas, that pose the greatest potential seismic hazards for the most populated urban corridor along the U.S. Pacific margin (**Fig. 1**). The fault-slip history of, and current strain along, the active faults must be determined to evaluate the hazard potential. In addition, the history of landslide generation related to earthquake ground motion is critical to determine the potential for generation of tsunamis that can devastate the coastal area.

The second field activity covered in this report involves the CMG project “Sources, Transportation, and Fate of Natural Oil and Gas Seepages.” Task 1 under this project is “Submarine Oil and Gas Seeps of the Southern Offshore Santa Maria Basin, California: Source Markers, Semiquantitation of Seepage Rates, Transport Pathways, and Relation to Oil Residues on the Coastline.” As part of the study, the MMS funded the USGS to carry out a sidescan-sonar survey of the area around Point Conception, California (**Fig. 1A**). The objective of the survey was to identify the most active natural hydrocarbon seepages to permit later sampling by remotely operated vehicles (ROVs) for the purpose of tagging the oil residues geochemically. This tagging effort would allow hydrocarbons from naturally occurring seepage to be distinguished from man-made oil spills, e.g. from ships, oil-producing platforms, or pipelines.

Study area

The priorities for the field-mapping program are keyed to those areas with the greatest potential for earthquakes and tsunamis that could impact the southern California populace. Previous cruises concentrated on offshore areas from the western Los Angeles metropolitan area south to San Diego (**Fig. 1B**. The scope of these earlier surveys is described in Normark *et al.* (1999a, b) and Gutmacher *et al.* (2000). For the 2002 seismic-reflection cruise, the main work area extended from Pt. Dume, near western Santa Monica Basin, west into the Santa Barbara Channel (see **Fig. 1A**).

The 2002 survey focused on the offshore extension into the Santa Barbara Channel of the fold and thrust belt that makes up the Western Transverse Ranges. In addition, in the western Santa Monica Basin geophysical data were obtained across the boundary between the strike-slip-dominated deformation of the southern inner California Borderland and the thrust deformation that predominates to the north (c.f., Normark and Piper, 1998, and Fisher *et al.*, in press). The structures in the study area reflect a complex evolution of the boundary between the Pacific and North America plates. This evolution included large-scale clockwise rotation of the Transverse Ranges and extensive rifting of the region to the south (Luyendyk *et al.*, 1980, 1985; Kammerling and Luyendyk, 1985; Hornafius, *et al.*, 1986; Legg, 1991; Crouch and Suppe; 1993, Bohannon and Geist, 1998; and Fuis *et al.*, 2001). **Figure 2** shows a generalized depiction of faults in the 2002 study area (adapted from McCulloch, 1989, Vedder et al., 1986, 1987, and written communication (2002) from C. Sorlien of the Institute for Crustal Studies at the University of California, Santa Barbara). Because of the complex tectonic history in the area, there are multiple interpretations and nomenclature for the fault and fold structures in western Santa Monica Basin and the Santa Barbara Channel (e.g., Vedder, 1987; Dolan *et al*., 1997; Pinter *et al*., 1998). The fault pattern depicted in **Figure 2** was that used for planning purposes for the cruise and does not reflect interpretation of the new data documented in this preliminary report.

Previously published overviews of the structure and tectonic activity in the inner Borderland area include Vedder *et al*., 1986; Vedder, 1987; Wallace, 1990; Petersen and Wesnousky, 1994; and ten Brink *et al.*, 2000). Much of the interpretation for the structure of Santa Barbara Channel is based on proprietary industry data. A major goal of the survey described here was to evaluate and resolve the structural interpretations currently available and to provide a direct stratigraphic tie to Ocean Drilling Program (ODP) Site 893 (**Fig. 2**; Shorebased Scientific Party, 1994; Kennett and Venz, 1995) to improve ground-truth via age control for the deformation history in the basin.

A major goal of mapping under the Cabrillo project is to precisely locate and image the active faults in the inner Borderland. Much of the earlier work cited above pre-dated the availability of the Global Positioning System (GPS), which is needed during marine surveys for accurate location of fault structures. In addition, much of the previous work was more focused on the deep structure and tectonic evolution of the Borderland. In order to be able to adequately determine the recency of offsets on faults, higher resolution geophysical data is required, that was not generally available. The detailed geologic and geophysical information obtained under this study is to be made available in GIS data bases that use new data to precisely locate active faults, to map recent submarine landslide deposits (e.g., Bohannon and Gardner, in press; Locat *et al.*, in press; Normark *et al.*, in press), and to identify potential fault and landslide tsunamigenic sources.

Figure 3 shows the tracklines for cruise A1-02-SC. **Figure 3A** shows the location of data obtained for the eight days of survey in support of the earthquake-hazard task. **Figure 3B** shows the position of the vessel during the sidescan-sonar survey during the first four operational days in the area.

OPERATIONS

This section provides an overview of the restrictions on acoustic sources used during the cruise as well as information about the vessel, personnel (**Table 1**), equipment used, and key operational events during the cruise (**Table 2**). See **Table 3** for types of data collected along each survey trackline.

Restrictions on use of the acoustic sound sources

The use of acoustic sources for seismic-reflection profiling is limited by regulations of both State and Federal agencies. The National Marine Fisheries Service (NMFS), which is the agency empowered to enforce the provisions of the Marine Mammal Protection Act (MMPA) requires that operations involving acoustic sources such as those used by the USGS for the 2002 cruise must be conducted under a permit granting Incidental Harassment Authorization (IHA). The IHA request process nominally takes 150 days and the request was submitted to NMFS in mid-January 2002. 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. The California Coastal Commission (CCC) and the California State Lands Commission (SLC) both have additional issues and regulations that pertain to offshore surveys. The procedures for acquiring necessary permits to conduct seismic-reflection surveys off California using small sound sources are reviewed by Childs *et al*. (1999).

The main limitation on the cruise operation stemming from the SLC is that the use of airgun sources is not permitted within State waters, i.e., within three miles of the coast (see **Fig. 2**). The operations log (**Table 2**) shows numerous equipment changes as a result of this restriction.

For previous USGS surveys in 1998, 1999, and 2000, during which multichannel seismic-reflection and high-resolution boomer systems were used offshore southern California, the project contracted with Cascadia Research to provide personnel for recording marine mammal sightings and noting their behavior (Normark *et al*., 1999a, b; Gutmacher *et al*., 2000). Marine mammal observers were used again during the 2002 surveys. One of the main functions of the mammal observers is to notify the USGS personnel currently on watch to shut off the sound sources, other than the echo-sounder, when marine mammals came within a certain radius of a given sound source, as detailed in the IHA permit. The purpose was to provide mitigation measures regarding incidental harassment as specified by the MMPA. 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 USGS personnel. The preclusion zone is a function of the power of the acoustic source and type of mammal sighted. Under the NMFS incidental harassment authorization for the 2002 cruise, the marine mammals covered by the NMFS permit were classified into two groups: 1) non-endangered species including orcas, pilot whales, certain dolphins, seals and sea lions, and 2) endangered species, including some mysticete whales and sperm whales. See **Appendix 1** for details concerning the animals covered by the NMFS permit for incidental harassment of marine mammals.

Three mitigation safety zones were created by NMFS under the mitigation permit for the two groups of animals depending on which sound source was in use. The sources had to be shut down when an affected mammal came within the prescribed safety zone. The safety zones were:

1. 250 m when the airgun was in use with respect to the mammals in group 2 above

2. 100 m when the airgun was in use for mammals in group 1 above; the 100 m safety zone also applied when the non-airgun equipment was in use and animals in group 2 were sighted.

3. 30 m when non-airgun equipment was in use with respect to mammals in group 1.

For safety zones 1 and 2, the radius of the mitigation zones exceeded the ship length + tow distance of the sound source, requiring observers to look forward, to the sides and aft. The operational requirements for the observers were specified in the permit from NMFS and are given in **Appendix 1**.

The California Coastal Commission, under authorization granted by provisions of the federal 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. On 9 April 2002, the USGS received unanimous approval from the CCC for operations as specified in the IHA permit.

The USGS received the IHA permit from NMFS on 13 June 2002. In order to fulfill the requirements of the permit, there had to be a minimum of two mammal observers on watch during any period when one or more of the seismic sound sources 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. In addition to fulfilling the mitigation aspects of the permit, the IHA required that marine-mammal observers monitor and record “mammal presence and activity”. The monitoring included recording the “species, group size, age classes, sex, behavior, travel velocity, distance and orientation from the survey vessel, location, and time”. The results of the monitoring were to be reported to the Southwest Region, NMFS, and the Office of Protected Resources within 160 days from the end of the geophysical survey cruise. **Appendix 1** is the report to NMFS from Cascadia Research that provides the results of the mitigation efforts together with the monitoring, and reporting of marine mammal activity during the geophysical survey.

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 80 shutdowns triggered by whale sightings by the marine mammal observers (see **Table 2**); and (3) the costs of the contract for the marine mammal observers and production of the required report for NMFS.

Research platform

The FY 2002 field program was conducted using a leased vessel, the 156-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 were no laboratory compartments on the *M/V Auriga*, but the large open fantail area was amenable to installation of CMG’s standard container shipping vans, each of which was outfitted for a specific scientific function (**Figs. 4A and 4B**).

For the cruise A1-02-SC, four of the five vans installed on the *M/V Auriga* were the mainstay of the survey activities:

1. an acquisition van for underway-watch activities involving the navigation system and primary geophysical instruments;

2. a mechanical shop used for maintaining the air compressor, airgun, and winches and davits used for launch and recovery of the profiling systems;

3. an electronics shop used for the maintenance of computers and electronics of the sound sources, and housing for the minisparker power supply and multichannel data processing; and

4. an office van that also served as storage for Huntec spares.

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 (**Figs. 4A and 4B**). **Figures 4 C to 4 E** show the layout of the geophysical equipment on the work deck of the vessel. **Figures 4F to 4J** show additional equipment referred to in this report as well as some of the van installations. The four vans and all associated deck equipment, including winches and davits, were loaded during a three-day mobilization period at Redwood City, CA.

Scientific Party

The scientific party for A1-02-SC included six scientific and technical staff from the USGS CABRILLO project as geophysical watchstanders (**Fig. 4K**), and three technical-support personnel from the Western Region CMG Marine Facilities staff (**Table 1**). In addition, there were six contract personnel, one to oversee operation of the Huntec deep-tow boomer system and five to provide a two-person, 24-hour watch for the marine-mammal mitigation effort whenever the seismic-reflection systems were in use. There was one personnel transfer on the 21st of June when one of the geophysical watchstanders went ashore by small boat, which brought replacement parts to repair the Chirp sonar (see Equipment Review below).

Equipment Review

A brief description of the survey equipment used during the cruise is given below. The systems used for the oil and gas seep survey are described first. See **Table 3** for which data types were collected along each trackline. For specific times of data collection and location of the tracklines, navigate from this website:

http://walrus.wr.usgs.gov/infobank/a/a102sc/html/a-1-02-sc.meta.html

Shipboard positioning system

Position data were collected with the USGS-designed YoNav Navigation system (Gann, 1992), with input from a CSI Wireless DGPS Max differential GPS receiver. The GPS antenna was mounted at the forward starboard corner of the acquisition van, which was about 16.3 m from the stern of the vessel (**Fig. 4B**). 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 (**Fig. 4I and 4J**). 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 navigational charts (**e.g., Fig. 4I**), 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. No problems with the shore-based reference stations were encountered during the survey; short periods without differential GPS were caused by the occasional operator-assisted computer crash. As in 2000, YoNav still did not deal gracefully with crossing UTM boundaries. As a result, we just pretended we were always in zone 10, where we began collecting data. Fortunately our tracks didn't take us too far into zone 11. A survey that traversed several UTM zones would need to use a complete set of reference-data layers for each one. Users would need to be facile in completely resetting YoNav's parameters when changing zones, something that appears easy but to truly convince YoNav of the new zone requires knowledge of the program's code.

Position control for sidescan-sonar towfish

To improve the quality of the seafloor mosaic image that was to be produced from the sidescan-sonar survey, an ORE Trackpoint II Plus acoustic-transponder system was used to directly position the sidescan-sonar towfish. The Trackpoint system consisted of a transducer installed in a vertical sounding tube, which was 7 meters forward and 7 meters to port of the GPS antenna mounted on the acquisition van. A transponder was mounted on the tow cable about one meter above the sidescan-sonar towfish. The system obtained range and bearing to the sidescan towfish to determine its map position. The position information was recorded on the header files for the sidescan-sonar data and by the YoNav system. Comparison of the depth data from the transponder and the sidescan towfish were within a meter of each other suggesting that the Trackpoint system was working well. The main operational constraint during the survey was the need to alternate transponders on the tow cable because of battery power limitations.

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 a safe tow depth for the Huntec and sidescan systems. The position of the davit for towing the 12-kHz fish, which was generally towed at the preferred depth of 10 m, is shown in **Figure 4C**. Digitized data were logged on the YoNav system, and the bathymetric profiles displayed on an EPC 1086 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 (**Table 2**). Regular observation of the 12-kHz display monitor suggests that there were few problems with the digital depth data.

Sidescan-sonar system

A Klein 2000 sidescan-sonar system was used to obtain images of the sea floor around Point Conception in support of the oil and gas seep survey for MMS. The Klein 2000 is a dual frequency system that transmits at both 100 and 500 kHz. While both frequencies were automatically recorded during the cruise, we chose to optimize the 100-kHz data in order to be able to cover the MMS area within the time allowed. The sidescan system has a sound pressure level (SPL) of about 210 dB re 1 μPa-m RMS; given the power output and high frequency, this instrument was not included for marine mammal mitigation.

To construct a continuous mosaic of the sea floor, the separation of tracklines was planned for 250 m and the transmit interval was set for a range of 175 m on both sides of the towfish. Over a smooth, horizontal sea floor, this configuration provided 100 m of overlap of acoustic-image data between adjacent tracklines. The received data were digitized at 1024 samples for each channel giving about 17-cm range resolution. The interval between transmit pulses was 0.23 sec.; at a tow speed of about 7.4 km/hr, the along-track resolution was about 50 cm. The sidescan instrument also had sensors for pitch, roll, heading, depth, and water temperature; these parameters were displayed on an Isis monitor and were incorporated into header files for the sidescan data. All data were recorded using proprietary Triton XTF file format. When the Chirp high-resolution system malfunctioned, the 3.5-kHz subbottom profiler CW (continuous wave) that was attached to the sidescan fish was turned on for a short time until we switched to the minisparker (JD 170, see **Table 2**). The sidescan towfish weighed about 170 kg with the 3.5 kHz system installed; the additional 145 kg of the profiler made the towfish more stable under tow, e.g., the vehicle used less cable to stay at the desired tow depth.

Chirp sonar system

A high-resolution subbottom profiling system was used during the sidescan-sonar survey to obtain images of the sub-seafloor structure associated with areas of oil and gas seeps. An Edgetech 512i Full Spectrum Sub Bottom (FSSB) profiling system, informally referred to as a Chirp system, was the preferred choice because it could be used with minimal acoustic interference while the sidescan sonar was operating. **Figure 4 (A and C)** shows that both the sidescan-sonar towfish and the Chirp sonar system were towed from the large A-frame on the *M/V AURIGA*. The FSSB 512i system operates with an output power of 2 kW. The source SPL for the FSSB 512i is 198 dB re 1 microPa-m RMS. Two choices of pulse bandwidths were used during the surveys. During the first 31 hours of the sidescan survey, the Chirp was operated with a bandwidth of 500–6000 Hz and pulse length of 20ms; for the remainder of its operational time (see below) we used a bandwidth of 500 Hz–7200 Hz and a pulse length of 30 ms. The vertical resolution with these operating parameters is about 40 cm, similar to the Huntec system described below. The Chirp system was triggered generally at a 0.5 to 1-sec interval, and was towed 5-10 m below the sea surface.

The data were recorded at a sampling rate of 25 to 50 kHz with the rate determined by the Delph recording system; these digital data were backed up on CD-ROM during the cruise. A paper record was also made using a TDU 1200 recorder. After two days the Chirp system malfunctioned on restart following a mammal shutdown (late JD 168, see **Table 2**). The digital signal processor board apparently did not tolerate even the recommended method of terminating the trigger required when we encountered marine mammals. The Chirp was repaired after replacement parts were brought to the ship four days later (JD 173), and with new shutdown procedures it worked flawlessly for the remainder of the cruise (**Tables 2 and 3**).

Huntec boomer system

A high-resolution Huntec DTS (Deep-Towed Seismic) boomer system (**Figs. 4C and 4D**) towed between 5 m and 120 m below the sea surface (depending upon the water depth) was used to image the upper tens of milliseconds of strata with a resolution of better than 0.5 ms (0.4 m). The Huntec system gives best results when operated in areas of deeper water (>300 m) but was used as a backup for the Chirp system in the shelf-depth water of the oil and gas seep survey. The SPL for the Huntec boomer source is 205 dB re 1 µPa-m RMS. Power output was 240 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 1.0 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 a sample frequency of 16 kHz and a 200 to 300 millisecond record length. The Huntec console filtered the data at 500-7500 Hz, then sent them to be displayed in real time on thermal film using an TDU 1200 recorder, as well as to the Delph where they were recorded as "raw". The data were then backed up on CD-ROM during the cruise. The average survey speed of about 4 kt (7.4 km/hr) resulted in a shot spacing between 1.0 and 2.0 m for the deep-tow boomer profiles. The position of the tow cable for the Huntec vehicle is shown in **Figure 4C and 4D**.

Huntec-sparker source

The Huntec system was used intermittently during the cruise either as the instrument of choice or as a backup for other systems that malfunctioned (**Table 3**). In addition to the boomer sound source, the Huntec towfish has a sparker source that was used during the cruise when other sound sources failed. The 500 J sparker source produces usable energy from 1 kHz to 6 kHz with peak power at about 1 kHz. Unlike the boomer source in the Huntec, however, the sparker source suffers from destructive interference from a strong bubble pulse, resulting in poorer resolution of reflecting surfaces (Mosher and Simpkin, 1999). Because the minisparker was unreparable at sea (see below), the Huntec-sparker was used the last 4 nights of the cruise, firing at 0.5 to 1-sec interval. It was recorded by the Delph system using a sample frequency of 16 kHz, and record length of 300 ms. It was also recorded on paper using a TDU 1200 recorder. The digital data were backed up on CD-ROM during the cruise.

Multichannel and single-channel seismic-reflection systems

The streamer for the multichannel systerm (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-GB DAT tapes. The 2 KJ minisparker data were recorded using a 0.25 msec sample rate and 1.5 sec record length, while the airgun data were recorded with a 0.5 msec sample rate and 3 sec record length. No filter was used; all frequencies were passed. The Geometrics seismograph worked for only 3 days (JD 170-173). Despite repeated attempts at repair and using fewer than 24 channels, no more useable data were collected with the MCS.

The primary sound source for the MCS was to have been a 35/35 in^3 double-chamber GI gun firing every 12 seconds at a pressure of about 3000 psi. However, the Sureshot ™ system failed to operate. This system is needed to fire the gun in "harmonic mode", wherein the second chamber is delayed relative to the initial trigger pulse in order to achieve the cleanest signal by minimizing the bubble pulse. As a result, MCS operations relied on only one chamber of the GI gun.

After the failure of the MCS, the GI gun source was used for single-channel profiling with a sleeve insert to produce a 24 in^3 chamber size. The airgun was then operated at 2000 psi. With the reduced chamber volume and reduced pressure of operation, the airgun could be triggered on a three-second interval for improved spatial resolution. The GI airgun with a 24 in^3 chamber had not been used previously so we did not have a direct measure of the sound pressure level for operation at reduced air pressure. For comparison, a 40 in^3 Bolt airgun, when operated at 2000 psi, produces an SPL of 216 dB re 1 microPa-m RMS (see Richardson *et al.*, 1995, p. 197). This is about 4 dB less than the 35 in^3 GI gun when the latter is operating normally for bubble suppression at 3000 psi. When the GI gun is operated with only a single 24 in^3 chamber at 2000 psi, its SPL is likely to be less than that of the 40 in^3 Bolt gun.

The sound source intended for MCS profiling during night operations was a SIG '2 mille' minisparker. The sparker electrodes are mounted on a small frame in a 'herring-bone' pattern with 50 electrodes on each side (**Fig. 4 F**). The minisparker power was 2 kJ for MCS work; at this power level, the source had an SPL of 204 dB re 1 µPa-m RMS as measured prior to the cruise. The manufacturer suggests energy produced at 2 kJ is in the frequency range of 890 to 1020 Hz with a pulse duration of one millisecond. For the multichannel seismic-reflection survey, the minisparker was discharged every 3 seconds. When used at 160 J during the MMS survey, with a single-channel streamer, the fire rate varied from 250-300 ms, depending on water depth.

The minisparker failed late on JD 173, after the first three days of the time devoted to the earthquake hazard survey. The 150-lb. main power transformer apparently could not sustain 2 KJ at a 3 sec fire rate, despite what the manufacturer's information indicated. It was not possible to repair it at sea.

A 2-channel, 5-m-long SIG streamer with 8 hydrophones at 0.5-m spacing was used for all non-MCS profiles with airgun or sparker sound sources. Data were collected using Triton-Elics International 'Delph Seismic' software. Data were recorded in SEG-Y format on the Delph system hard disc using a sample frequency of 16 kHz for the sparker and 4 kHz for the airgun, 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 (night) and airgun (day) data were also displayed in real time on thermal film using a TDU 850 recorder.

General Operations

The geophysical survey was set for 15 to 27 June, 2002, departing from and returning to the port of Redwood City, California, on 14 and 29 June, respectively. The ship departed early in the morning on 14 June 2002 and was in position to deploy gear after lunch on the 15th (**Table 2**). The initial work was chosen to be the sidescan-sonar survey in support of the oil and gas seep mapping activity (**Fig. 3B**). The work area around Pt. Conception is notorious for rough seas, and the decision to immediately begin surveying for this task was based on the good weather encountered upon arrival in the area. The good weather persisted for only a day during which time the survey in the most exposed area was completed. Then the decision was made to finish the remaining sidescan-sonar survey areas by moving between Pt. Conception which is exposed to strong coastal winds (up to 50 kt), and the near-shore area just east of Point Conception, which is sheltered from northerly winds.

The survey to identify active hydrocarbon seeps involved the collection of side-scan sonar images. In addition, the shallow structure and sediment cover in the area was imaged during the survey using a high-resolution Chirp sonar (see equipment review that follows this section). A 12-kHz echo-sounding system was used throughout the survey not only to provide information on local sea-floor relief as a safety factor for the more deeply towed sidescan-sonar system, but also because the 12-KHz system is very effective for imaging actively seeping gas in the water column. As shown in Table 2, the surveying was interrupted on several occasions for repair or modification of one of the instruments as well as for equipment maintenance, such as removal of kelp and float lines of crab pots. Equipment problems with the Chirp sonar limited the collection of subbottom information to about 60% of the trackline length shown in Figure 3B. Minisparker (160J) data were collected along 3 of the remaining sidescan lines, plus on a grid to provide ties with a number of Chirp lines. In addition, the survey activities were interrupted 21 times when the acoustic sources were shut down because marine mammals had entered one of the safety zones established by NMFS under the IHA permit for the cruise (Table 2 and Appendix 1). The shutdowns for marine mammals totaled 3.1 hours during the four days of surveying. The sidescan-sonar survey was completed by noon on the 19th of June, at which time the vessel transited farther east in Santa Barbara Channel to begin the earthquake hazard survey.

The remainder of the cruise time, which was in support of the task to image active fault zones and determine fault-slip history in the inner borderland, was spent in Santa Barbara Channel and the westernmost corner of Santa Monica Basin (tracklines in **Fig. 3A).** The irregular grid of the survey tracks, e.g., groups of track patterns with different trends and line spacing, are a result of the multiple objectives for this part of the cruise. In collaboration with scientists from UC Santa Barbara, many of the tracklines were planned to fill in gaps or follow specific geologic structures deduced from proprietary industry data sets. Here we also had poor wind conditions and this plus equipment failures contributed to many tracklines not being run.

As planned, the primary survey modes involved use of the airgun acoustic source for multichannel seismic-reflection data in areas outside the State three-mile limit and in the daytime, when the mammal observers could effectively observe within the 250-m radius of safe approach for the endangered species. Within State waters and at night, the minisparker would be used as the sound source for MCS data acquisition. The multichannel seismic-reflection system would be accompanied by a high-resolution reflection system to image the upper tens of meters of sediment under the sea floor. In general, previous work in the Borderland showed that the Huntec data is of highest quality in water depths exceeding 300 m (Gutmacher *et al.*, 2000). The Chirp sonar would be used in place of the Huntec system for the upper slope and shelf parts of the survey. In summary, the choice of sound sources used during the survey was intended to be dependent on time of day, distance from the shore, and water depth. Only the 12 kHz echo sounder could be operated in all conditions.

Unfortunately, there was significant loss of survey time, and considerable revision of plans, as a result of equipment malfunctions. The minisparker source failed after three nights of operation. Just prior to that (JD 173), the control and recording system for the multichannel system malfunctioned and effectively ended multichannel operations despite three days of attempted repairs. Thereafter, various alternative modes for single-channel seismic-reflection profiling were employed including the use of the Huntec-sparker at night and pairing the airgun with the Chirp during daylight hours. In addition to the loss of data as a result of equipment malfunction, the shutdowns for marine mammals added 59 interruptions (for 10 hours, 38 minutes) during the eight days of surveying. **Table 2** lists the sequence of equipment alternatives that were tried during this part of the cruise and shows the number and length of shutdowns resulting from encounters with marine mammals. A review of **Table 3** shows the equipment used during the day versus the night.

OVERVIEW OF SEISMIC-REFLECTION DATA

This section briefly reviews the variety, and illustrates the utility, of the sidescan sonar and seismic-reflection data collected on A1-02-SC. In general, two acoustic imaging systems (not including the 12-kHz echo-sounder, which was operated at all times except during maintenance) were used during all survey work aside from that related to equipment repair and testing, e.g., Chirp used with sidescan sonar or single-channel airgun, and Huntec boomer used with airgun multichannel profiling. For that reason, examples of each type of seismic-reflection data are shown with an inset map showing all tracklines along which that data type was obtained. Most examples are taken from the area of the seismic-hazard survey.

Figure 5 is an excerpt from the sidescan-sonar mosaic of the area west of Point Conception. Locations of anomalous reflections in the water column on sidescan-sonar and 12 kHz records, which might be evidence for active seeps, are also shown. These anomalies could result from gas rising from the seafloor; a strong reflection is observed, particularly on 12-kHz echo-sounding profiles, and an acoustic shadow results from the efficiency of the reflection. A water sample with elevated methane concentration was obtained during a previous cruise (Lorenson *et al.* 2003) from an area of circular features in the southeastern part of the image in **Figure 5**. The floor of these circular targets are typically 10 m to 20 m in diameter and exhibit stronger acoustic backscatter than the surrounding sea floor as would be expected from either coarser grain size of sediment or greater roughness. As such, they might possibly form either by cratering of the sea floor as a result of gas discharge or are patches of tarry residue from a seep. The large size of the features is not typical of biologic origin such as those formed by rays. Further sampling and photography will be necessary to confirm the origin of these features.

The Chirp sonar and the Huntec deep-tow boomer systems were the best high-resolution profiling systems available and both were used for the oil and gas seep survey as well as the seismic-hazard survey. The Chirp sonar profile in **Figure 6** is from the north side of Santa Cruz Island, and shows recent sediment onlapping an unconformity cut in older folded sediment. Acoustic penetration exceeded 50 meters locally. The Huntec boomer record of **Figure 7** shows recent sediment onlapping both flanks of a structural high in the middle of Santa Barbara Basin. The resolution of the Huntec is slightly better than for the Chirp sonar and because it is towed below the surface, the records are less degraded as a result of vertical motion of the vessel. The Huntec-sparker was used after the primary SIG minisparker source failed. As noted in the previous section, the Huntec-sparker does not produce as clean a signal as either the Chirp sonar or Huntec boomer (compare **Figure 8** with **Figures 6 and 7**). In addition, use of the Huntec-sparker was commonly in shallow water and the water-surface reflected pulse from the Huntec fish, which is towed below the surface, gives rise to multiples that obscure the subbottom structure.

Figure 9 shows GI-gun data crossing the mid-basin structural high on a line adjacent to the Huntec-boomer profile shown in **Figure 7**. The GI gun source using the 35 in^3 chamber at 3000 psi provides sufficient power to image the upper 1 km below the sea floor. The record shown in **Figure 9** is based on only one channel of the 24 channel streamer, and the image quality will be improved with processing of all data channels. The deeper structure of this fault-bounded ridge is well shown but it is not clear whether older sediment or rock is exposed in outcrop near the axis of the anticlinal structure. A higher resolution image such as that provided by the Huntec data is needed to confirm that older sediment does outcrop near the crest of the ridge. In order to select optimum sampling sites for determining the age of deformation, data from both the high- and low-resolution profiling systems are needed.

The minisparker source is excellent for providing details of sediment cover and shallow structures along the shelf and slope. **Figure 10** shows the folded and truncated sediment underlying the shelf near the city of Santa Barbara. A relatively young submarine landslide is also easily recognized near the base of the slope on this line. In general, however, the minisparker source is limited to less than 500 m of subbottom penetration. As a result, the minisparker multichannel data is not useful in defining the deeper structures in the Santa Barbara Basin; it was primarily intended to be used inside the California 3-mile limit where all airgun use is prohibited. **Figure 11** shows that the GI gun operated at the lower pressure and with the smaller gun chamber provides resolution equivalent to the SIG minisparker source but with improved subbottom penetration. This profile shows a complex history of deposition with slope-parallel muddy sediment (the interval just above the multiples indicated) that overlies faulted coarser sediment and is turn overlain by prograding deltaic sediment. The deltaic beds are then onlapped by nearly horizontal late-stage basin fill.

Slope failure is common along the north slope of Santa Barbara Basin, e.g. see Edwards *et al.*, 1995. **Figure 12** shows a minisparker dip profile across the slide scar and deposit of one of the larger failures, which shows well in multibeam bathymetric data (MBARI, 2001). The seismic-reflection data shown were collected expressly to help support funding requests for geotechnical studies that were submitted by others to both the National Science Foundation and the Ocean Drilling Project.

SUMMARY

The cruise A1-02-SC covered two separate studies. One was a survey for MMS to help identity active oil and gas seeps; the second study was part of ongoing work at the USGS on geologic hazards offshore of Southern California. The MMS survey included an area of notoriously poor sea state and wind conditions through much of the year. Surveying started in the area west of Pt. Conception simply because good sea conditions were encountered upon arrival in southern California. The weather deteriorated after one day, however, and the remainder of the survey for MMS required working in the survey area well east of Pt. Conception during the day and evening hours to remain somewhat sheltered from strong (to 50 knots) northerly winds. By midnight, winds generally decreased and allowed operations to resume closer to Pt. Conception. High-resolution Chirp sonar data were obtained during much of the side-scan survey, but equipment failure resulted in using the minisparker at 160 J to provide a limited grid of subbottom data in the eastern part of the oil and gas seep target area.

After completion of the survey for MMS, the seismic-hazard survey encountered poor weather conditions as well. However, problems with equipment failure were the major complication for this part of the cruise. As a result, not all planned tracklines were completed and the ongoing equipment failure fostered ingenious substitution of both sound sources and receiving systems. Several of these substitutions resulted in the collection of excellent-quality high-resolution seismic-reflection data, e.g. the 24 in^3 airgun data (**Figure 11**). The amount of data lost to shutdown of the acoustic sources (**Table 2**) to meet conditions of the Incidental Harassment Authorization concerning marine mammals further exacerbated the problem of meeting seismic-hazard project goals. Despite these operational difficulties, much useful data were obtained.

ACKNOWLEDGEMENTS

We thank the captain 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 once again transformed the *Auriga* from crab boat to research vessel -- and back -- in record time. Larry Kooker, Mike Boyle, and Kevin O'Toole, were outstanding in their efforts to keep the survey activity alive as the various equipment failures occurred. We salute the mammal observers, who stood watch too often in the most appalling wind and spray. 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
Mike Fisher (1)	USGS	Chief scientist
Chris Gutmacher (1)	USGS	Assistant chief scientist
Beth Feingold (1)	USGS	Navigation
Lori Hibbeler (1)	USGS	Navigation
Jane Reid (2)	USGS	Data Acquisition
Ray Sliter (1)	USGS	Data Acquisition
Kevin O'Toole (1)	USGS	MT
Mike Boyle (1)	USGS	ET
Larry Kooker (1)	USGS	ET
Mike Belliveau (1)	Geoforce Consultants	Huntec support
Todd Chandler (1)	Cascadia Research	Mammal observation, chief
Randy Lumper (1)	Cascadia Research	Mammal observation
Laura Maycollado (1)	Cascadia Research	Mammal observation
Beth Phillips (1)	Cascadia Research	Mammal observation
Christina Tombach (1)	Cascadia Research	Mammal observation
Ken Robinson (1)	F/V Northwind Inc.	Captain
Kevin Blakley (1)	F/V Northwind Inc.	First Mate
Jamie Lauritzen (1)	F/V Northwind Inc.	Second Mate
Mike Horton (1)	F/V Northwind Inc.,	Chief Engineer
Mike Henderson (1)	F/V Northwind Inc.	Engineer
Modu Ndiaye (1)	F/V Northwind Inc.	Chef, not just cook!

(1) 14-29 June
(2) 14-21 June

Table 2. Operational Log

Local time is 7 hours behind Julian Day (JD) and Greenwich Mean Time (GMT)
June 15, 2002 = JD 166
Dawn about 0530 local = 1230z
Dark about 2030 local = 0330z next JD
Mammal shutdown = shutdown of acoustic sources called by mammal observers

DATE/TIME JD/GMT	**ACTIVITY**
165/1500	Depart USGS Marine Facility, Port of Redwood City
166/1900	Circle twice to calibrate gyro compass for YoNav
166/1928	Start launching equipment to begin survey for MMS oil-seep task
166/2152	Begin MMS survey with sidescan sonar, Chirp profiler, and 12 kHz
166/2241-2246	Mammal shutdown
166/2348-167/0011	Mammal shutdown
167/0439-0555	Retrieve sidescan tow fish; add fins to stabilize attitude; resume survey
167/0646-0650	Mammal shutdown
167/1021-1026	Mammal shutdown
167/1429-1510	Mammal shutdown
167/1515-1520	Mammal shutdown
167/1553-1557	Mammal shutdown
167/1629-1630	Mammal shutdown
167/1806-1823	Retrieve sidescan, 12-kHz, Chirp tow fish to untangle from crab pots
167/1930	All tow fish back in water to resume survey
167/2125-2128	Mammal shutdown
167/2226-2240	Mammal shutdown
167/2255-2320	Mammal shutdown
168/0026-0041	Mammal shutdown
168/0118-0128	Mammal shutdown
168/0134-0137	Mammal shutdown
168/0159-0203	Mammal shutdown
168/0206-0247	Chirp system off for short transit
168/0327-0329	Chirp system off, fiddle with controls
168/0631-0634	Mammal shutdown
168/0656-0657	Mammal shutdown
168/0734-0742	Mammal shutdown
168/0750-0804	Chirp system off to remove crab pots
168/1203-1206	Mammal shutdown
168/1500-1507	Mammal shutdown
168/1518-1526	Sidescan off for maintenance
168/1526-1528	Mammal shutdown
168/2259-2339	Sidescan off for launch of Huntec fish
168/2301	Chirp sonar off for Huntec test (failed on restart, off til JD 173)

DATE/TIME JD/GMT	**ACTIVITY**
168/2312-2341	12 kHz off for launch of Huntec fish
168/2352-169/0052	Huntec on, but not working properly. Retrieved for maintenance
169/0518-0619	Sidescan off to untangle from crab pots
169/0834-0845	Sidescan off to check for crab pots
169/1550-1606	Sidescan off: tow fish retrieved to connect 3.5 kHz profiling system
169/1606-2020	Sidescan on
169/2020-2037	Sidescan off to disconnect 3.5 kHz profiling system
169/2045	Huntec on
170/0047	Sidescan and Huntec off, switch to Minisparker (160J)
170/0204-0538	Minisparker on, pause at 0538 to change fire rate
170/0542-1319	Minisparker on
170/1335-1740	Sidescan on for completion of the work for MMS around Pt. Conception
170/1745	12 kHz off; prepare for transit to earthquake-hazard survey area
170/2223-171/0010	GI gun on, testing it and multichannel system
170/2327-173/1943	12 kHz on
171/0032	GI gun on
171/0145-0153	Mammal shutdown
171/0242-0307	Mammal shutdown
171/0343	GI gun off for night ops
171/0412	Minisparker on
171/0608-0744	Mammal shutdown
171/0819-0836	Mammal shutdown
171/1512	Minisparker off, swap gear
171/1530-1620	Test GI gun with ailing Sureshot
171/1628	Airgun on (Sureshot no longer working, using GI gun in airgun mode)
171/1630-1635	Mammal shutdown
171/1642-1650	Huntec on, off at 1650 when alarm rang
171/1700	Huntec on
171/1938-1944	Mammal shutdown
171/2009	Airgun and Huntec on again after shutdown ended between tracklines
171/2153-2157	Mammal shutdown
171/2159-2209	Mammal shutdown
171/2321-2324	Mammal shutdown
171/2347-172/0018	Mammal shutdown
172/0022-0025	Mammal shutdown
172/0027-0032	Mammal shutdown
172/0112-0130	Mammal shutdown
172/0140-0146	Mammal shutdown
172/0228-0240	Mammal shutdown, swap gear
172/0340-1212	Minisparker on for night ops
172/0524-0526	Mammal shutdown

DATE/TIME JD/GMT	**ACTIVITY**
172/1251	Airgun and Huntec on for day ops
172/1309-1314	Mammal shutdown
172/1330-1335	YoNav accidental shutdown
172/1330-1345	Huntec off; temporary shutdown
172/1601-1607	Mammal shutdown
172/1753-1757	Mammal shutdown
172/1933-2009	Airgun off for transfer of personnel and Chirp parts
172/2054-2112	Mammal shutdown
172/2120-2128	Mammal shutdown
172/2214-2218	Mammal shutdown
172/2328-173/0017	Airgun off for maintenance
173/0137-0139	Mammal shutdown
173/0210	Airgun and Huntec off for night ops
173/0310	Chirp on (repaired with parts brought to ship)
173/0338	Minisparker on
173/1136-1148	Mammal shutdown
173/1157	MCS controller crash (turns out to be end of MCS for cruise)
173/1200	Minisparker off
173/1215	Chirp off
173/1256-1340	Airgun on, testing multichannel system
173/1502	Chirp on
173/1627-1643	Airgun on to test MCS again, at 1643 both airgun and chirp off
173/1644-1653	Mammal shutdown
173/1658-1703	Mammal shutdown
173/1718-1930	Airgun on
173/1943	12 kHz off for transit
173/2202	12 kHz on; minisparker on
173/2210	Chirp on
173/2240-2249	Minisparker off for a few minutes
173/2241-2247	Mammal shutdown
173/2253	Minisparker fails catastrophically, cannot repair during cruise
173/2315-2316	YoNav crash, down for one minute
173/2321-2324	Mammal shutdown
173/2329-2333	Mammal shutdown
173/2338-2346	Mammal shutdown
173/2355-174/0002	Mammal shutdown
174/0051	Airgun on (single-channel mode), sleeve inserted to make it 24 cu. in.
174/0124-0126	Mammal shutdown
174/0330	Airgun off for night ops, continue with Chirp
174/0741-0920	Mammal shutdown
174/0921-0946	Mammal shutdown

DATE/TIME JD/GMT	ACTIVITY
174/0951-1045	Mammal shutdown
174/1302	Airgun on
174/1343-1346	Mammal shutdown
174/1350-1352	Mammal shutdown
174/1505-1509	Mammal shutdown
174/1515-1527	Mammal shutdown
174/1531-1536	Mammal shutdown
174/1558-1602	Mammal shutdown
174/1631-1648	Mammal shutdown
174/1725-1730	Mammal shutdown
174/1736-1741	Mammal shutdown
174/1856-1905	Mammal shutdown
174/1915-1920	Mammal shutdown
175/0051	Airgun off for night operation
175/0052	Chirp off
175/0054	12 kHz off for transit
175/0352	12 kHz on
175/0410-1255	Huntec sparker source on
175/1324	Airgun on; Chirp on
175/1520-1528	Airgun off for 3-mile limit
175/1905-1908	Airgun off for 3-mile limit
175/2117	Airgun off, remove sleeve and prepare to try MC system again
175/2206-2216	Airgun on, testing multichannel system
175/2306	Airgun on, testing multichannel system with 12 channels only
175/2328-2333	Mammal shutdown
176/0053-0058	Airgun off briefly; Strataview crashed
176/0140-0144	Chirp off briefly
176/0324	Airgun off; change gear for night operation
176/0403-1304	Huntec sparker source on for single channel
176/1337-1410	Airgun on with 24 cu.in. sleeve; recording both single and multichannel
176/1448-1452	Airgun on; single channel only; turn off for 3-mile limit
176/1510	Airgun on, single channel only
176/1528	Multichannel recording on also
176/1805	Chirp on
176/1822	Airgun off to replace flooded float
176/1847	Airgun on; record both single channel and multichannel
176/2156-2213	Airgun off for 3-mile limit, then continue both SC and MC recording
176/2346	Multichannel recording off for good – thoroughly broken; continue single channel. MC recording after JD 173 too poor and erratic to process.
177/0202-0246	Airgun off for 3-mile limit; back on at 0246
177/0300-0309	Mammal shutdown

DATE/TIME JD/GMT	ACTIVITY
177/0346	12 kHz, Chirp, and single channel Airgun off for transit to night ops area
177/0459	12 kHz and Huntec sparker source on for night operation
177/0701-0704	Mammal shutdown
177/0710-0713	Mammal shutdown
177/0723-0735	Mammal shutdown
177/0936-0943	Mammal shutdown
177/1335-1340	Mammal shutdown
177/1347	12 kHz and Huntec sparker source off for transit
177/1529	Chirp sonar on
177/1537	Airgun on; single channel recording
177/1624	12 kHz on
177/1901-1904	Mammal shutdown
177/1921-2049	Airgun off; inside 3-mile limit
177/2243-2246	Mammal shutdown
178/0041-0211	Airgun off; inside 3-mile limit
178/0346	Chirp sonar and Airgun off for night operation
178/0401-0408	Huntec sparker source on; change to Chirp system
178/0409-0414	Chirp sonar on
178/0415	Change back to Huntec sparker source
178/0652-0700	Mammal shutdown
178/0734-0801	Mammal shutdown
178/0805-0813	Mammal shutdown
178/1212	Huntec sparker source off
178/1229	Chirp sonar on
178/1238	Airgun on; single channel recording
178/1519-1521	Mammal shutdown
178/2335	Chirp sonar off; Airgun source off, end single channel profiling
178/2336	12 kHz off; prepare to transit to Redwood City
179/0020-180/1400	Transit to Redwood City

Table 3. A1-02-SC Data type along tracklines in time order

(x) indicates that type of data exists for a short part of line only OR is very poor as in the case of unprocessable MCAG data starting JD 175-end of cruise. Sound source codes are as follows; see text for details:

CHIRP= chirp sonar subbottom profiler; HUNT= Huntec boomer; MCMS= multichannel minisparker; MCAG= multichannel airgun; SCMS= single-channel minisparker; SCAG= single-channel airgun; HTSP= Huntec's sparker; BA12= 12-kHz bathymetry; SCAN= Klein 2000 sidescan sonar.

Line #	Start-End JD/Time	CHIRP	HUNT	MCMS	MCAG	SCMS	SCAG	HTSP	BA12	SCAN
02ss01	166/2152-2308	x							x	x
02ss02	166/2328-167/0034	x							x	x
02ss03	167/0041-0157	x							x	x
02ss04	167/0207-0318	x							x	x
02ss05	167/0325-0439	x							x	x
02ss05a	167/0558-0641	x							x	x
02ss06	167/0650-0759	x							x	x
02ss07	167/0807-0924	x							x	x
02ss08	167/0934-1048	x							x	x
02ss09	167/1104-1220	x							x	x
02ss10	167/1231-1349	x							x	x
02ss11	167/1356-1514	x							x	x
02ss12	167/1522-1641	x							x	x
02ss13	167/1649-1806	x							x	x
02ss14	167/2014-2131	x							x	x
02ss15	167/2140-2300	x							x	x
02ss16	167/2316-168/0028	x							x	x
02ss17	168/0047-0206	x							x	x
02ss43	168/0256-0358	x							x	x
02ss44	168/0409-0451	x							x	x
02ss41	168/0504-0547	x							x	x
02ss42	168/0555-0641	x							x	x
02ss40	168/0649-0732	x							x	x
02ss39	168/0805-0847	x							x	x
02ss37	168/0859-0947	x							x	x
02ss38	168/0957-1046	x							x	x
02ss38x	168/1047-1054	x							x	x
02ss38x2	168/1055-1103	x							x	x
02ss28w	168/1118-1216	x							x	x
02ss27w	168/1228-1347	x							x	x
02ss26w	168/1358-1516	x							x	x
02ss25w	168/1556-1707	x							x	x
02ss23w	168/1718-1825	x							x	x
02ss21w	168/1832-1933	x							x	x
02ss19w	168/1943-2035	x							x	x
02ss20w	168/2041-2138	x							x	x
02ss22w	168/2154-2256	x							x	x
02ss25wa	168/2343-169/0052		(x)						x	x
0224test	169/0108-0217								x	x
02ss24w	169/0230-0347								x	x
02ss20aw	169/0406-0508								x	x

Line #	Start-End JD/Time	CHIRP	HUNT	MCMS	MCAG	SCMS	SCAG	HTSP	BA12	SCAN
02ss29	169/0511-0518								x	x
02ss27e	169/0634-0833								x	x
02ss26e	169/0851-1028								x	x
02ss25e	169/1036-1207								x	x
02ss24e	169/1214-1350								x	x
02ss22e	169/1405-1548								x	x
02ss20e	169/1618-1728								x	x
02ss18e	169/1738-1828								x	x
02ss18a	169/1832-1902								x	x
02ss19e	169/1919-2002								x	x
02ss28e	169/2104-2356		x						x	x
02ms45	170/0220-0248					x			x	
02ms46	170/0252-0402					x			x	
02ms47	170/0407-0419					x			x	
02ms48	170/0426-0441					x			x	
02ms49	170/0448-0502					x			x	
02ms50	170/0515-0530					x			x	
02ms50a	170/0542-0614					x			x	
02ms51	170/0616-0634					x			x	
02ms52	170/0640-0701					x			x	
02ms53	170/0719-0814					x			x	
02ms54	170/0816-0847					x			x	
02ms55	170/0851-0906					x			x	
02ms56	170/0908-0954					x			x	
02ms57	170/0958-1014					x			x	
02ms58	170/1015-1201					x			x	
02ms61	170/1204-1210					x			x	
02ms60	170/1215-1233					x			x	
02ms59	170/1240-1251					x			x	
02ms59dl	170/1253-1258					x			x	
02ms62	170/1258-1319					x			x	
02ss23e	170/1347-1541								x	x
02ss21e	170/1549-1740								x	x
821	171/0031-0343				x				x	
1860T	171/0421-0521			x					x	
1860	171/0532-0733			x					x	
1867	171/0754-0906			x					x	
1866	171/0918-1013			x					x	
1865	171/1022-1114			x					x	
1864	171/1117-1213			x					x	
1868	171/1217-1326			x					x	
1860B	171/1352-1500			x					x	
820	171/1628-1805		x		x				x	
1808	171/1819-1941		x		x				x	
821A	171/1957-2051		x		x				x	
1803	171/2138-2240		x		x				x	
815	171/2307-2311		x		x				x	
815A	171/2311-172/0228		x		x				x	
1868A	172/0349-0550			x					x	
1869	172/0654-0846			x					x	
1870	172/0916-1100			x					x	
179	172/1116-1208			x					x	
816	172/1314-1448		x		x				x	

Line #	Start-End JD/Time	CHIRP	HUNT	MCMS	MCAG	SCMS	SCAG	HTSP	BA12	SCAN
816T	172/1514-1612		x		x				x	
817	172/1619-1817		x		x				x	
818	172/1824-2102		x		x				x	
819	172/2202-2324		x		x				x	
1864A	173/0032-0210		x		x				x	
1862	173/0338-0457	x		x					x	
1863	173/0554-0626	x		x					x	
1863A	173/0626-0834	x		x					x	
1863T	173/0840-0859	x							x	
1864B	173/0906-1056	x		x					x	
1876	173/1057-1119	x		x					x	
1876T	173/1122-1133	x		x					x	
1877	173/1135-1214	x		x					x	
815B1	173/1507-1555	x							x	
1910	173/1620-1645	x							x	
815B	173/1718-1925						x		x	
1800	173/2212-2337	x				x			x	
1802	174/0002-0140	x					x		x	
1801	174/0155-0324	x					x		x	
1801T	174/0348-0431	x							x	
1804	174/0435-0621	x							x	
1810	174/0652-0740	x							x	
1813	174/0946-1018	x							x	
1815	174/1045-1124	x							x	
1817	174/1156-1239	x							x	
1821	174/1314-1439	x					x		x	
1830	174/1455-1620	x					x		x	
1831	174/1627-1755	x					x		x	
1832	174/1801-1856	x					x		x	
1825	174/1940-2120	x					x		x	
815C	174/2141-2254	x					x		x	
1804A	174/2317-175/0049	x					x		x	
1880	175/0430-0547							x	x	
1850	175/0619-0816							x	x	
1851	175/0834-1033							x	x	
1852	175/1045-1241							x	x	
1855	175/1327-1520	x					x		x	
1840	175/1531-1702	x					x		x	
811	175/1711-1856	x					x		x	
1841	175/1909-2055	x					x		x	
810	175/2106-2216	x					(x)		x	
809	175/2229-176/0032	x			(x)				x	
809T	176/0041-0105	x			(x)				x	
801	176/0109-0324	x			(x)				x	
1884	176/0445-0615							x	x	
1854	176/0637-0845							x	x	
1853	176/0859-1057							x	x	
1858	176/1125-1301							x	x	
802	176/1338-1410				(x)				x	
802A	176/1511-1721				(x)		x		x	
803	176/1912-2100	x			(x)		x		x	
803T	176/2103-2211	x			(x)		x		x	
804	176/2215-2337	x			(x)		x		x	

Line #	Start-End JD/Time	CHIRP	HUNT	MCMS	MCAG	SCMS	SCAG	HTSP	BA12	SCAN
804T	176/2345-177/0026	x					x		x	
805	177/0032-0201	x					x		x	
805T	177/0205-0244	x							x	
806	177/0249-0346	x					x		x	
806A	177/0506-0534							x	x	
806AT	177/0546-0624							x	x	
805A	177/0626-0708							x	x	
805AT	177/0713-0806							x	x	
804A	177/0811-0850							x	x	
1887	177/0851-1040							x	x	
1856	177/1046-1223							x	x	
1883	177/1242-1343							x	x	
813	177/1531-1924	x					x		x	
813T	177/1933-2043	x							x	
823	177/2047-178/0059	x					x		x	
823T	178/0106-0203	x							x	
822	178/0211-0346	x					x		x	
1911	178/0512-0719							x	x	
1912	178/0721-0929							x	x	
1913	178/0931-1025							x	x	
1863B	178/1048-1106							x	x	
1863BT	178/1112-1208							x	x	
816A	178/1246-1603	x					x		x	
816AT	178/1607-1659	x					x		x	
817A	178/1702-2003	x					x		x	
800	178/2015-2334	x					x		x	

Figure Captions

Figure 1. A) Map of the southern California Borderland showing the area of the CABRILLO task involving seismic-reflection imaging of active fault zones and fault-slip history in the inner borderland and shelf offshore southern California. The area shaded in darker blue shows the survey limits permitted for the 2002 cruise.

B) Trackline map showing high-resolution seismic-reflection data previously collected under this task in 1998 through 2000 (compiled from Normark et al, 1999a, b and Gutmacher, 2000). Cores taken in 1998 and 1999 to date fault movement are shown as small dots.

Figure 2. Map showing faults in the study area (thin red faults are adapted from McCulloch, 1989, Vedder et al., 1986, 1987; thick black faults are adapted from written communication (2002) from C. Sorlien of the Institute for Crustal Studies at the University of California, Santa Barbara). The black faults in particular were identified as prime survey objectives based on recent work by our colleagues at UC Santa Barbara using unpublished 3D seismic-reflection data. Only a few fault names are shown here due to lack of standardized nomenclature.

Figure 3. A) Map showing the tracklines along which data were collected during cruise A1-02-SC for the imaging of active faults in Santa Barbara Channel and western Santa Monica Basin.

B) Map showing the tracklines along which sidescan-sonar data were obtained for the collaborative study with MMS. Water-column methane anomalies from (Lorenson *et al*., 2003) are based on an earlier cruise in support of the MMS collaboration and were used in part to determine survey area. Open white rectangle shows area of sidescan-sonar image in **Figure 5**.

Figure 4. Photographs of the survey vessel M/V AURIGA and the placement of equipment and laboratory vans for the geophysical surveys.

A) Vessel departing Port of Redwood City showing the utilization of after-deck space;

B) View aft from bridge level showing the 5 vans and air compressor (AC). AV: Acquisition Van, which was the control center for scientific operations; ET was the Electronic Technician's work area and also housed the minisparker power supply and computer for processing multichannel data; MT: Mechanical Technician's workshop for repair of all deck-mounted winches, davits, air compressor, etc.; OFFICE van also served as storage for Huntec tools and spares; DORM was a two-person stateroom mounted on the 01 deck.

C) Overview of equipment on rear deck (see **4D** through **4G** for details). Note blue davit from which the 12-kHz fish was towed;

D) Tow vehicles for acoustic systems (see text for details; SS is the sidescan fish);

E) Winches and reels for acoustic systems. Geopulse is a towed catamaran brought as a backup boomer acoustic source; MCS is the reel for the multichannel system's 24-channel streamer;

F) Sparker electrodes for minisparker system;

G) Single-channel streamer;

H) part of interior of Acquisition Van showing a few of the monitors for seismic-reflection profiling systems;

I) YONAV installation in Acquisition Van (see text for details);

J) YONAV monitor on bridge deck for vessel navigation control;

K) Scientific watchstanders prior to sailing (note smiles).

Figure 5. Sidescan-sonar mosaic from the area for the oil and gas seep survey (location in **Fig. 03B**). Water-column anomalies in southeast quadrant of this image are in an area of numerous semi-circular pock marks on the sea floor that might be associated with seep activity.

Figure 6. High-resolution Chirp sonar profile across the northern slope of Santa Cruz Island. Inset shows location of profile and all survey lines along which Chirp sonar data were collected.

Figure 7. High-resolution Huntec deep-tow boomer profile showing a structural high along the center of Santa Barbara Basin. Inset shows location of profile and all survey lines along which Huntec boomer data were collected.

Figure 8. Single-channel seismic-reflection profile that used the Huntec sparker sound source. Inset shows location of profile and all survey lines along which the Huntec sparker source was used to collect single-channel reflection data.

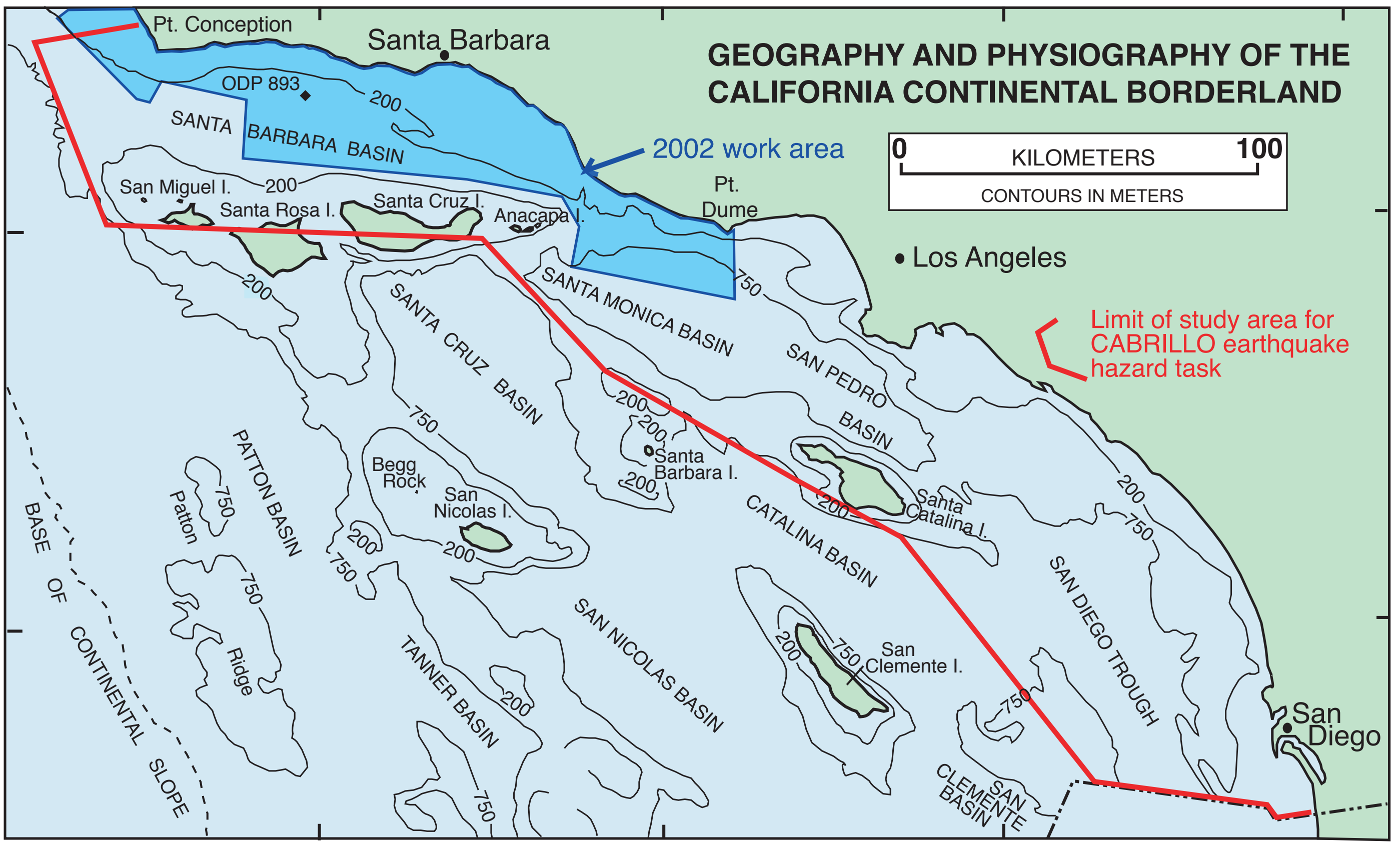
Figure 9. Example of multichannel seismic-reflection data (profile taken from one of the 24 channels recorded) obtained with the 35 in^3 GI gun source operated in an 'airgun' mode with only one chamber used (see text). Inset shows location of profile and all survey lines along which the 35 in^3 GI gun sound source was used to collect multichannel reflection data.

Figure 10. Example of multichannel seismic-reflection data (profile taking from one of the 24 channels recorded) obtained with the 2 kJ minisparker source. Inset shows location of profile and all survey lines along which the minisparker sound source was used to collect multichannel reflection data.

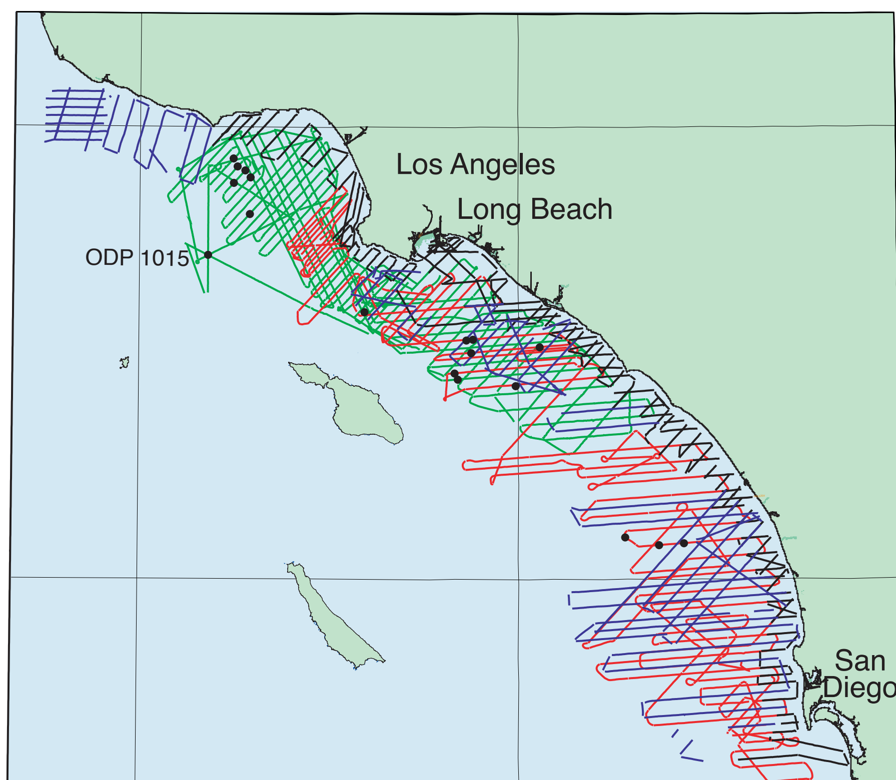
Figure 11. High-resolution single-channel seismic-reflection profile from the slope northeast of Santa Cruz Island using a single 24 in^3 chamber on the GI gun to provide a faster firing rate. Compare the resolution of this profile with the Chirp sonar data shown in **Figure 6** and the 35 in^3 GI gun record of **Figure 9**. Inset shows location of profile and all survey lines along which single-channel airgun data were collected.

Figure 12. Minisparker seismic-reflection profile across the Goleta submarine slide, probably the largest recent mass-transport deposit in Santa Barbara Basin. Location of profile shown in inset.

A



B



LEGEND

High-resolution boomer seismic-reflection data

- 1998 Huntec
- 1999 Huntec
- 2000 Huntec
- 2000 Geopulse

The Huntec boomer source is towed 30 m to 50 m below the surface; the Geopulse source is in a surface-towed sled.

Multichannel seismic-reflection data using an air gun source were collected during the1998 and 1999 cruises. During 1998, data acquisition was limited to about 60% of the tracklines shown. The seismic-reflection data effectively image the upper 1 to 2 sec.

FIGURE 1

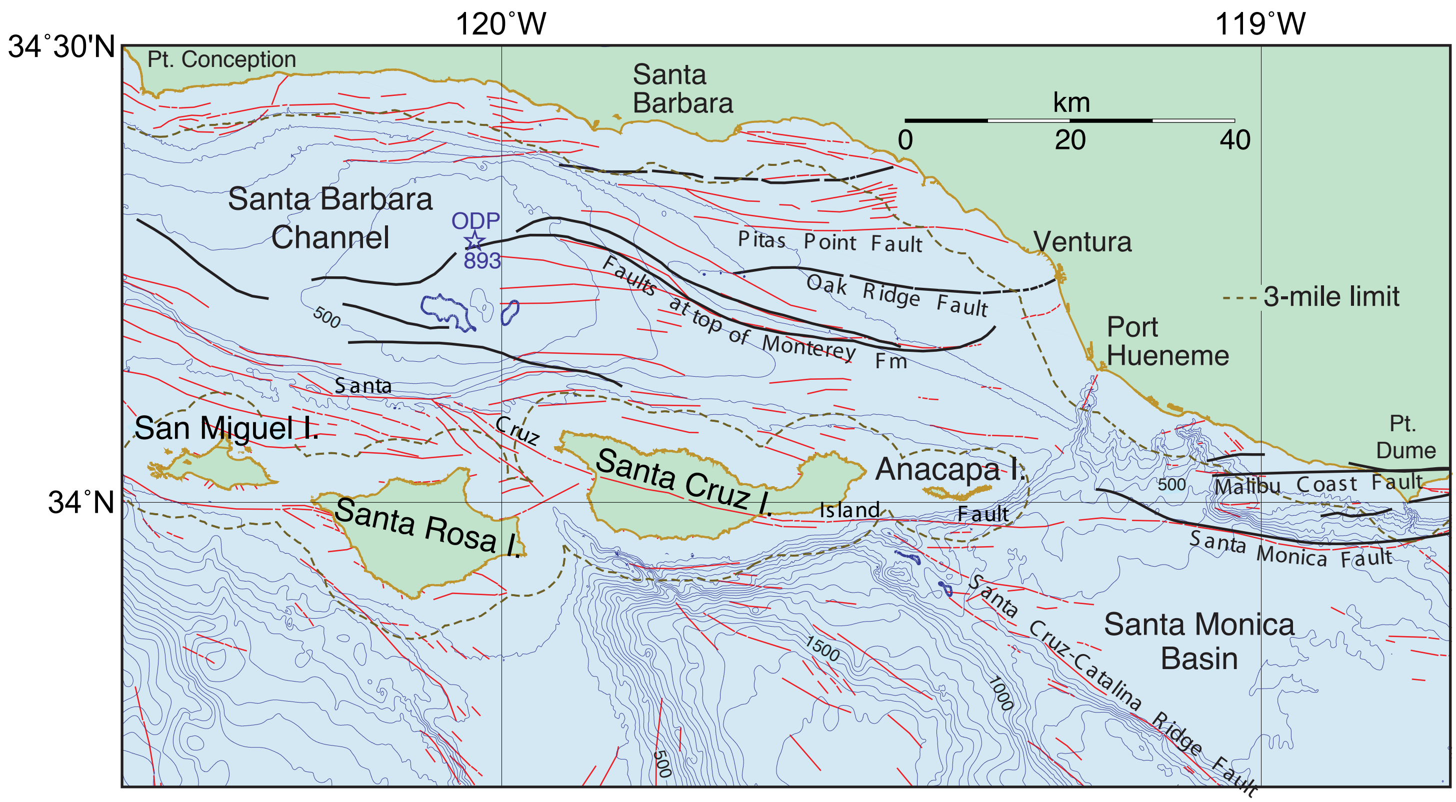

120˚W
119˚W
34˚30'N
34˚N
Pt. Conception
Santa
Barbara
km
0
20
40
Santa Barbara
Channel
ODP
893
Pitas Point Fault
Ventura
Oak Ridge Fault
Faults at top of Monterey Fm
3-mile limit
Port
Hueneme
500
Santa
Cruz
San Miguel I.
Santa Cruz I.
Anacapa I.
Island
Fault
Pt.
Dume
Malibu Coast Fault
Santa Rosa I.
Santa Monica Fault
Santa Cruz-Catalina Ridge Fault
Santa Monica
Basin
1500
1000
500

FIGURE 2

A

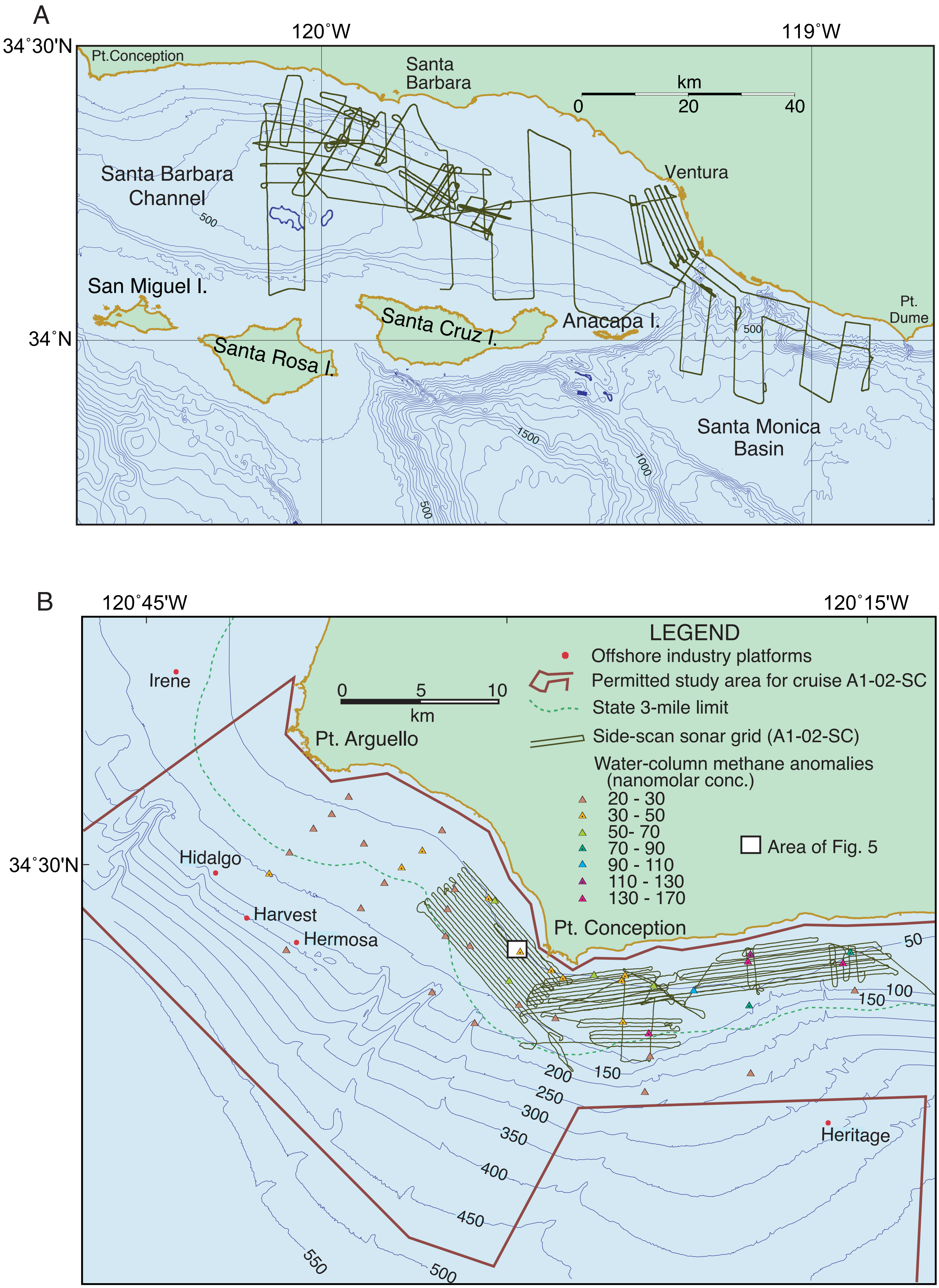
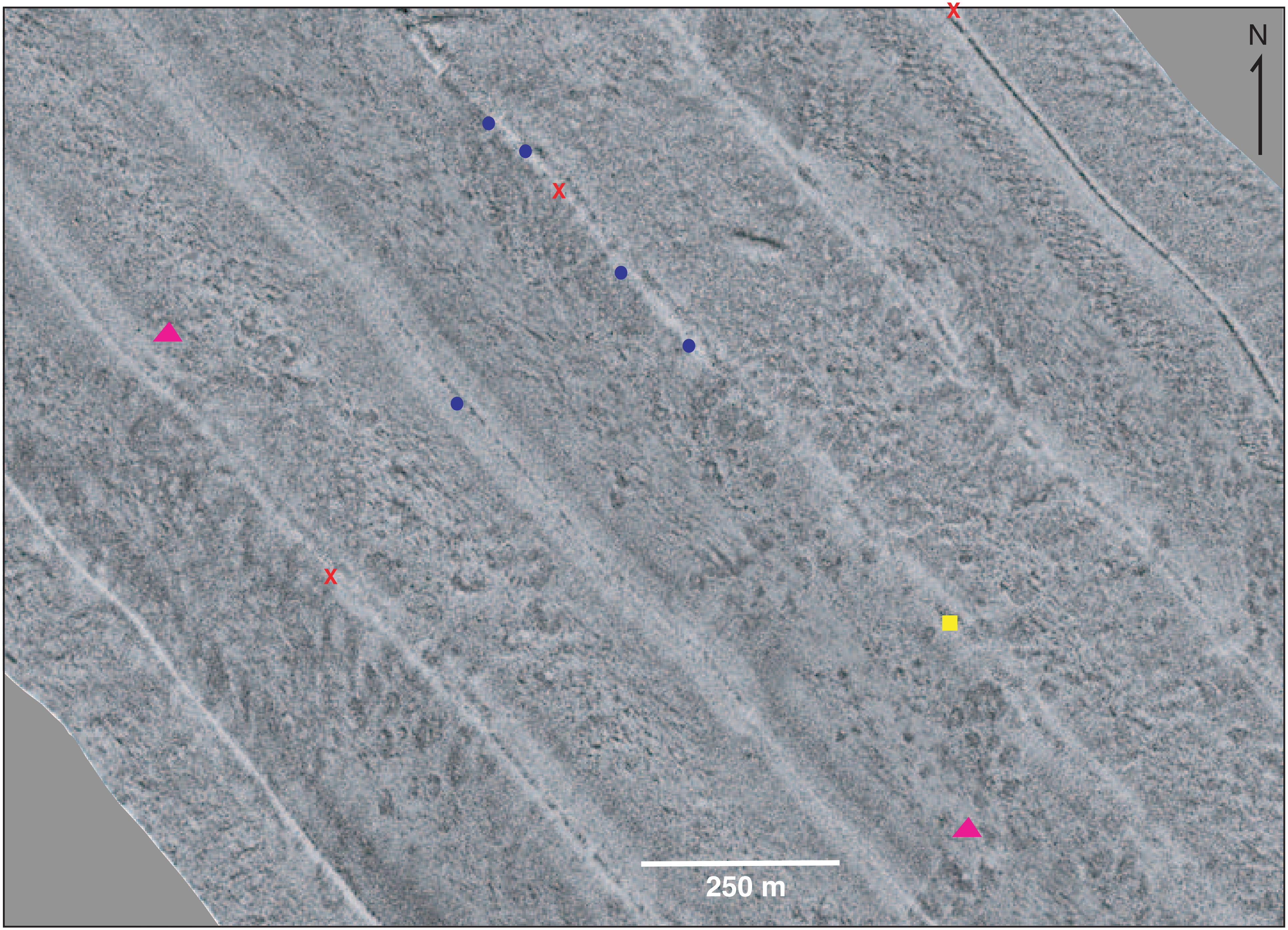

120˚W
119˚W
34˚30'N
34˚N
Pt.Conception
Santa Barbara
km
0
20
40
Santa Barbara Channel
500
Ventura
San Miguel I.
Santa Cruz I.
Anacapa I.
Santa Rosa I.
Pt. Dume
Santa Monica Basin
1500
1000
B
120˚45'W
120˚15'W
34˚30'N
LEGEND
Offshore industry platforms
Permitted study area for cruise A1-02-SC
State 3-mile limit
Side-scan sonar grid (A1-02-SC)
Water-column methane anomalies (nanomolar conc.)
20 - 30
30 - 50
50- 70
70 - 90
90 - 110
110 - 130
130 - 170
Area of Fig. 5
Irene
Pt. Arguello
0
5
10
km
Hidalgo
Harvest
Hermosa
Pt. Conception
Heritage
50
100
150
200
250
300
350
400
450
500
550

FIGURE 3


AURIGA
A
AV
ET
MT
OFFICE
AC
DORM
B
BOAZ
C
CHIRP
HUNTEC
SS
12 KHZ
D
MCS
CHIRP
HUNTEC
GEOPULSE
SS
E
F
G

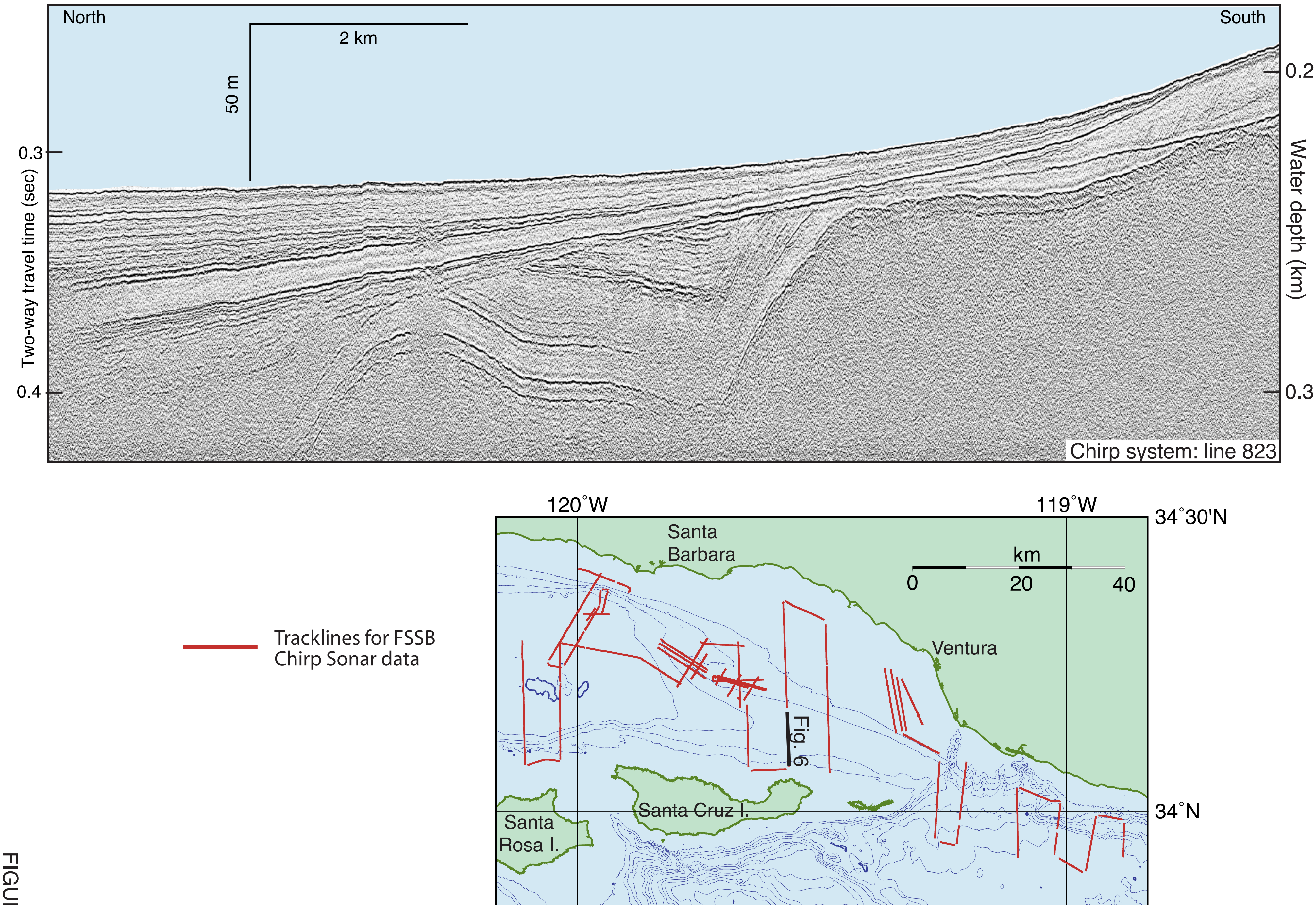
FIGURE 4A-G

FIGURE 4H-K



X Acoustic target (sidescan sonar, this study)
● Acoustic target (12 kHz, this study)
■ Water column methane anomaly (Lorenson et al, 2003)
▲ Acoustic target (12 kHz, Lorenson et al, 2003)

FIGURE 5



North
South
2 km
50 m
0.3
0.4
Two-way travel time (sec)
0.2
0.3
Water depth (km)
Chirp system: line 823
120˚W
119˚W
34˚30'N
34˚N
Santa Barbara
Ventura
km
0
20
40
Fig. 6
Santa Cruz I.
Santa Rosa I.
Tracklines for FSSB Chirp Sonar data

FIGURE 6

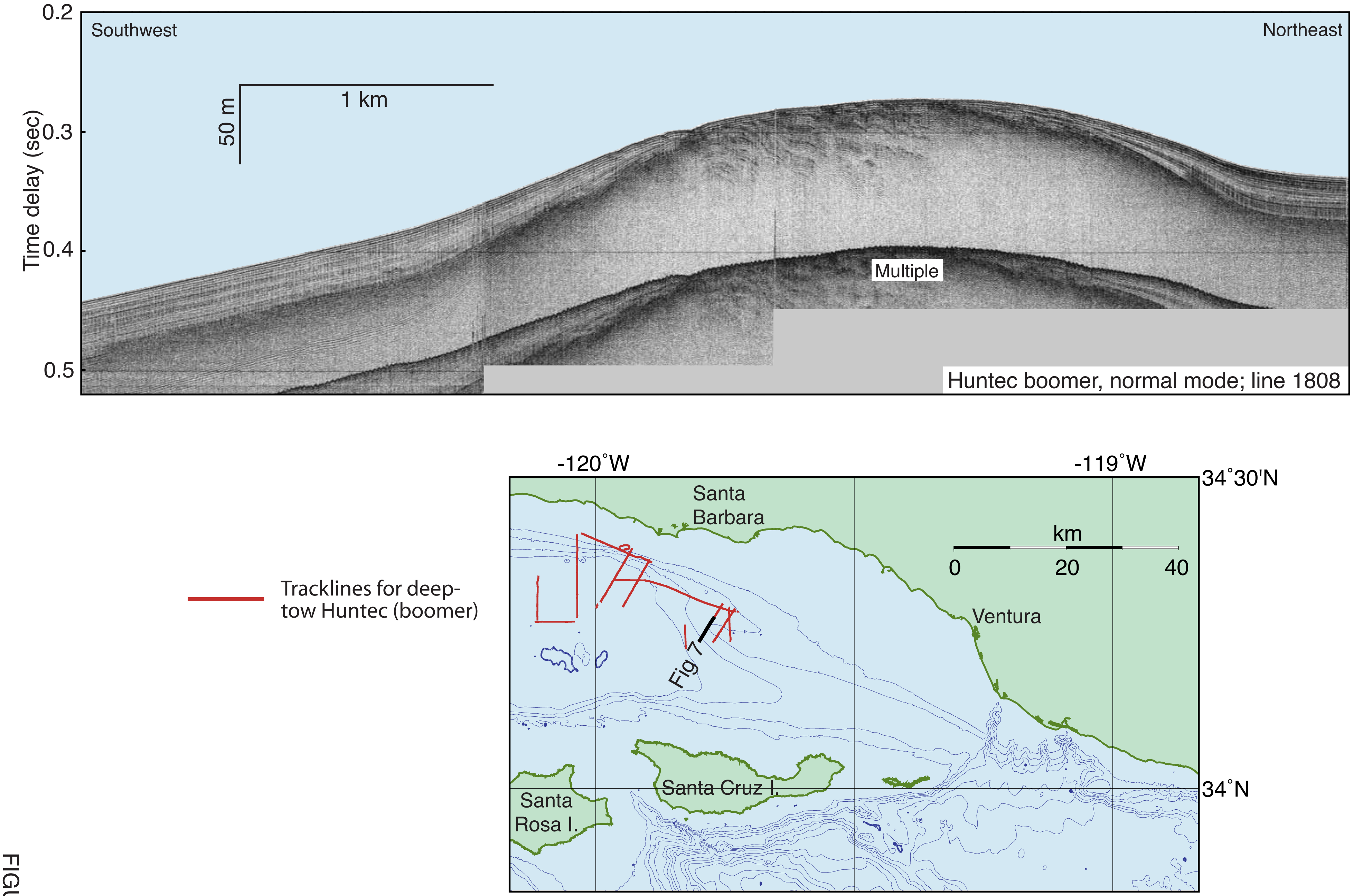
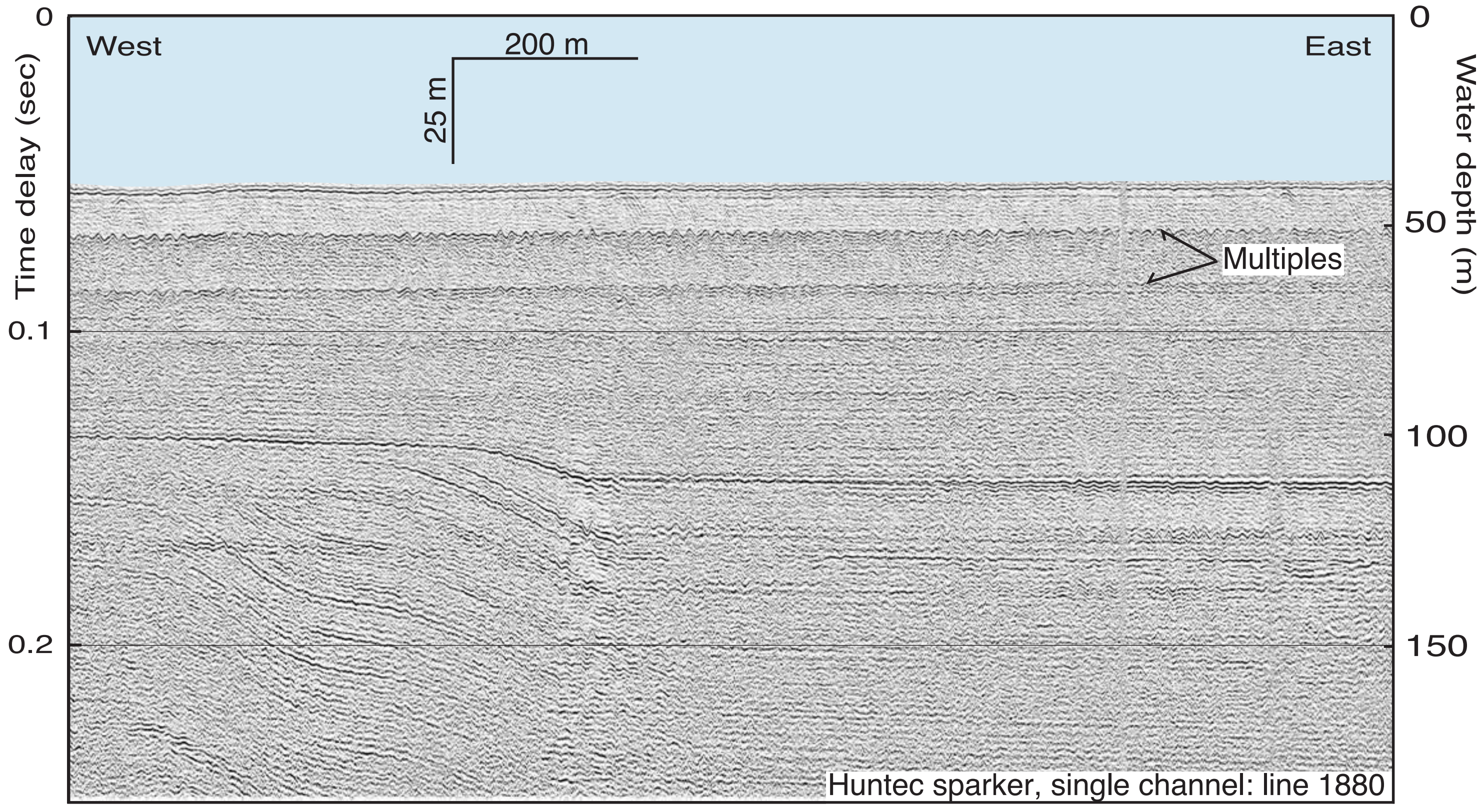

0.2
0.3
0.4
0.5
Time delay (sec)
Southwest
Northeast
1 km
50 m
Multiple
Huntec boomer, normal mode; line 1808
-120˚W
-119˚W
34˚30'N
34˚N
Santa Barbara
Ventura
km
0
20
40
Fig 7
Santa Cruz I.
Santa Rosa I.
Tracklines for deep-tow Huntec (boomer)

FIGURE 7


0
West
200 m
25 m
East
0
Time delay (sec)
Water depth (m)
50
Multiples
0.1
100
0.2
150
Huntec sparker, single channel: line 1880

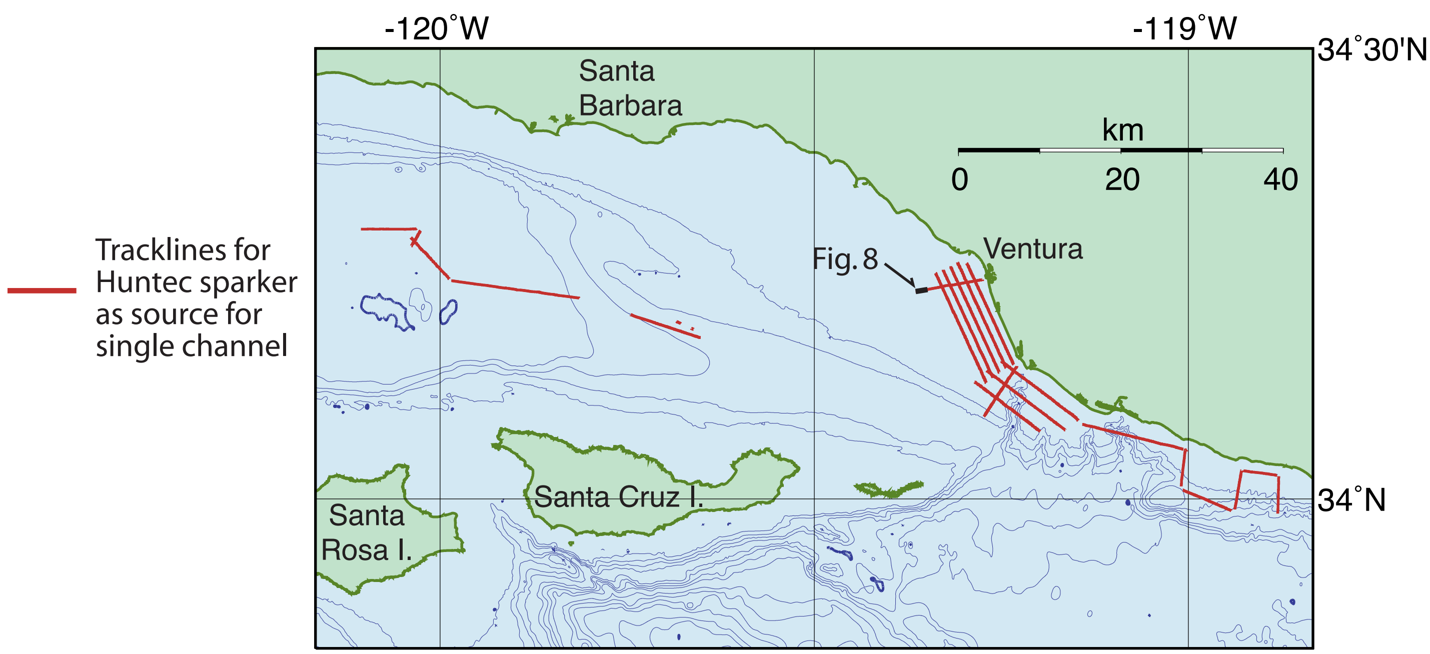

-120˚W
-119˚W
34˚30'N
Santa
Barbara
km
0
20
40
Tracklines for
Huntec sparker
as source for
single channel
Fig. 8
Ventura
Santa Cruz I.
Santa
Rosa I.
34˚N

FIGURE 8

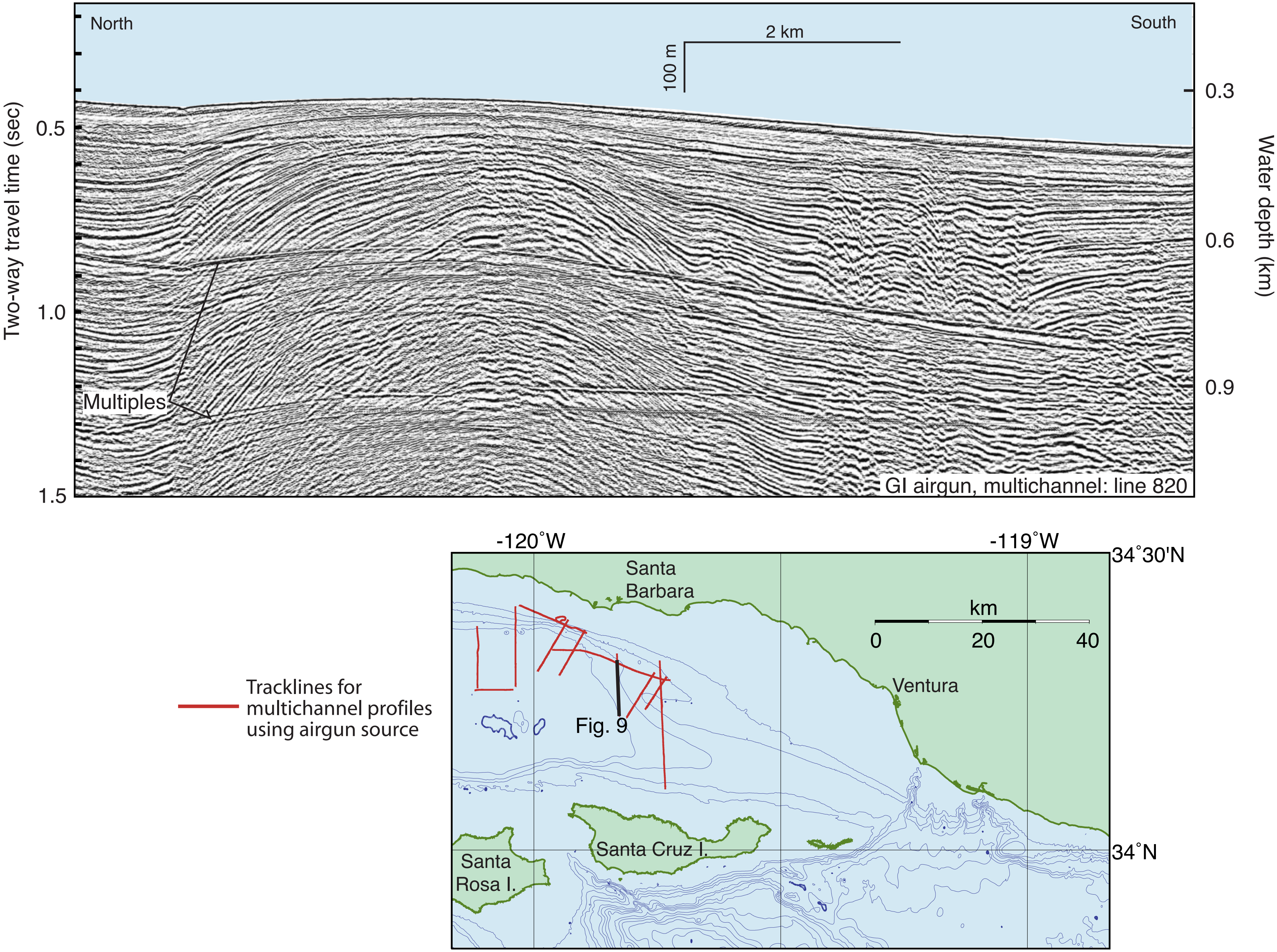

North
South
2 km
100 m
Two-way travel time (sec)
0.5
1.0
1.5
Water depth (km)
0.3
0.6
0.9
Multiples
GI airgun, multichannel: line 820
-120˚W
-119˚W
34˚30'N
34˚N
Santa Barbara
km
0
20
40
Ventura
Fig. 9
Santa Cruz I.
Santa Rosa I.
Tracklines for multichannel profiles using airgun source

FIGURE 9

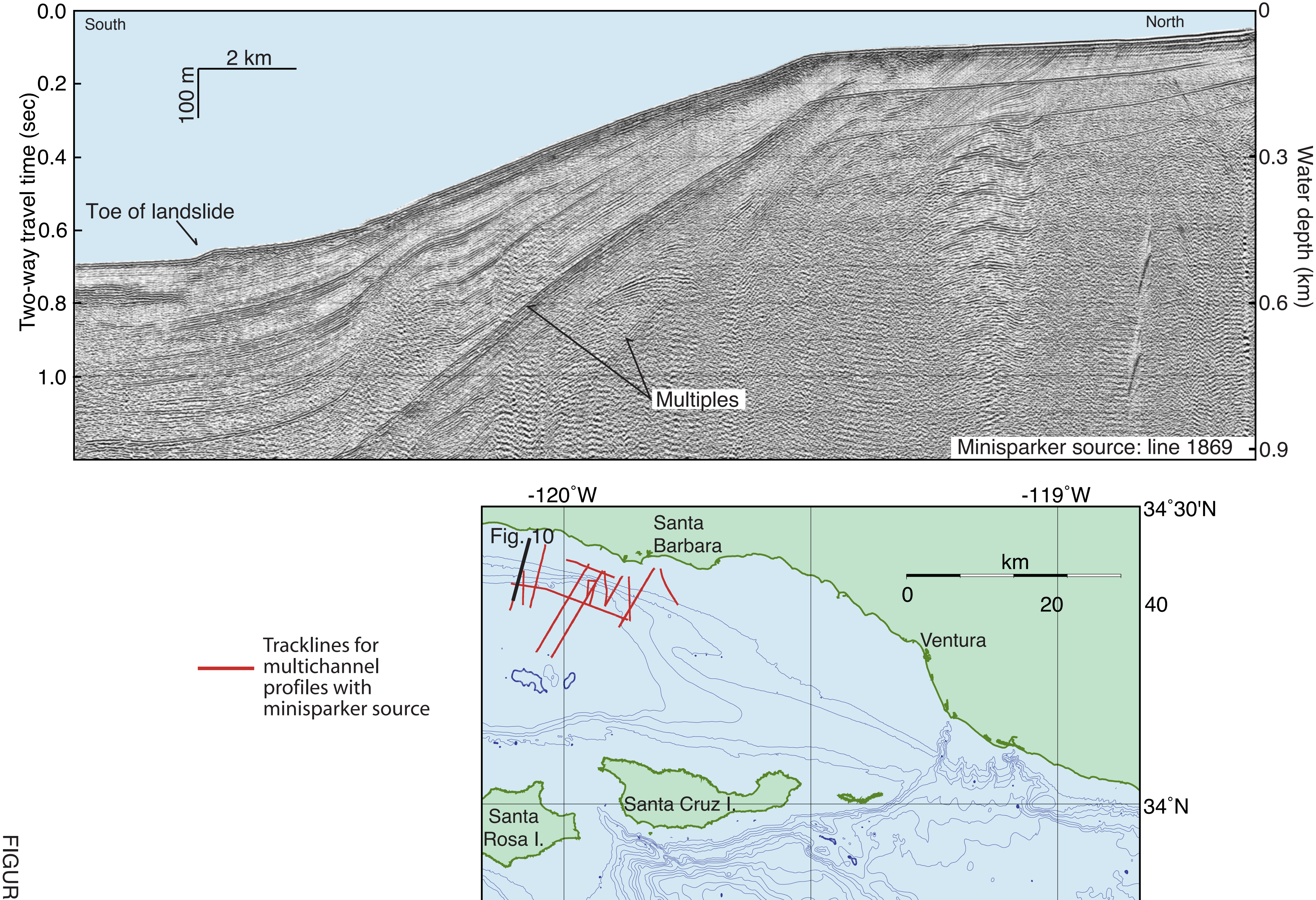
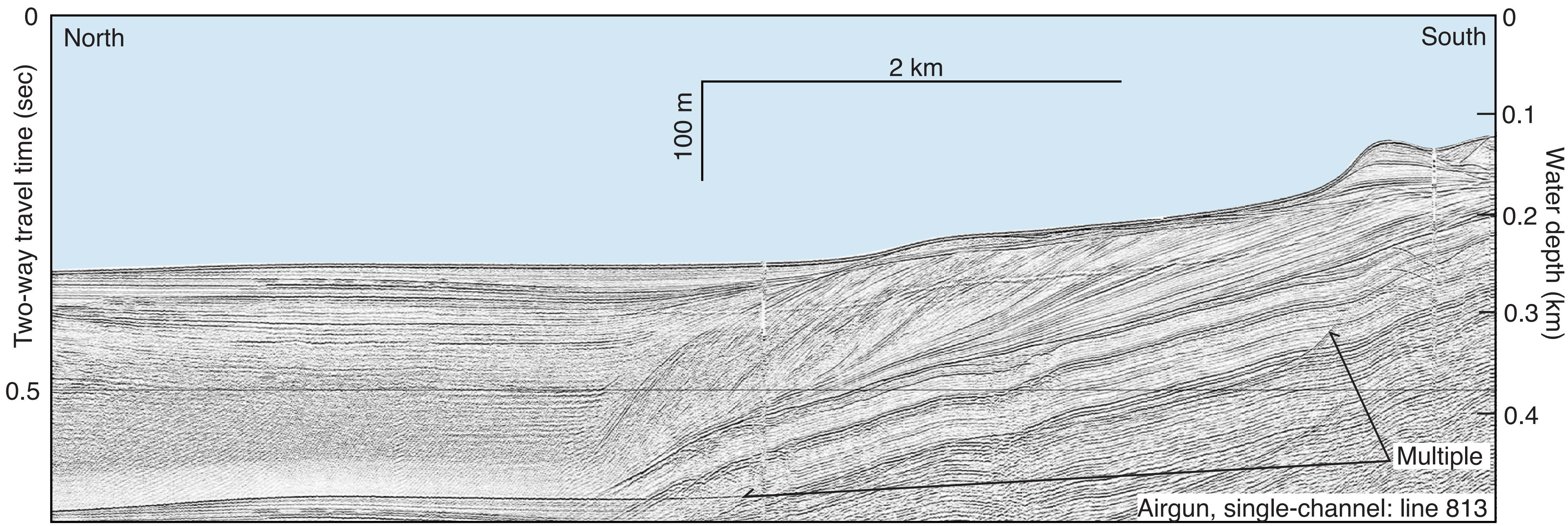
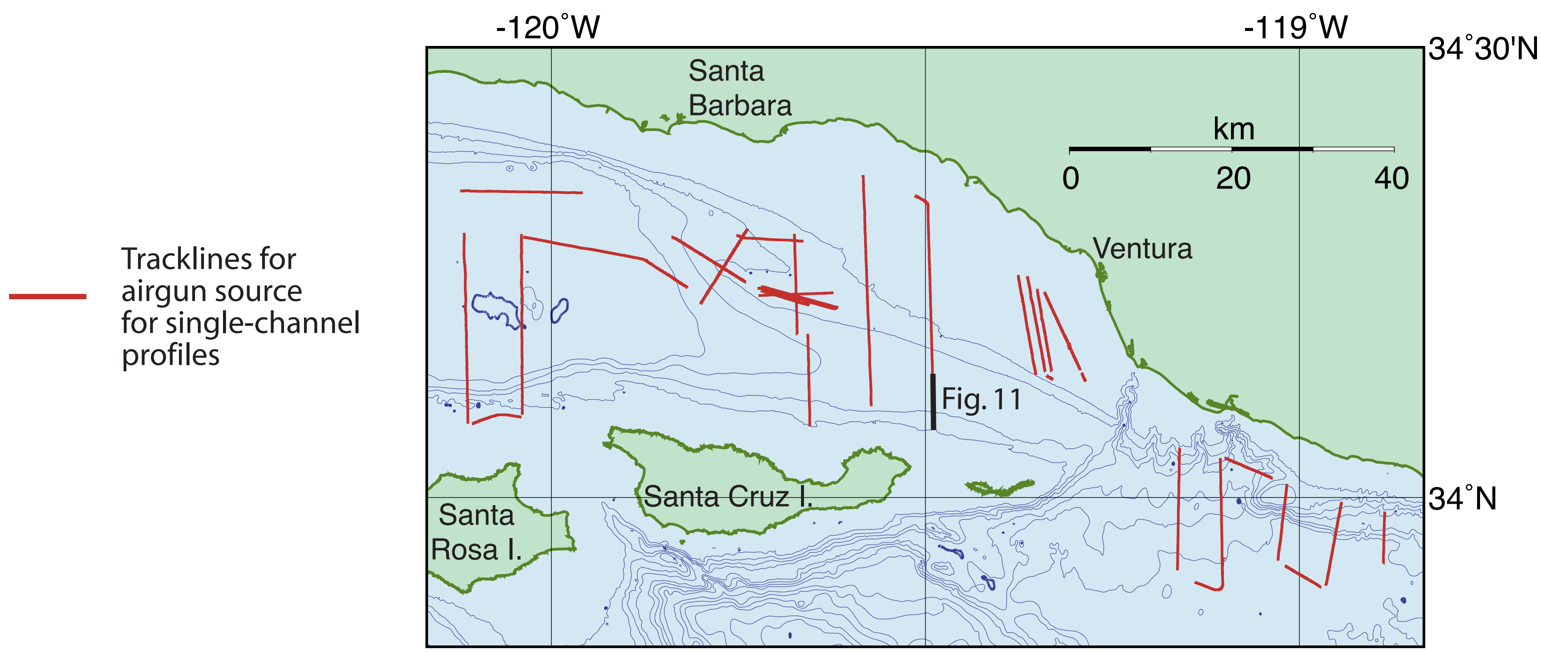

0.0
0.2
0.4
0.6
0.8
1.0
Two-way travel time (sec)
South
North
2 km
100 m
Toe of landslide
Multiples
Minisparker source: line 1869
0
0.3
0.6
0.9
Water depth (km)
-120˚W
-119˚W
34˚30'N
40
34˚N
Fig. 10
Santa Barbara
km
0
20
Ventura
Santa Cruz I.
Santa Rosa I.
Tracklines for multichannel profiles with minisparker source

FIGURE 10



0
North
South
0
2 km
100 m
0.1
Two-way travel time (sec)
Water depth (km)
0.2
0.3
0.5
0.4
Multiple
Airgun, single-channel: line 813



-120˚W
-119˚W
34˚30'N
Santa
Barbara
km
0
20
40
Ventura
Tracklines for
airgun source
for single-channel
profiles
Fig. 11
Santa Cruz I.
Santa
Rosa I.
34˚N

FIGURE 11

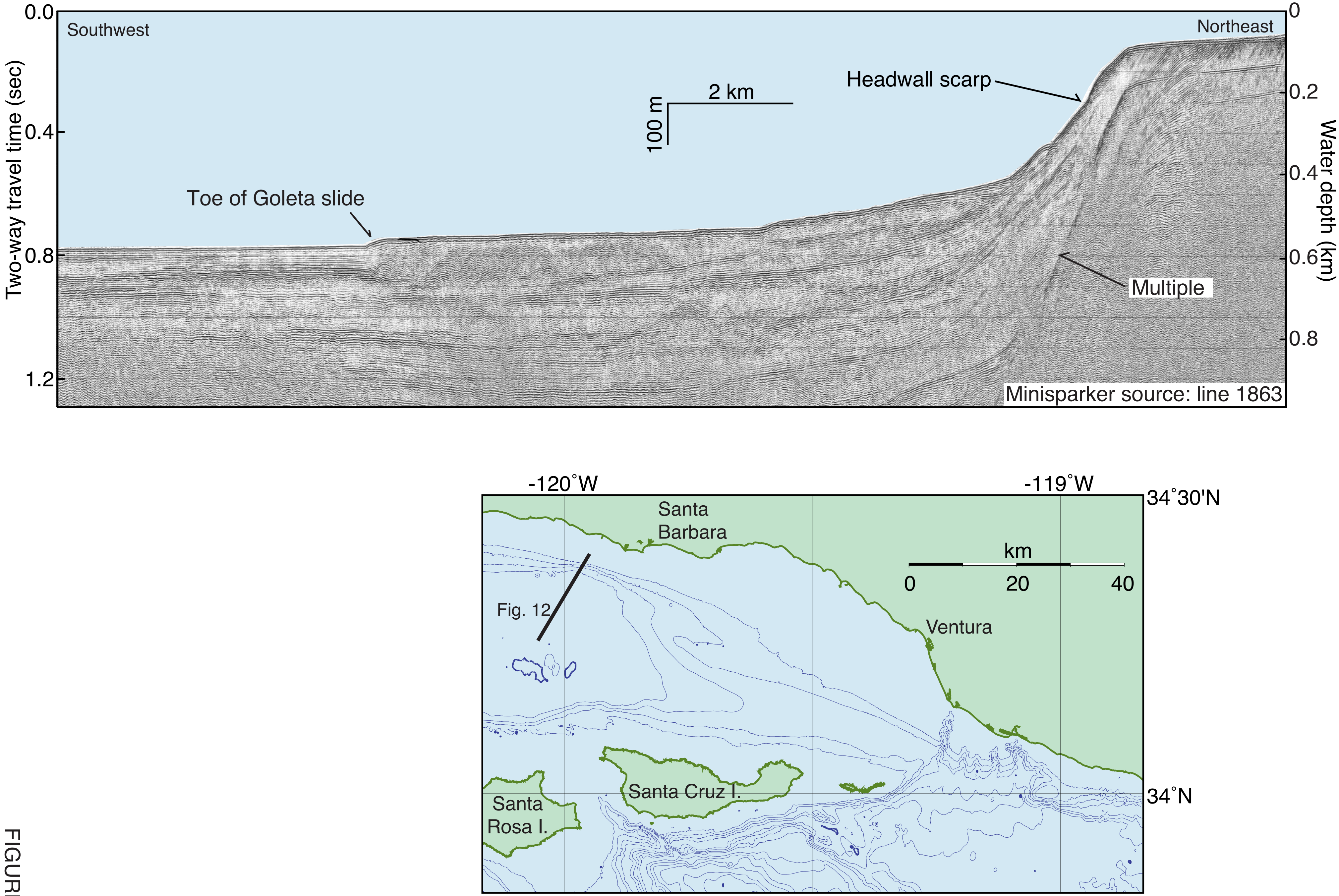

0.0
0.4
0.8
1.2
Two-way travel time (sec)
Southwest
Northeast
0
0.2
0.4
0.6
0.8
Water depth (km)
2 km
100 m
Headwall scarp
Toe of Goleta slide
Multiple
Minisparker source: line 1863
-120˚W
-119˚W
34˚30'N
34˚N
Santa Barbara
km
0
20
40
Fig. 12
Ventura
Santa Cruz I.
Santa Rosa I.

FIGURE 12

Appendix 1

USGS OF 03-110

Report prepared by

Cascadia Research

Under contract to the USGS in support of

Cruise A1-02-SC

FINAL REPORT

MARINE MAMMAL OBSERVATIONS AND MITIGATION ASSOCIATED WITH USGS SEISMIC-REFLECTION SURVEYS IN THE SANTA BARBARA CHANNEL 2002

Final Report Prepared for

U.S. Geological Survey
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December 2002

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EXECUTIVE SUMMARY

From 14 to 28 June 2002, the U.S. Geological Survey conducted seismic-reflection surveys in the Santa Barbara Channel area off of southern California. 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 the marine mammal mitigation and monitoring program conducted in conjunction with this USGS surveys. In addition to mitigating from the survey ship there was an effort to tag large whales ahead of the research vessel and monitor both their behavior and the levels of sound received by the animal from the survey vessel.

A small two-chamber generator-injector (GI) airgun was used during daylight hours only. The GI gun of the size we used has a sound-pressure level (SPL) of about 220 dB re 1 μPa-m RMS with a sound pulse duration of 10 ms. Problems with the airgun on 22 June required that it primarily be used with only a sleeved single chamber. This reduced capacity from 70 in^3 down to 24 in^3 and reduced pressure (3000psi to 2000psi). Other lower-power sound sources were also used including a high-resolution Huntec™ boomer system, an Edgetech 512i Chirp sub-bottom profiler, and a minisparker. Two sets of safety zones were used, one for the airgun and a smaller one when only the lower power sound sources were in use.

The primary objectives of the marine mammal study were to: 1) help mitigate impacts on marine mammals by providing immediate information on the presence of any marine mammals close enough to the sound source to risk injury so that the sound source can be turned off, 2) document the presence and number of marine mammals present in the vicinity of USGS survey operations, and 3) document reactions of marine mammals to the survey ship and sound sources. We also had secondary objectives to attach tags to blue and humpback whales in the vicinity of the seismic-reflection survey as well as examine changes in distribution of whales in reaction to the passage of the survey vessel.

The research effort was primarily conducted directly from the seismic-reflection survey vessel (*Auriga*). Observers conducted 24-hour-a-day observations from the survey ship during all seismic-reflection operations. There was a total of 289.3 hours of observation during day and night in the study area including 85.7 hours of observation while the airgun was firing.

The mammal observers requested shut-down of sound source operations for marine mammals 83 times, 64 during the day and 19 at night. A total of 38 shutdowns called while the airgun was in operation (termed high power) and 45 shutdowns occurred while the airgun was not in use but one of the other low power sources were in use. The principal species triggering shut-downs (45%) were common dolphins. Observers made 504 sightings of 6,537 marine mammals representing 11 species over the course of the survey. California sea lions were the most common followed by common dolphins and humpback whales. Marine mammals were observed exhibiting a variety of behaviors during the period of observation with no clear indication of distress or problems related to sound source operation. Animals tended to be oriented away from the ship more often than toward the ship in all types of operation modes.

We deployed suction-cup attached tags with acoustic recorders to blue and humpback whales in the general vicinity as the seismic-survey operations. Unfortunately it proved difficult to opportunistically get these tags on animals directly ahead of the path of the survey ship. Despite these problems we did place tags on several animals within a few km of the ship while the ship was operating the single-chamber airgun. While these tag deployments did not allow an evaluation of changes in whale behavior in response to specific received sound levels from the *Auriga*, we did obtain useful data on whale behavior and the tags on two occasions obtained recordings of the airgun in the distance.

We were able to evaluate any changes in blue whale distribution in response to the single-chamber airgun on one day where we conducted repeated transects with a 2nd vessel through an area of blue whale concentration before, during, and after passage of the survey vessel. These did not indicate any dramatic shift in blue whales away from the area where the ship operated.

There has been heightened concern in recent years about the potential impacts of underwater sounds on marine mammals. This concern has been heightened by recent evidence of strandings of marine mammals in relation to operation of mid-frequency sound sources by the military. In 2002, the stranding of several beaked whales was documented in the Sea of Cortez in close proximity to operation of a large air-gun array. The sound sources involved in the current study were dramatically smaller (less than 100 in^3 compared to several thousand in^3). While animals seemed to orient away from the survey vessel and in general were sighted farther away when the airgun was firing, we did not see any signs of distress or shifts in overall distribution in response to this survey.

INTRODUCTION

From 14 to 28 June 2002, the U.S. Geological Survey conducted seismic-reflection surveys in the Santa Barbara Channel area off of southern California. 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 the marine mammal mitigation and monitoring program conducted in conjunction with this USGS surveys. Cascadia has performed similar mitigation services off of California in 1998, 1999, and 2000, however this was the first mitigation project in the Santa Barbara Channel. In addition to mitigating from the survey ship there was an effort to tag large whales ahead of the research vessel and monitor both their behavior and the levels of sound received by the animal from the survey vessel.

BACKGROUND AND SOUND SOURCE DESCRIPTION (FROM USGS)

The USGS collected seismic-reflection data using a number of different instrument systems described in detail below.

GI Airgun

A small airgun of special type called a generator-injector, or GI gun (trademark of Seismic Systems, Inc., Houston, TX) was used during daylight hours only. This type of airgun consists of two small airguns within a single steel body. The two small airguns are fired sequentially, with the precise timing required to nullify the bubble oscillations that typify sound pulses from a single airgun of common type. These oscillations impede detailed analysis of fault structure. For arrays consisting of many airguns, bubble oscillations are cancelled by careful selection of airgun sizes. The GI gun is a mini-array that is carefully adjusted to achieve the desired bubble cancellation. Airguns and GI guns with similar chamber sizes have similar peak output pressures. The GI gun for this survey had two chambers of equal size-35 cubic inches- and was fired every 12 seconds. Compressed air delivered to the GI gun had a pressure of about 3000 psi. The gun was towed 12 meters behind the vessel and suspended from a float to maintain a depth of about 1 m.

The manufacturer's literature indicates that a GI gun of the size we used has a sound-pressure level (SPL) of about 220 dB re 1 μPa-m RMS. The GI gun's output sound pulse has a duration of about 10 ms. The amplitude spectrum of this pulse, as shown by the manufacturer's data, indicates that most of the sound energy is at frequencies below 500 Hz. Field measurements by USGS personnel indicates that the GI gun produces low sound amplitudes at frequencies above 500 Hz.

Problems with the GI airgun occurred at 1700 on 22 June. After this time the airgun was primarily used with only a sleeved single chamber. This reduced capacity from 70 in^3 down to 24 in^3 The airgun was also operated at a reduced pressure (3000psi to 2000psi). There were only brief tests of the gun at larger capacity after that. Safety zones were not altered from those initially prescribed even with the reduced capacity of the airgun.

Other sound sources

Huntec. The Huntec system was used intermittently during the cruise whether as the instrument of choice or as a backup for other systems that malfunctioned. The high-resolution Huntec™ boomer system uses an electrically powered sound source that is towed behind the ship at depths between 30 m and 160 m below the sea surface. The hydrophone arrays for listening are attached to the tow vehicle that houses the sound source. The Huntec™ was primarily used in water depths greater than 300 m. The system was triggered at 0.5 to 1.25 second intervals, depending upon the source tow depth. This system provides detailed information about stratified sediment, so that dates obtained from fossils in sediment samples can be correlated with episodes of fault offset. The sound pressure level (SPL) for this unit is 205 dB re 1 μPa-m RMS. The output-sound bandwidth is 0.5 kHz to 8 kHz, with the main peak at 4.5 kHz.

Chirp. In the shallow water parts of the survey area, typically in water depths from 20 m to 300 m, an Edgetech 512i Chirp sub-bottom profiler was used. The source level for the Chirp was 198 dB re 1 microPa-m RMS and the frequency band of the Chirp was 1 kHz-12 kHz. Firing occurred generally at 0.5 to 1 s interval.

Mini-Sparker. The sound source used for multichannel seismic-reflection (MCS) profiling during night operations or within the state three-mile limit was an SIG '2 mille' minisparker. The sparker electrodes are mounted on a small frame in a 'herring-bone' pattern with 50 electrodes on each side. The minisparker power was 2 kJ for MCS work: at this power level, the source had an SPL of 204 dB re 1 μPa-m RMS as measured prior to the cruise. The manufacturer suggests energy produced at 2 kJ is in the frequency range of 890 to 1020 Hz with a pulse duration of one millisecond. For the multichannel seismic-reflection survey, the minisparker was discharged every 2 seconds. When used with a single-channel streamer, at 400 J, the fire rate varied from 300-750 ms, depending on water depth. Additionally, the Huntec towfish had a sparker source that was used during the cruise when other sound sources failed. The 0.5 kJ sparker source produces usable energy from 1 kHz to 6 kHz with peak power at about 1 kHz.

Periodically during the survey, a sidescan-sonar system was used to obtain a high-resolution image of the seafloor. The sidescan system has a sound pressure level (SPL) of about 210 dB re 1 μPa-m RMS with a frequency bandwidth of the outgoing signal of 100khz to 500 kHz. Given the low power output and high frequency, this instrument was not included for marine mammal mitigation.

OBJECTIVES

The primary objectives of the marine mammal study were as follows:

1. Help mitigate impacts on marine mammals by providing immediate information on the presence of any marine mammals close enough to the sound source to risk injury so that the sound source can be turned off.
2. Document the presence and number of marine mammals present in the vicinity of USGS survey operations.
3. Document reactions of marine mammals to the survey ship and sound sources

Secondary objectives were as follows:

1. Attach tags to blue and humpback whales in the vicinity of the seismic-reflection survey vessel to monitor vocalizations, depth of dives and levels of received sound level.
2. Obtain identification photos of whales in the vicinity and compare them to an existing catalog of known animals.

METHODS

General Approach

The research effort consisted of observations made directly from the seismic-reflection survey vessel (*Auriga*) to provide mitigation, document marine mammals exposed to the sound source during hours of investigation, and monitor reactions of marine mammals close to the seismic-reflection survey vessel. Five observers conducted 24-hour-a-day observations from the survey ship during all seismic-reflection operations, with one observer monitoring forward from a platform in front of the bridge and one observer monitoring aft, towards the stern of the ship from a platform just behind the bridge or roaming the aft deck at night. At all times the bow observer was 6.4 m above the water, 5.8 m aft of the bow and 40.9 m from the stern of the vessel. During daytime operations the stern observer was 9.9 m above the water, 11.6m aft of the bow and 35 m from the stern of the vessel. Due to visibility problems during night operations it was more effective for the aft observer to leave the aft platform and roam the stern of the vessel.

In conjunction with the surveys from the *Auriga*, we also opportunistically conducted photo-ID and tagging of humpback and blue whales in the vicinity of the ship. The tagging was designed to gather behavioral data on humpback and blue whales with small suction-cup attached tags that recorded underwater behavior as well as received sound level. We also conducted some opportunistic repeated transects from the Scripps Institutes of Oceanography vessel *Robert Gordon Sproul* in a region of high blue whale abundance before, during, and after passage of the *Auriga* through the area.

Observations

Mammal observations were conducted during transit periods before and after the survey (June 14 and 28) and 24 hours a day during all sound source operations. At least one half hour of observations was conducted before the start up of any equipment to make sure the area was clear of mammals.

Daytime operations began about a half hour before sunrise and continued until about a half hour after sunset. Daytime sighting data was gathered using *Tasco 7x50* reticle binoculars or handheld clinometers. Night observations began when conditions became too dark for sightings to be made within the mitigation zone. In years past all night operations were conducted with the forward observer using night vision goggles. This year we experimented by using the ship’s powerful sodium lights at night. Night vision goggles were used when it was not possible to keep the ship’s sodium lights on.

Data on survey effort and sightings were recorded on a datasheet recording information to track survey effort, which includes observers on duty, and weather conditions (Beaufort sea state, cloud cover, swell height, precipitation, visibility, etc.). For each sighting the time, bearing and reticle, degree, or estimated distance to the sighting, species, group size, surface behavior orientation and travel direction were recorded.

Distances to sightings were calculated using the vertical angle to the animal (based on either the reticle reading through the binoculars for distant sightings or a hand held clinometer for close sightings) and the known elevation above the water. This was then used to evaluate whether a sighting was within the mitigation safety zones.

Mitigation and safety zones

To allow a quick determination of a mammal's 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 array: 1) 0-60 degrees off the bow or ahead of the ship, 2) 60-120 degrees off the bow or to the side of the ship, and 3) 120 to 180 degrees off the bow or astern of the ship. Observers used a polaris (angle board) to determine which of the three arcs the sighting occurred in (Table 1). The cut-off vertical angle, which represented each of the safety zones, was also written on the polaris allowing observers to quickly see whether the animal was inside the safety zone or not.

Observers were instructed to call for a shutdown 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 appeared likely that the direction of travel of the survey vessel would result in the marine mammal being within the safety zone shortly. Following a shutdown of sound-source equipment, marine mammals were tracked until they were outside the safety zone at which time sound source operations resumed.

Under the NMFS incidental harassment authorization permit marine mammals were classified into two groups:

Group 1 (non-endangered): bottlenose dolphins (*Tursiops truncatus*), common dolphin(*Delphinus delphis*), killer whale (*Orcinius orca*), pacific white-sided dolphin (*Lagenorhynchus obliquidens*), Risso's dolphin (*Grampus griseus*), pilot whales (*Globicephala macrorhynchus*), Dall's porpoise (*Phocoenoides dalli*), gray whale (*Eschrichtius robustus*), minke whale (*Balaenoptera acutorostrata*), harbor seal (*Phoca vitulina*), elephant seal (*Mirounga angustirostris*), California sea lion (*Zalophus californianus*), and northern fur seal (*Callorhinus ursinus*). Sea turtles were also included in this group.

Group 2 (endangered): mysticete whales not listed in group 1, and sperm whales (*Physeter macrocephalus*)

Three mitigation safety zones were created by NMFS under the mitigation permit for the two groups of animals depending on which sound source was in use. The safety zones were:

1. 250 m from sound source while the airgun was in use for mammals in group 2 above.
2. 100 m from sound source while the airgun was in use for mammals in group 1, or 100 m from sound source with the non-airgun equipment in use for animals in group 2.
3. 30 m from sound source while the non-airgun equipment was in use for mammals in group 1.

Tagging

Two types of tags were attached to humpback and blue whales in the Santa Barbara Channel during the time period that the USGS surveys were being conducted. These were part of a separate study but tag deployments were attempted when possible close to the survey vessel. The two tag systems are described below.

Greeneridge acoustic tag: This tag developed by Bill Burgess with ONR support recorded underwater sound and dive depth. The tag was potted in resin and was much smaller than in previous tag deployments. The tag sampled acoustics with 16-bit resolution at bandwidths up to 14 kHz, as well as temperature and depth with 12-bit resolution. Constant acoustic sampling at 2 kHz fills the 576-MB solid-state flash disk in 41 hours. Low-power three-volt electronics allow a single half-AA-cell lithium battery to power the entire tag.

WHOI(Woods Hole Oceanographic Institute) **digital tag**: The WHOI digital tag has been developed in recent years and successfully tested on a number of species. A graduate student at WHOI, Becky Woodward, collaborated with us in conducting deployments in the Santa Barbara Channel. The digital tag consists of:

- a hydrophone (acoustic) channel with a 12-bit analog-to-digital converter, and a programmable gain filter. The typical acoustic sampling rates are 16kHz or 32 kHz.
- additional sensors, sampled at 12 bits and roughly 23 Hz (when audio sampling is 16 kHz), including
- a pressure sensor to measure depth, 0-2000m, resolution of 0.5m.
- a thermistor both for water temperature and to correct the pressure sensor readings.
- 3-axis accelerometers to measure pitch and roll.
- 3-axis solid-state magnetometers to measure heading.
- a salt water switch to detect surfacings and to trigger the initial recording of data.
- depending on the tag version, from 400 megabytes to 1.6 gigabytes of flash memory to record up to 20 hours of acoustic and sensor data when sampling at 16 kHz. Lossless compression will be investigated.
- a nichrome wire release mechanism, which can be triggered to corrode away slowly and release the tag from the animal after a set amount of time. When the nichrome wire has corroded away, a small valve is opened, flooding the suction cups and allowing it to float to the surface.
- a VHF radio beacon to enable tracking and focal observations of the whale when it surfaces, and to find the tag for recovery when the suction cups release from the animal.
- a real-time clock to give an accurate time base and to trigger events such as the nichrome wire release.
- an infrared serial port for menu-based user interface and for data transfer. LEDs (active only before deployment) also provide the user with the tag state (armed for recording).
- a low-power digital signal processor capable of 100 million instructions per second, enabling complex compression and detection routines.
- a lithium ion polymer rechargeable battery pack, 2 Watt-Hours. Power consumption when recording is about 150 mW.

Two ship experiment

On 27 June, with the use of nearby Scripps vessel *Robert Gordon Sproul* we were able to collect data on blue whale distribution before, during and after the *Auriga* ship transited through an area while firing the airgun (reduced chamber airgun). Concurrent with this experiment, the Cascadia RHIB (ridged hull inflatable boat) was also trying to deploy instrument packages onto the backs of blue whales.

Starting at 0737 on the morning of the 27th, and continuing through 1546 the *Sproul* surveyed repeatedly along an east-west transect on 34°07N between 120°00W and 120°08W. This was an area the *Auriga* was scheduled to travel through and in which we anticipated from surveys the previous day would contain high numbers of blue whales. Observations aboard the *Sproul* were made and recorded using similar methods to those employed on the survey *Auriga*. Including turnaround time, each transect was about an hour in duration and except for small deviations were conducted at consistent course and speed.

RESULTS

Marine mammal mitigation

There was a total of 289.3 hours of observation during day and night in the study area (Table 2). Daylight operations totaled 188.0 hours and included 85.7 hours of observation while the airgun was firing (High Power), 53.7 hours while the airgun was not firing but one of the other sound sources (Huntec, Chirp, or minisparker) was operating (Low Power) and 48.6 hours where none of these were operating (no power). Night operations did not include any operations of the airgun.

The mammal observers requested shut-down of sound source operations for marine mammals 83 times, 64 times during daylight observations, and 19 times during night observations. There were 38 shutdowns called while the airgun was in operation (termed high power) and 45 shutdowns occurred while the airgun was not in use but one of the other low power sources were in use (Table 3). Forty five percent of shut downs requested were in response to groups of common dolphins (short or long beak) swimming into or near the safety zone. California sea lions and Pacific white-sided dolphins were responsible for 23% and 22% of shutdowns, respectively. Shutdowns were requested on 8 occasions for whales, six times for humpback and twice for blue whales. One of the two blue whale shutdowns was a mistake, after a resight was made it was determined that the animal was well outside the safety zone and the shut-down should not have been called.

Weather conditions were worse during the early part of the survey during operations outside the Santa Barbara Channel. From 15-22 June the sea state was above a Beaufort 5, reducing the distances at which marine mammals could be sighted; 74% of the daylight sightings during the worst period (17-21 June) were made within 200 m of the survey vessel.

A total of 101.5 hours of observation were conducted at night over the duration of the cruise. There were 19 shutdowns called during night operations from just 68 sightings of marine mammals. This reflected the close distance at which marine mammals were sighted at night. The distance of initial sightings at night was 55.4 m compared to 585 m during daylight. During this particular cruise the observation team used the *Auriga's* sodium lights to illuminate the safety zones for 10 nights and the night vision goggles for 3 nights (June 15-16, June 19-20 and June

20-21) when it was not possible to use the sodium lights. Sightings per hour were 0.24 with sodium lights and 0.03 without the use of the sodium lights.

Marine mammal sightings

Observers identified 11 species over the course of the survey. There were a total of 504 marine mammal sightings (not including re-sightings), comprised of 6,537 animals (Table 4). Of the above sightings, the observers were able to make 409 "resightings" following the initial documentation of animals. California sea lions were the most abundant species in the study area, accounting for 56% of the total initial sightings. Common dolphin and humpback whale were the second and third most common species sighted over the mitigation period with 12% and 10% of the initial sightings, followed by Pacific white-sided dolphins, blue whales, Risso's dolphin, Dall's porpoise, harbor seal, sea otter and elephant seal. Humpback whales, Dall's porpoise and Risso's dolphin were also observed during the transit periods to and from the study area.

A wide range of marine mammal species were sighted during all types of sound source operations (Table 5). During daylight operations, sighting rates of large whales and small cetaceans were higher and pinniped sightings lower during airgun operations compared to when lower power sound sources or no sound sources were operating (Table 6). This was likely a result of the different areas that these operations occurred. Daylight operations outside of the Santa Barbara Channel did not involve use of the airgun, while daylight operations inside the Santa Barbara Channel (where whale and small cetacean densities are higher) generally did involve use of the airgun.

There were differences in distances at which some marine mammal groups were initially sighted depending on the sound source operating (Table 7). The differences in distance were statistically significant among these three groups (high power, low power, or no sound source) for pinnipeds ($F= 6.98$, $p=0.001$) but not for small cetaceans ($F=0.83$, $p>0.05$). The results for large whales were more ambiguous with the overall Analysis of Variance being not significant ($F=2.26$, $p>0.05$) among the three groups but among the pair-wise comparisons sightings during air-gun operation were at significantly greater distances than during no sound source operations (t-test, ,<0.05). For pinnipeds as well the initial sightings were made at distances greatest from the ship when the airgun was operating and closest to the ship when no sound source was operating.

Orientation and behavior of marine mammals

Marine mammals were observed exhibiting a variety of behaviors during the period of observation (Table 8). The most common behaviors observed were classified as fast travel and slow travel. Other common behaviors were milling, which can indicate foraging or feeding activity, porpoising, and stationary or hauled behavior (pinnipeds). Less common behaviors included feeding and breaching. Dive behaviors were categorized separately since they can reflect a reaction to the survey vessel following the initial sighting (Table 9). For initial sightings the dive behavior "fast roll/porpoising" was observed 46% of the time where dive behavior was noted. "Slow roll" was observed 32% of the time. Fluke up dive, splash and vertical sink were also observed on a few occasions. Rooster tail and stationary behaviors were seen infrequently.

Observers noted the direction of travel in relation to the *Auriga* for all sightings except when the animal was too far away to determine heading or the animal was stationary (Table 10).

The majority of marine mammals were observed traveling on a tangent to the direction towards the vessel (left or right from the observers perspective). For both humpback and blue whales, animals were initially observed oriented away from the vessel much more than oriented toward the vessel (12 times away and only 1 time toward). This encompassed periods of all types of sound source operation and could have reflected a reaction to the ship itself. Dolphin species were most commonly observed headed toward the survey vessel compared to away (Table 10) and reflected their tendency to approach to vessel to bowride even when sound sources were operating.

Tagging

Both types of tags were attached to humpback and blue whales in the Santa Barbara Channel during the period of the USGS surveys (Table 11). Unfortunately it proved difficult to opportunistically get these tags on animals directly ahead of the path of the survey ship so that there would be a close approach during the period the tag was on: This difficulty stemmed from a number of factors:

1. The concentration of whales in most areas the ship was operating was not high enough to reliably be able to find and place tags on animals ahead of the ship.
2. The humpback whales encountered through most of the survey period were engaged in fish feeding with unpredictable and erratic surface intervals and movements making tagging approaches harder.
3. We did not have control over where and when the survey ship was operating and often could not anticipate its direction of travel, this made it difficult to insure that we found animals and deployed tags in the right area.
4. Weather was not cooperative for much of the study period
5. The dual chamber GI gun was not functioning for the latter half of the survey period when blue whales were present in larger numbers and deployments were made near the ship.

Despite these problems we did place tags on several animals within a few km of the ship while the ship was operating the lower power single chamber airgun (Table 11). The deployments made when the survey ship was closest were all on 27 June in the same area as the two-ship experiment described below.

The three deployments on blue whales conducted on 27 June stayed on the whales from a few minutes to 1.5 hours (Table 11). The initial deployment was on a single blue whale ahead of the path of the approaching survey ship. The tag was only on for 12 minutes and recorded a single dive series to about 120 m before coming off. The longest deployment of the three was as the survey ship was just heading out of the area. During the 1.5 hours this tag was on the whale it recorded seven dive series down to about 160 m and showing repeated underwater feeding lunges. While these tag deployments did not allow an evaluation of changes in whale behavior in response to specific received sound levels from the *Auriga*, we did obtain useful data on whale behavior and the tags on two occasions obtained recordings of the airgun in the distance.

Two-ship experiment

The repeated transects through the area of blue whale concentration during the passage of the *Auriga* did not indicate any dramatic shift in blue whales away from the ship (Figure 1). This was after the malfunction of the GI airgun and so the sound source was only the single-chamber lower-power airgun. The repeated transects showed that while the concentration of blue whales tended to shift slightly mostly east and west through the morning and into the early afternoon, these shifts did not appear to coincide with any avoidance or attraction to areas where the sound sources was operating. There did not appear to be any decrease in overall number of whales or any shift in distribution of whales away from the areas the sound source has traversed.

DISCUSSION

Species encountered during this survey is consistent with what would be expected in the region at this time of year. Both common dolphins and California sea lions are considered the most common marine mammals in near shore waters of Southern California. Over a 12-day survey we would expect to sight more baleen whales in the Santa Barbara Channel Islands than were sighted by the observers on the *Auriga* in 2002. Lower numbers of sightings are most likely due to challenging sighting conditions over the first week of the survey.

Species sighted and behaviors exhibited in this study were similar to those seen in past USGS surveys in this region (Calambokidis et al. 1998, Calambokidis and Chandler 2000). "Distress" behavior (fluke slapping, pec slapping, head slapping, continuous breaching) was not observed.

Unlike the animals sighted in this report, a USGS survey off of Southern California in 1998 reported twice the number of animals traveling away from the survey vessel as in any other direction. This difference could not be explained by a difference in species between the two years, but it could be dependent on number of sightings and different regions of study. Animals sighted in 1998 were in the Southern California Bight and perhaps more likely to avoid ships than animals in the Channel Islands where there is less vessel traffic. The 1998 survey had 133 sightings, whereas the 2002 survey had almost four times that number of sightings. The orientation of animals sighted headed away from the survey vessel increased from initial sighting to resighting from 17% to 27%. The reversal of travel direction may be explained by the animals reaching a sound threshold upon approaching the vessel, but the trend was seen with all sound sources and no sound source in operation.

Night observations have been a source of frustration for observers in past years due to low visibility and the possibility of not being able to detect marine mammals within the safety zones. In 1998 and 2000 observers used night vision goggles for night observations with varying sighting numbers that were highly dependent on weather. For the 1999 USGS cruise night time mitigation was unnecessary, but observers spent 6 hours over the course of the survey evaluating the quality of available night vision equipment. Observers found in 2002 that sighting rates were higher when using the sodium lights and unanimously felt they were more effective at detecting marine mammals than with the night vision equipment and the lights off. Sodium lights gave the forward observer greater peripheral vision and greatly enhanced the "roaming" aft observers' ability to see animals at greater distances. Even with the sodium lights to illuminate the water, the observers still lack an effective method for judging distance from the survey vessel.

The tagging effort conducted opportunistically in association with these cruises demonstrated the promise of this approach but also the difficulty in getting animals, weather, the survey vessel, and a successful tag deployment to all occur at the same place. This was complicated by the relatively low power sound source in use during the latter half of the survey. Control of the survey vessel would be required to improve the chances of getting data on the underwater behavior of whales in relation to received sound level.

Observations of the distribution of blue whales before, during, and after passage of the survey vessel using a different ship, proved valuable and allowed an evaluation of any shifts in whale distribution in response to passage of the survey ship. This was successful due to the high density of animals in this region and good information from the USGS survey crew of the anticipated route of the survey vessel.

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ACKNOWLEDGEMENTS

A number of people and organizations assisted in the completion of this project. Thanks to observers on the *Auriga* Todd Chandler, Laura May-Collado, Elizabeth Phillips, Randy Lumper, and Christina Tombach. Thanks to the captain and crew of the *Auriga* for their help throughout the survey. The project was funded and organized by the U.S. Geological Survey; we thank especially Mike Fisher, Dave Hogg, Bill Nomark, and Chris Gutmacher. Mike Fisher, Bill Nomark, and Chris Gutmacher all also provided useful comments on a draft of this report.

A number of people assisted in the tagging and 2nd ship components of this research. Thanks go to the crew and personnel with Scripps Institutes of Oceanography (SIO) who helped with the observations from the RV *Robert Gordon Sproul*. Erin Oleson and John Hildebrand organized this effort. Kristin Rasmussen served as the lead observer aboard the Sproul along with Sherwin Cotler, Jessica Burtenshaw, and Oscar Torres. Joe Olson of Cetacean Technology, Mark McDonald of Whale Acoustics, Jeremy Winn and Becky Woodward associated with Woods Hole Oceanographic Institute (WHOI), and Bill Burgess of Greeneridge Sciences assisted with the tag deployments. WHOI and Greeneridge provided the tags deployed on whales. The tagging portion of the study was supported by the Office of Naval Research.

FIGURES AND TABLES

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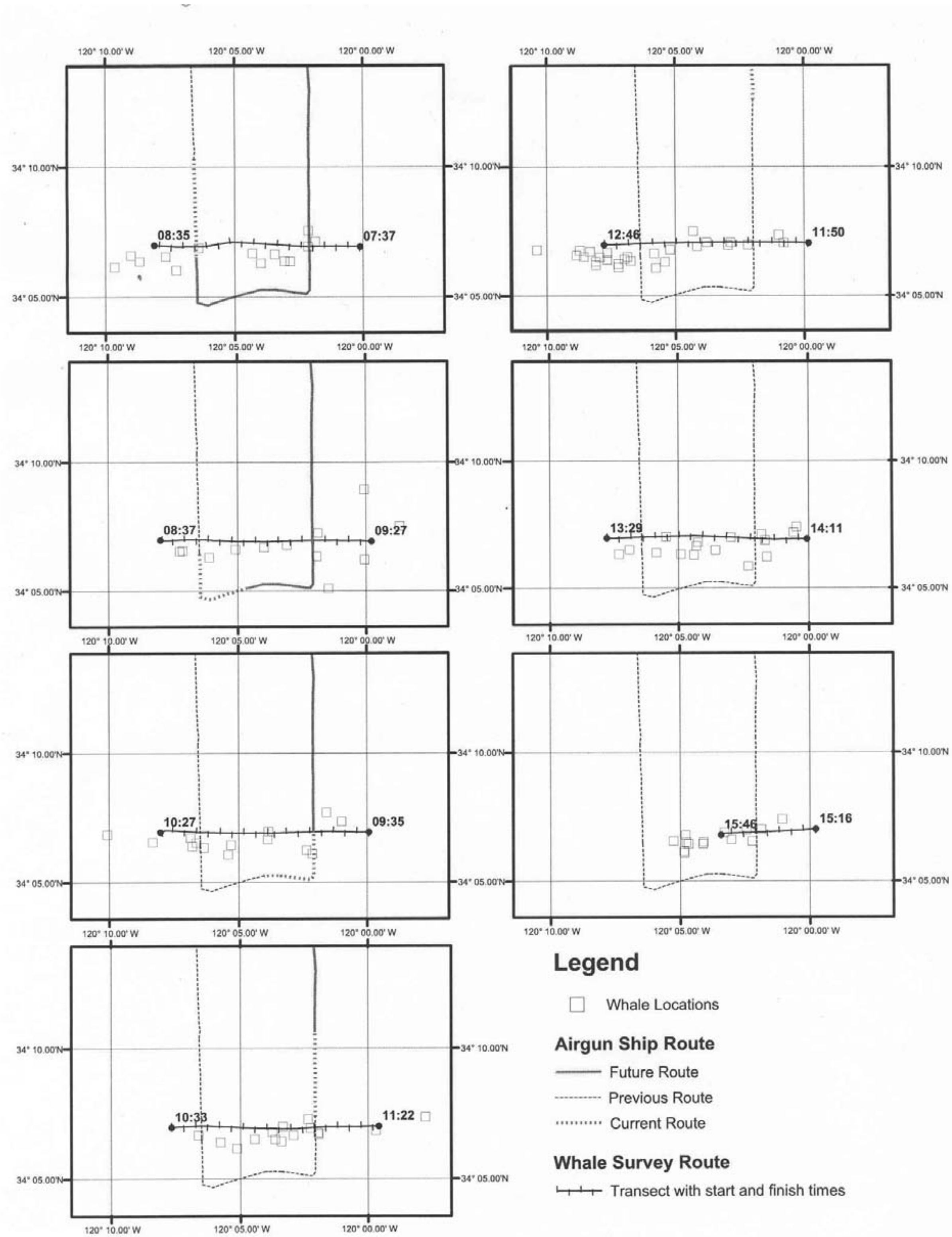

Figure 1. Plots showing the location of blue whales sighted during transects by the *Sproul*, before, during and after passage of the Auriga firing the single-chamber airgun on 27 June 2002 in the Santa Barbara Channel.

Table 1. Safety zone matrix showing the two groups of marine mammals and their vertical angle cutoffs for three arcs around the Auriga. Any vertical angle reading equal to or greater to that shown for each arc warranted a call for shutdown.

	Cut-off	Bow			Aft		
Species	**distance**	**0-60 Deg.**	**60-120 Deg.**	**120-180 Deg.**	**0-60 Deg.**	**60-120 Deg.**	**120-180 Deg.**
Airgun							
Non-endangered	100	3	3	n/a	n/a	3	3
Endangered	250	1	1	n/a	n/a	1.5	1.5
Other sound sources							
Non-endangered	30	10	10	n/a	n/a	4.5	4.5
Endangered	100	3	3	n/a	n/a	4	4

n/a (not applicable) = section not visible from that observation post

Table 2. Sound sources used and hours of operation during the survey. To allow summary of data all modes involving use of the airgun were termed high power. Other sources in the absence of the airgun were considered low power.

	Hours at operation			
Operational seismic equipment	**No Power**	**Low Power**	**High Power**	**Total**
None	61.5			
Chirp		60.9		
Huntec (boomer mode)		6.9		
Mini-Sparker (either SIG or Huntec in Sparker mode)		66.1		
Chirp and Mini-Sparker		8.3		
Chirp and Multi-Chamber airgun			9.3	
Chirp and Single-Chamber airgun			46.2	
Huntec and Multi-Chamber airgun			19.8	
Multi-Chamber airgun			8.0	
Single-Chamber airgun			2.3	
Total hours at power	61.5	142.2	85.6	289.3

Table 3. Shutdowns by species and sound source level during the survey.

Species	Seismic Sound Source Level		
	Low Power	**High Power**	**Total**
Large whales			
Blue whale	1	1	2
Humpback whale	2	4	6
Small cetaceans			
Delphinus species	17	20	37
Pacific white-sided dolphin	8	10	18
Risso's dolphin		1	1
Pinnipeds			
California sea lion	17	2	19
Total	45	38	83

Table 4. Summary of sightings and resightings by species during the 2002 survey. 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	22	29	46	68
Humpback whale	51	67	164	249
Unidentified large whale	32	44	14	22
Unidentified small whale	1	1		
Total large whales	106	141	224	339
Small cetaceans				
Delphinus species (DD and DC)	62	3,521	97	9,131
Pacific white-sided dolphin	24	155	31	323
Risso's dolphin	3	4		
Dall's porpoise	1	2		
Unidentified dolphin	19	2,013	7	246
Unidentified small cetacean	1	1		
Total small cetaceans	110	5,696	135	9,700
Pinnipeds				
California sea lion	283	695	50	272
Elephant seal	1	1		
Harbor seal	3	3		
Sea otter	1	1		
Total Pinnipeds	288	700	50	272
Grand Total	504	6,537	409	10,311

Table 5. Summary of sightings and total number of animals observed with the operating sound source. Resightings are not included.

	No Power		Low Power		High Power	
Species	**# Sit**	**# Anim**	**# Sit**	**# Anim**	**# Sit**	**# Anim**
Large whales						
Blue whale					22	29
Humpback whale	9	12	20	29	22	26
Unidentified large whale	6	8	7	9	19	27
Unidentified small whale	1	1				
Small cetaceans						
Delphinus species	8	675	23	661	31	2185
Pacific white-sided dolphin	3	15	8	69	13	71
Risso's dolphin					3	4
Dall's porpoise			1	2		
Unidentified dolphin	5	1519	5	117	9	377
Unidentified small cetacean			1	1		
Pinnipeds						
California sea lion	79	278	122	276	82	141
Elephant seal					1	1
Harbor seal	1	1	2	2		
Sea otter			1	1		
Grand Total	112	2509	190	1167	202	2861

Table 6. Day time sighting rate of groups of marine mammals by type of sound source in operation.

		# of sightings			# of sightings per hour		
Sound source level	**Hours**	**Large whales**	**Small cetaceans**	**Pinnipeds**	**Large whales**	**Small cetaceans**	**Pinnipeds**
High	86	63	56	83	0.74	0.65	0.97
Low	54	26	21	77	0.48	0.39	1.43
None	49	16	15	79	0.33	0.31	1.63
Total	188	105	92	239	0.56	0.49	1.27

Table 7. Average distances (in meters) of marine mammals sighted during daylight observations by type of sound source.

Marine mammal	n	Mean	SD
Large whale			
High power	63	1,642	1,048
Low power	26	1,353	1,490
No power	16	1,005	537
Total	105	4,001	3,075
Pinniped			
High power	83	250	294
Low power	77	141	210
No power	79	131	130
Total	239	522	634
Small cetacean			
High power	56	629	806
Low power	21	512	602
No power	15	806	1,212
Total	92	1,947	2,620
Grand Total	436	6,469	6,329

Table 8. Primary behavior of marine mammals based on type of sound source in operation.

Behavior	Sightings				Resightings			
	No Power	Low Power	High Power	Total	No Power	Low Power	High Power	Total
Fast travel	47	113	84	244	53	33	43	129
Slow Travel	45	56	86	187	49	47	118	214
Hauled		1	3	4			1	1
Milling	4	9	4	17	6	8	15	29
Stationary	8	2	4	14	1		2	3
Breach		1	1	2			3	3
Feed	1	1		2		1		1
Total	105	183	182	470	109	89	182	380

Table 9. Summary of the dive behaviors observed during sightings and resightings during surveys in the Santa Barbara Channel, 2002.

Species	Dive behavior								
	Breach	Fluke Dive	Porpoise/ Fast roll	Rooster tail	Stationary	Splash	Slow roll	Vertical rise	Vertical sink
				Sightings					
Large whales									
Blue whale							21		
Humpback whale		11				1	27		
Unidentified large whale		2				1	5		
Small cetaceans									
Delphinus species			42			3	14		
Pacific white-sided dolphin			10				13		
Risso's dolphin							3		
Dall's porpoise				1					
Unidentified dolphin			14				5		
Unidentified small cetacean			1						
Pinnipeds									
California sea lion			164	3	1	8	73	5	6
Elephant seal							1		
Harbor seal									2
Sea otter							1		
Total (sighting)		13	231	4	1	13	163	5	8
				Resightings					
Large whales									
Blue whale		6					31	1	
Humpback whale	2	30	2				107	1	1
Unidentified large whale							4		
Small cetaceans									
Delphinus species			61			5	28		
Pacific white-sided dolphin			13				18		
Risso's dolphin									
Dall's porpoise									
Unidentified dolphin			3			3	1		
Unidentified small cetacean									
Pinnipeds									
California sea lion			34		1		11		1
Elephant seal									
Harbor seal									
Sea otter									
Total (Resighting)	2	36	113		1	8	200	2	2
Grand Total (sighting and Resighting)	2	49	344	4	2	21	363	7	10

Table 10. Orientation and distance to some marine mammal species during initial sighting from the survey vessel.

Species	Distance(m)	Orientation to survey vessel			
		Away	Left	Right	Toward
Blue whale	1-200				
	201-500		3	1	
	501-1000		1	1	
	1001-2000	2	2	1	
	>2000	2	5	1	
Total		4	11	4	
Humpback whale	1-200			2	
	201-500	1	4	4	
	501-1000	4	1	2	
	1001-2000	2	5	9	1
	>2000	1	3	2	
Total		8	13	19	1
Delphinus	1-200	10	6		17
	201-500	1	5	3	2
	501-1000		2	1	3
	1001-2000		1	3	3
	>2000				1
Total		11	14	7	26
Pacific white-sided dolphin	1-200	2	4	3	7
	201-500		2	2	1
	501-1000		1		
	1001-2000			1	
	>2000				
Total		2	7	6	8
California sea lion	1-200	35	72	49	63
	201-500	6	13	17	4
	501-1000	1	1	4	2
	1001-2000			1	
	>2000				
Total		42	86	71	69

Table 11. Summary of tag deployments in the Santa Barbara Channel in June 2002 during USGS surveys.

Deploy Date/ time	Tag	Sp	Deployment Latitude	Deployment Longitde	Detach Time	Hours on	Detach reason	Recovery Time	Recovery Latitude	Recovery Longitde	Num	SN#	Beh	Type of deployment	Track data	Dive	Skin	Reaction	Comments
6/19/02 11:06	Burgess	Mn	34 18.77	119 51.43	11:25	0.3	Front gummy gone only rear held suction	6/19/02 11:25	34 20.25	119 51.87	2	8	Mill	Put tag on whale	Mostly complete	Yes	None	Tail slap	Tag slid back on one cup, acoustic saturation prob from vibration
6/22/02 10:45	dTag	Mn	34 12.65	119 50.82	10:48	0.0	Failure of front cup to seal	6/22/02 10:52	34 12.71	119 50.79	1	11	Travel	Attach tag	Short	Yes	None	NR	Out-bound freighter approaching
6/23/02 11:19	dTag	BM	34 08.01	119 53.21	12:29	1.2	Detached early	6/22/02 12:30	34 06.52	119 48.59	2	8	Travel	Put tag on trail whale	Good incl. post-tag	Good	010623-1 from robot head	Pos. early terminatio n of SS	Trail animal does not surface next series but appears to be normal pattern
6/24/02 12:34	dTag	BM	34 08.34	119 56.11	19:51	7.3	Unclear, wire had burned but was set for 2h	6/25/02 15:00	34 15.82	120 12.42	1	1	Mill - travel	Put tag on single	Ex intil 1900	Good	010624-1 robot 020625-1 tag	Pos. sink and early term. of SS	Tag recovered the next dat
6/25/02 18:02	Burgess	BM	34 06.98	120 10.21	18:05	0.0	Put on backwards	6/26/02 18:08	34 06.97	120 10.07	1	3	mill	Tag put on whale	Too short	Dive to 20 m	None	Sink, term. SS	Out of position (1 engine) tag put on backward
6/26/02 7:58	Burgess	BM	34 07.42	120 00.36	8:02	0.1	Rear gummy was gone (blown out on tagging?)	6/26/02 8:07	34 07.48	120 00.57	2	2	Mill	Put tag on trail of pair	Too short	Single dive to 60m	None	Sink, accel., term. SS	Used flex head, may not have gotten solid press on, gummies good
6/26/02 9:03	Burgess	BM	34 06.85	120 04.25	11:54	2.8	Tag slid on whale, gummies intact suction good after	6/26/02 12:00	34 06.65	120 04.79	1	4	Mill, travel	Put tag on single	9:03-10:20 then lost signal	8 dive series to about 165m	020626-2 (sm. Sk from cup)	Accel., extends SS dive	Solid attachment, 2nd appr on SS stayed with animal below surface
6/27/02 7:27	Burgess	BM	34 06.64	120 05.53	7:39	0.2	Good atchmt. rear gummy blew out	6/27/02 7:41	34 06.68	120 05.61	1	2	Mill	Put tag on single	Short	One dive series to 120 m	020627-1	Suspend SS, back flex	Lead gummy out, USGS ship appr.
6/27/02 10:22	Burgess	BM	34 06.84	120 03.84	10:24	0.0	Attached underwater, no good atchmt.	6/27/02 10:25	34 06.83	120 03..84	1	11	Mill	Brief attach to single	Too short	Comes off on 1st dive	None	Sink	
6/27/02 10:49	Burgess	BM	34 06.92	120 03.17	12:18	1.5	Gummies intact	6/27/02 12:21	34 06.59	120 06.02	1	13	Mill	Put tag on single	None	7 feeding dive series to 160m	None	Interrupt SS then resume	USGS ship moving away