# Cruise Report for A1-98-SC Southern California Earthquake Hazards Project

*By* William R. Normark[1], Robert G. Bohannon[1], Ray Sliter[1], Gita Dunhill[1], David W. Scholl[1], Jane Laursen[2], Jane A. Reid[1], and David Holton[1]

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[1]U.S. Geological Survey, Menlo Park, California 94025
[2]Aarhus Universitet, Aarhus, Denmark

# INTRODUCTION

## Project description

The focus of the Southern California Earthquake Hazards project, within the Western Region Coastal and Marine Geology team (WRCMG), is to identify the landslide and earthquake hazards and related ground-deformation processes that can potentially impact the social and economic well-being of the inhabitants of the Southern California coastal region, the most populated urban corridor along the U.S. Pacific margin. The primary objective is to help mitigate the earthquake hazards for the Southern California region by improving our understanding of how deformation is distributed (spatially and temporally) in the offshore with respect to the onshore region. To meet this overall objective, we are investigating the distribution, character, and relative intensity of active (i.e., primarily Holocene) deformation within the basins and along the shelf adjacent to the most highly populated areas (**Fig. 1**). In addition, the project will examine the Pliocene-Pleistocene record of how this deformation has shifted in space and time. The results of this study should improve our knowledge of shifting deformation for both the long-term ($10^5$ to several $10^6$ yr) and short-term (<50 ky) time frames and enable us to identify actively deforming structures that may constitute current significant seismic hazards.

## Study area

The active field program for this hazards project is intended to focus on those areas with the greatest potential for impact on the Southern California populace: **1)** the coastal strip (coastal zone and continental shelf) between Los Angeles and San Diego, where much of the hazard appears to be associated with strike-slip or oblique-slip faults; **2)** active faults within the Santa Monica, San Pedro, and San Diego Trough basins, where more extensive sedimentation has left a greater stratigraphic record; **3)** the offshore extension into the Santa Barbara Channel of the fold and thrust belt of the Western Transverse Range; **4)** the boundary (Channel Islands region) between the inner California Borderland (strike-slip dominated deformation) and the Santa Barbara Channel (thrust and fold deformation). **Figure 2** shows a generalized depiction of faults in the southern California region. Over the last decade, both site-specific studies and regional tectonic syntheses for the borderland have identified the general distribution of the offshore (and related onshore) fault systems (e.g., see Clarke et al., 1985; Ziony and Yerkes, 1985; Vedder et al., 1986; Vedder, 1987; Wallace, 1990; Legg, 1991; Crouch and Suppe, 1993; Clarke and Kennedy, 1997; Dolan et al., 1997; Pinter et al., 1998; and Bohannon and Geist, 1998).

Cruise A1-98-SC, the subject of this report, focused on the western part of area **2** noted above (**Fig. 1**) and discusses the first completed field program for the project. During the first year of the project, FY 1997, an expedition (S1-97-SC) was initiated to survey the same area, but equipment failure terminated the primary geophysical operation after only 30 hours (**Fig. 3A**). The planned trackline survey for the A1-98-SC survey was intended to take advantage of the survey pattern begun during cruise S1-97-SC. Tracklines were plotted at a 2 km spacing aligned perpendicular to the shelf break and basin slope and on an "orthogonal" set aligned to intercept major structural features that are oblique to the trend of the basin slope and shelf edge (**Fig. 3B**).

In addition to the primary survey grid (**Fig. 3B**), several transects were planned to tie the high-resolution geophysical data to Ocean Drilling Program (ODP) Site 1015 (**Figs. 1 and 3**; ODP Leg 167 Shipboard Scientific Party, 1997). Site 1015 was continuously cored to 150 meters below the sea floor. Based on a previous Huntec deep-tow boomer survey in the western Santa Monica Basin, Piper et al. (in press) correlated the boomer seismic-stratigraphy with the Site 1015 cores. Normark and Piper (1998), using age control based primarily on Site 1015 and comparison with Site 893 in Santa Barbara Basin (ODP Leg 146 Shorebase Scientific Party, 1994; Kennett and Venz, 1995), show that the deep-tow boomer system typically resolves reflectors as old as 20 ka in the basin floor and lower slope areas of Santa Monica Basin. Normark and Piper s (1998) correlation of the basin-wide seismic stratigraphy can thus provide estimates of timing for movement on folds and faults during the Holocene to the extent that the seismic stratigraphy can be extended thoughout the eastern part of Santa Monica basin.

## OPERATIONS

This section gives an overview of the vessel, equipment, personnel, and key operational events during the cruise. For general cruise operational information, refer to FACS files accessible at:

http://walrus.wr.usgs.gov/infobank/a/a198sc/html/a-1-98-sc.meta.html

### Research platform

The FY 1998 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 are no laboratory compartments on the M/V AURIGA, but the large open fantail area is amenable to installation of standard container shipping vans, each of which was outfitted for specific scientific function **(Fig. 4)**. The M/V AURIGA was staffed with a ship's crew of six, and during the cruise, the ship's crew provided an excellent level of support to the project activity throughout the field operation.

For the cruise A1-98-SC, three of the four scientific vans installed on the M/V AURIGA were the mainstay of the project survey activities: (1) an electronics lab/underway-watch van for operating the navigation system and primary geophysical instruments, (2) a mechanical shop used for maintaining the air compressor for the seismic-reflection sound source and the winches and davits used for launch and recovery of both the Huntec deep-towed boomer as well as the streamer and sound source for the high-resolution reflection profiling system; and (3) a small office van. Figure 4 shows the layout of equipment on the vessel. The science vans and all associated deck equipment, including winches, davits, high-pressure air compressors, etc., were loaded during a four-day mobilization period at Redwood City, CA.

The geophysical survey was set for 9 to 23 August, 1998, departing and returning to Fish Harbor on Terminal Island in the port of Long Beach. Most of the scientific party embarked at Fish Harbor in late morning 9 August.

**Scientific Party**

The scientific party for A1-98-SC included four personnel from the southern California earthquake hazards project of WRCMG, two USGS volunteers, and four technical-support personnel from the WRCMG Marine Facilities staff (Table 1). In addition, there were three contract personnel, one to oversee operation of the deep-tow boomer and two to provide a 24-hour watch for marine mammals.

**Operational Log**

Figure 3B shows the general plan for survey lines during the cruise. Equipment problems, however, during the initial startup period for operations, which commenced immediately after clearing the approaches to the port of Long Beach, required a series of modifications to the proposed survey grid. Within the first week, three return visits to Fish Harbor were required, initially to allow a commercial compressor technician to diagnose and on a second visit, to effect repairs. The third return to port was required to pick up parts to allow repairs for the multi-channel streamer. Figure 5 shows the final survey tracklines; the tracklines colors distinguish the different combinations of equipment used.

Table 2 shows the milestones for the main activities and comments on the effect(s) on the intended cruise operations. Date and time are given in Julian Day (JD) /Greenwich Mean Time (GMT); subtract 7 hours for local time.

Table 2 does not log the activities of the marine-mammal observers from Cascadia Research Collective. The observers were responsible for recording sightings of marine mammals and determining when any mammals covered by the Marine Mammal Protection Act came close enough to the seismic-reflection sound sources to require cessation of survey activity. The protocols for shut down of the sound sources were established prior to departure, and the decision to shut down was solely the responsibility of the marine-mammal observer and was not the subject of veto by the geophysical watchstanders. The basic protocols requiring shutdown were when baleen whales approached within 200 m and when odontocetes (e.g., dolphins) or pinnipeds (e.g., seals) were within 100 m. The protocol area was not a simple radius from the sound sources but an egg-shaped area that extended forward of and along the sides of the vessel by the stated protocol range.

Sea lions, dolphins, and whales were all observed numerous times during the survey, requiring shutdowns as frequently as several times a day. Most shutdowns were on the order of 5 to 10 minutes in length. Shutdowns tended to occur in the same general areas on each transit, e.g., dolphins feeding in waters above the upper slope, so it was not practical to attempt to retrace the trackline and acquire the missing data. Information on equipment shutdowns for both the Huntec and MCS equipment, caused either by mammal sightings, change of equipment, travel inside the 3 mile limit for the MCS, or port visits is given at http://walrus.wr.usgs.gov/infobank/a/a198sc/nav/a-1-98-sc.nav_lines

Appendix 1 is the report provided by the Cascadia Research Collective detailing the activities of the marine-mammal observers.

## Equipment Review

A brief description of and operational parameters for the primary survey equipment used during the cruise are given below. For specific times of operation and changes in system operation, refer to the FACS file found at:

http://walrus.wr.usgs.gov/infobank/a/a198sc/nav/a-1-98-sc.nav_lines

### Shipboard positioning system

Position data was collected with the USGS-designed YoNav Navigation system, which can accept a wide range of input data including GPS, LORAN C (either hyperbolic or rho-rho), transit satellites, and microwave frequency, shorebased, transponder systems. The YoNav system is a PC-based data-acquisition and display program written in Microsoft C/C++ designed to provide navigation services on almost any DOS platform. The YoNav system incorporates a real-time trackline display and line-generating software for both the ships' bridge and scientific personnel and is described in detail in Gann (1992). The display shows the ship's position relative to the desired survey line; the captain and mates on the M/V AURIGA quickly adapted to the position display and were able to stay within defined line parameters most of the time. An added advantage of the YoNav system is that the display could also be set to show one or more of several reference-data layers including bathymetric contours, shaded-relief images from multibeam-sounding data, tracklines of previous surveys, and compilations of seafloor structural features.

The YoNav system worked well, using GPS input to provide position data every six seconds for 24 hrs/day . The preferred mode of operation was differential GPS, but both the shorebased reference-GPS stations used during the survey (Long Beach and Point Loma) would periodically shut down resulting in a noticeable degrading of the ability to keep within the 50-m cross-track limits set for line-following by the bridge watch. Most of the periods without differential GPS were limited to a few minutes or tens of minutes; during the last two days of surveying, however, the differential GPS reference was commonly unavailable for several hours at a time. The intervals without GPS commonly show as 'wiggly' lines in the track plot of Figure 5.

The complete navigation file can be obtained at:

http://walrus.wr.usgs.gov/infobank/a/a198sc/nav/a-1-98-sc.065

### Huntec

A high-resolution Huntec DTS boomer system towed between 6 m and 160 m below the sea surface (depending upon the water depth) was used to image the upper few tens of milliseconds of strata with a resolution of better than 0.5 ms (0.4 m). Power output was 350 Joules, with a firing rate that was also dependent on water depth, ranging from 0.75 sec over the shelf and upper basin slopes in 0.25 sec intervals to 1.25 sec over the deeper parts of the basins. Returning signals were received with a 5-m-long Benthos 10-element hydrophone array. Signals were filtered at 800-6000 Hz and recorded at a 0.25 sec sweep. The data were recorded both on paper using an EPC recorder and on magneto-optical disc. The average survey speed of about 3.8 kt (7 km/hr) resulted in a shot spacing between 1.5 and 2.5 m for the deep-tow boomer profiles.

The Huntec system operated throughout the cruise with the exception of shutdowns for the three return visits to Long Beach for replacement parts and service for the multichannel-seismic system components and interruptions due to mammal interference. The Huntec was also off briefly during the sound-source-measurement experiment during the 18th of August (see Table 2).

Multichannel seismic-reflection system (MCS)

As a result of equipment problems, the multi-channel seismic-reflection (MCS) profiling activity during the cruise used two different sound sources and two different streamers to receive signals. The primary sound source was a 35/35 $in^3$ double-chamber GI gun firing every 12 seconds at a pressure of about 3000 psi. A Sureshot system was used 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. The most efficient settings for the Sureshot control are given in Table 3. The GI gun was towed 12 meters behind the vessel and suspended from a float to maintain a depth of about 1 meter. Catastrophic failure of the gun resulted in changing to the backup sound source, a 40 $in^3$ Bolt airgun, which was deployed for the last 48 hours of data collection. This airgun, which had a wave-shape kit to reduce the effect of the bubble pulse, was towed at a depth of about 4 meters using 2000 psi air pressure and fired at a six-second shot rate.

The primary streamer for the MCS operation was a 24-channel ITI streamer with 10-m-long groups and 3 phones per group. This streamer was unusable for the first part of the survey because of extensive corrosion of the wiring in the termination box of the deck cable; this problem had gone undetected during a ’thorough’ quality-control check by the manufacturer in the few weeks prior to departure of this cruise. The backup receiving system, a 24-channel ITI streamer with 6.25 m groups and 1 phone per group, was used initially until repairs could be effected on the primary streamer. Failure of the GI gun late in the survey as noted above meant that three combinations of sound source and streamers were used during the operation: primary sound source with backup streamer, primary sound source and streamer, and backup sound source with primary receiver. Table 3B reviews the operational periods for the equipment.

Data were collected using a STRATAVIEW digital recording system and a Geometrics marine controller. Shots were triggered by the YoNav system. Data was recorded in SEGD format on 2-gbyte DAT tapes using a 1 msec sample rate and a three second record length. A 60-Hz notch filter was used; otherwise all frequency bands were passed. A total of approximately 250 hours (20 gigabytes) of data were collected.

Bathymetry ODEC

A 3.5-kHz chirp-source reflection-profiling system was installed on the M/V AURIGA to provide a continuous water-depth profile and as a backup high-resolution seismic-reflection system should the Huntec system fail. The rapid sweep rate (0.25 sec) of the Huntec system coupled with the lack of a direct measurement of the tow depth of the Huntec vehicle prevents a rapid and accurate measure of the water depth. During transects across the basin slopes, when the water depth would change rapidly, the Huntec recording system requires frequent time-delay changes. An independent measure of the water depth is desirable to avoid using the Huntec as a bottom-sampling device. The ODEC (Ocean Data Equipment Corporation) system was tested early in the cruise during the period of repairs for the air compressor. The ODEC 3.5 kHz system, however, provided too much interference with the Huntec signal, especially at shallower water depths where the Huntec had to be towed closer to the sea surface (and, therefore, closer to the ODEC tow fish). The system was not used again during the cruise.

A summary of the locations of cruise information is given in Table 4.

## OVERVIEW OF SEISMIC-REFLECTION DATA

This section briefly examines how the data obtained met the objectives of the project by providing a stratigraphic framework for evaluation or structural features. The sampled survey lines are selected to illustrate the three combinations of primary and secondary sound sources and streamers used to obtain the multi-channel seismic-reflection data. Figure 6 shows location of the three profile segments selected for Figures 7, 8, and 9 with respect to the shaded relief map showing basin and slope physiography.

Survey line 30, which is oriented north-northwest, is a slightly oblique crossing of the northeastern margin of Santa Monica Basin in the area where the structural style changes from oblique or strike slip to a more compressive setting related to the Transverse Ranges (Wright, 1991). The segment of line 30 that is shown contiguously in Figure 7A and B is from the lower continental slope, and the nearly flat dip of the sea floor and subbottom reflectors result from this slope-parallel transect. The terrace at the righthand side of the profile segment in 7A is the wall of the small submarine canyon at the left edge of 7B. This canyon might mark the surface expression of a fault. In this profile, which crosses the canyon at a low angle, there appears to be a contrast in character of the sedimentary package on either side of the fault; in Figure 7A, the deeper reflections are short and chaotic, contrasting with those to the south-southeast that are more continuous and more gently dipping (Fig. 7B).

The deep-tow boomer data of Figure 7C provides detailed stratigraphy for the upper 50 m of the section seen in Figure 7A. To the north-northwest, a thin cover (3 m to 5 m thick) of undisturbed sediment overlies a zone of disrupted and chaotic reflectors that might result from faulting or from gas trapped in the section. There is some indication of this zone of disruption down to a depth of 0.9 sec (water delay) in the multi-channel profile of Figure 7A. Between this zone of chaotic reflectors and the upper edge of the submarine canyon to the south-southeast, there are local strong, but discontinuous, reflectors that probably result from trapped gas in a zone from 20 to 30 mbsf. These discontinuous strong reflections conform to the bedding surfaces except where the bedding dips south-southeast approaching the canyon (righthand end of Fig. 7C) and are commonly observed on the deep-tow boomer profiles in water depths of 400 to 500 m in the western part of Santa Monica Bay. The sediments onlapping the dipping reflector package has slight positive relief and might be an overbank deposit (levee) of turbidity currents moving through the canyon. The southern margin of the canyon shows abrupt truncation of the slope reflectors to a depth of at least 80 mbsf; the narrow, steep walls of the canyon do not permit a clear interpretation of whether this is an expression of the fault observed in the multi-channel record. The sediment drape observed in Figure 7C forms a marked unconformity through much of Figure 7D.

Figures 8A, 8B, 8D and 8E show two segments from the southern part of survey line 42, which obliquely crosses line 30 and extends into the basin where ponded turbidites from Hueneme and Dume fans in the basin plain were cored at ODP Site 1015 (Figs. 5, 6). The turbidites are thought to rest on crystalline basement of the

Catalina Schist complex, which floors Santa Monica Basin and may be the strong reflector observed at 1.6 to 1.7 sec depth in Figure 8A. A small anticline that deforms the seafloor and underlying sediment is the major structure observed near the base of the Santa Monica Basin margin (Fig. 8B). There is some indication at depth (below about 1.4 sec. in Fig. 8B) that both flanks of this fold might be faulted. The internal structure of the core of the anticline is not resolved in the deep-tow boomer profile (Fig. 8E), but the record is consistent with faulting on the basinward flank of the anticline and deformation of the youngest sediment in the basin. The boomer profile in Figure 8D suggests that an incipient anticlinal structure is gently uplifting the basin fill slightly farther out in the basin, but the deeper structure in the turbidite basin fill is unclear (Fig. 8A).

The northeastern margin of Santa Monica Basin is characterized by a gentle wedging of the youngest sediment fill, which onlaps the Miocene basement that is clearly exposed on the adjacent shelf (Figure 8C). The shelf edge is not well shown in this example of the multi-channel data, but folding of the older (presumably) Miocene strata is clear.

The well-stratified character of the basin fill as seen in Figure 8D is typical of the entire basin plain area (Piper et al., 1999). Resolution of the bedding is about 40 cm with acoustic penetration to depths of 50 m to 80 m depending on the coarseness of the sediment section. The lithostratigraphy observed in the ODP cores at site 1015 (Fig. 6) has been correlated with Huntec deep-tow boomer profiles previously acquired in Santa Monica Basin (Normark and Piper, 1998; Piper et al., 1999). The earlier survey data did not directly cross the ODP Site 1015, so the existing correlation is based on extrapolation of key reflectors in the boomer records from tracklines no closer than 5 km. Figure 8D shows a part of the Huntec data from line 42, and the tentative correlation with the stratigraphic framework of Normark and Piper (1998) is shown; their correlation suggests that reflector J is about 16 ka and reflector O is about 5 to 8 ka. The possible deformation related to the incipient anticline in Figure 8D would thus be as young as reflector M, which they suggest is 12 ka.

The segment of multi-channel seismic-reflection data from line 83 (Figure 9A) is a parallel to the general bathymetric contours across the upper basin slope south of the Long Beach shelf. The orientation of this line is at a high angle to the local structures, which include the Palos Verdes fault. One of the branches of a complex submarine-canyon system that trends south across the shelf and slope is imaged at the northeastern end of the profile shown in Figure 9A. In part, the position and trend of these canyons might be controlled by several young faults. Southwest of the canyon system, the Huntec boomer data provide excellent details of the stratigraphy and structure in the upper 40 to 90 m of the slope sequence. The small basin feature in Figure 9B, for example, appears to be a growing syncline with less deformation progressively higher in the sediment fill. A chaotic layer whose irregular surface underlies the basin floor at about 5 m depth is probably a debris flow from the exposed and truncated strata immediately upslope to the northeast. The southwest edge of the basin is probably fault controlled, and some of the youngest reflectors appear to be truncated at the basin edge (Figure 9B).

Farther southwest, both the multi-channel and boomer profiles show folding and faulting on the San Pedro Basin slope (Figure 9A and C). The probable offsets seen in the strong subbottom reflector in the Huntec profile of Figure 9C mimic the deeper structures seen in Figure 9A.

## DISCUSSION AND SUMMARY

As shown in the examples discussed above, the seismic-reflection systems deployed for the 1998 earthquake-hazard survey generally provided satisfactory information for defining structures in the upper kilometer of sediment and basement in the inner basin areas. As expected, the only initial difference observed in the appearance of profiles from the three configurations of the multi-channel system is the somewhat more pronounced ringing with the air gun sound source, e.g., compare Figures 7B and 9A, which are in similar water depths. The extended period of survey without the multi-channel system, particularly during the first week of the cruise, may result in a need to conduct additional studies in the Santa Monica Bay area. The system was working well for the work southeast of the San Pedro shelf, where the trackline spacing was designed to identify the major structures in order to provide guidance for followup surveys.

The Huntec deep-towed boomer obtained excellent data quality throughout the survey with little degradation in quality over the deeper basin areas of the survey. The stratigraphic tie to upper 75 m of the section cored ODP Site 1015 might permit relatively precise age assignments for deformation along the northern Santa Monica Basin margin. It does not appear, however, that the boomer data collected during this cruise will permit extension of the ODP stratigraphic control farther southwest into San Pedro Basin without additional survey effort.

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## FIGURE CAPTIONS

FIGURE 1: Physiography of the southern California borderland showing the major basins and islands. The primary study area (red lines) for data collection for the offshore earthquake hazards project includes the innermost basins and islands and extends from the western margin of Santa Barbara Basin to the Mexican-U.S. EEZ boundary southwest of San Diego. The area of the 1998 survey that is the subject of this report is also shown (Figs. 2 and 5).

FIGURE 2: Generalized fault pattern for the inner southern California borderland modified from Legg (1991).

FIGURE 3: (A) Trackline map showing seismic-reflection data available to the project that was used for cruise-planning purposes. (B) Pre-cruise plan of survey tracklines for A1-98-SC. The survey priorities were to complete the Santa Monica Basin grid first with 2 km line spacing and then move to the area between Palos Verdes Peninsula and Dana Point on a 4-km grid.

FIGURE 4: Photos of the M/V AURIGA showing placement of the laboratory vans and other deck equipment and the M/V MARLIN, which was used for the sound-source-parameter measurements. (A) M/V AURIGA; (B) deck equipment viewed from fantail showing primary multi-channel streamer (yellow cable on reel) with the core van in background, and the Huntec winch (center right) with the air compressor in back; (C) deck vans (view aft) with office van in foreground supporting inflatable boat, mechanical shop behind to left, electronics van behind to right, and the core van (far right); (D) M/V MARLIN, a diving support boat used for the sound-source measurements.

FIGURE 5: Trackline plot for A1-98-SC survey. The Huntec deep-tow boomer operated during all of the survey. The high-resolution multi-channel system was not operational during the first 4 days of the survey; the different color tracklines indicate the different combinations of sound-sources and and streamers (see operational log (Table 2) for details.

FIGURE 6: Shaded relief map of the inner basins of the California borderland between Port Hueneme and Dana Point. Locations of the multi-channel seismic-reflection and Huntec deep-tow boomer profiles in Figures 7 to 9 are shown.

FIGURE 7: (**A and B**) Contiguous sections of multi-channel seismic-reflection data from Line 30 showing data obtained with the primary sound source (GI gun) and the backup streamer; see Table 2. Possible fault control of Santa Monica Canyon is indicated. (**C and D**) Huntec deep-tow boomer profiles along the same contiguous sections shown in A and B providing details of stratigraphy for the upper 50 m of sediment along the basin slope. Prominent but discontinuous reflections at varying stratigraphic levels that probably reflect gas-charged horizons are prominent in C; section in D shows the resolution of stratigraphic detail that is typical for Huntec records from basin-slope settings during the cruise. Profile locations in Figure 6.

FIGURE 8: (**A, B, and C**) Non-contiguous sections of multi-channel seismic-reflection data from Line 42 obtained with the primary sound source and primary streamer; see Table 2. An anticlinal structure near the base of the Santa Monica Basin slope (B) is deforming turbidite fill in the basin. Section C shows deformation in older, presumed Miocene-age sedimentary section. (**D and E**) Huntec deep-tow boomer profiles along the same sections shown in A and B providing details of stratigraphy for the upper 50 m of sediment along the basin slope. The letters along the left margins of both profiles identify the depth to the key reflectors correlated with the sediment cored at ODP Site 1015 (Normark and Piper, 1998). Profile locations in Figure 6**.**

FIGURE 9: (A) Section of multichannel seismic-reflection data from Line 83 obtained with the backup Bolt air-gun sound source and the primary streamer; see Table 2. This slope-parallel section shows evidence for multiple faults and associated deformation. The Huntec profiles (B and C) from two parts of the profile in A show extensive areas of truncation of slope sediment and possible mass-wasting deposits in the upper 50 m of sediment. Profile locations in Figure 6.

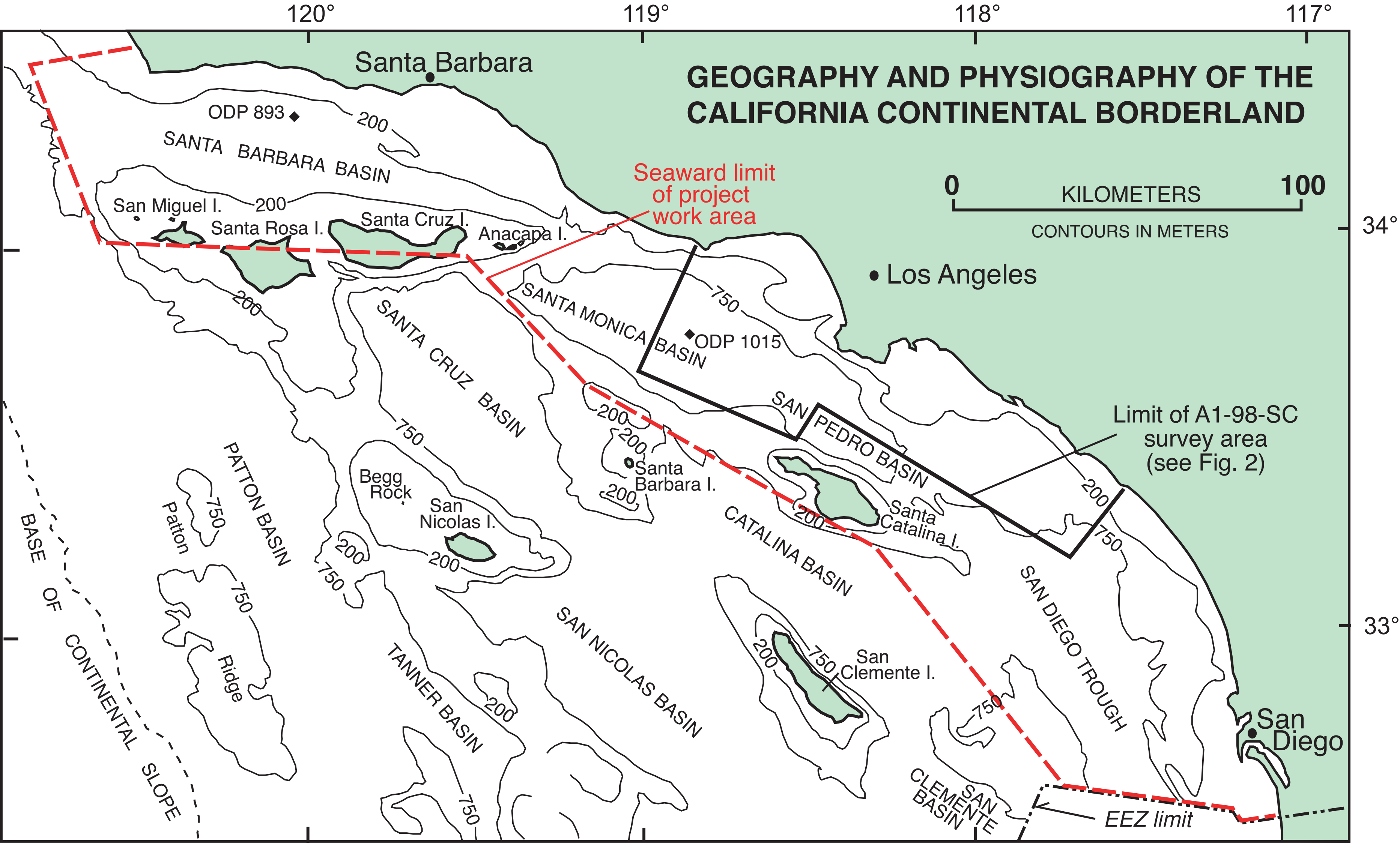

GEOGRAPHY AND PHYSIOGRAPHY OF THE CALIFORNIA CONTINENTAL BORDERLAND
120°
119°
118°
117°
34°
33°
0 KILOMETERS 100
CONTOURS IN METERS
Santa Barbara
ODP 893
SANTA BARBARA BASIN
San Miguel I.
Santa Rosa I.
Santa Cruz I.
Anacapa I.
Seaward limit of project work area
Los Angeles
SANTA MONICA BASIN
ODP 1015
SANTA CRUZ BASIN
SAN PEDRO BASIN
Limit of A1-98-SC survey area (see Fig. 2)
Santa Barbara I.
Santa Catalina I.
Begg Rock
San Nicolas I.
PATTON BASIN
Patton Ridge
BASE OF CONTINENTAL SLOPE
CATALINA BASIN
SAN DIEGO TROUGH
SAN NICOLAS BASIN
TANNER BASIN
San Clemente I.
SAN CLEMENTE BASIN
San Diego
EEZ limit
200
750

FIGURE 1

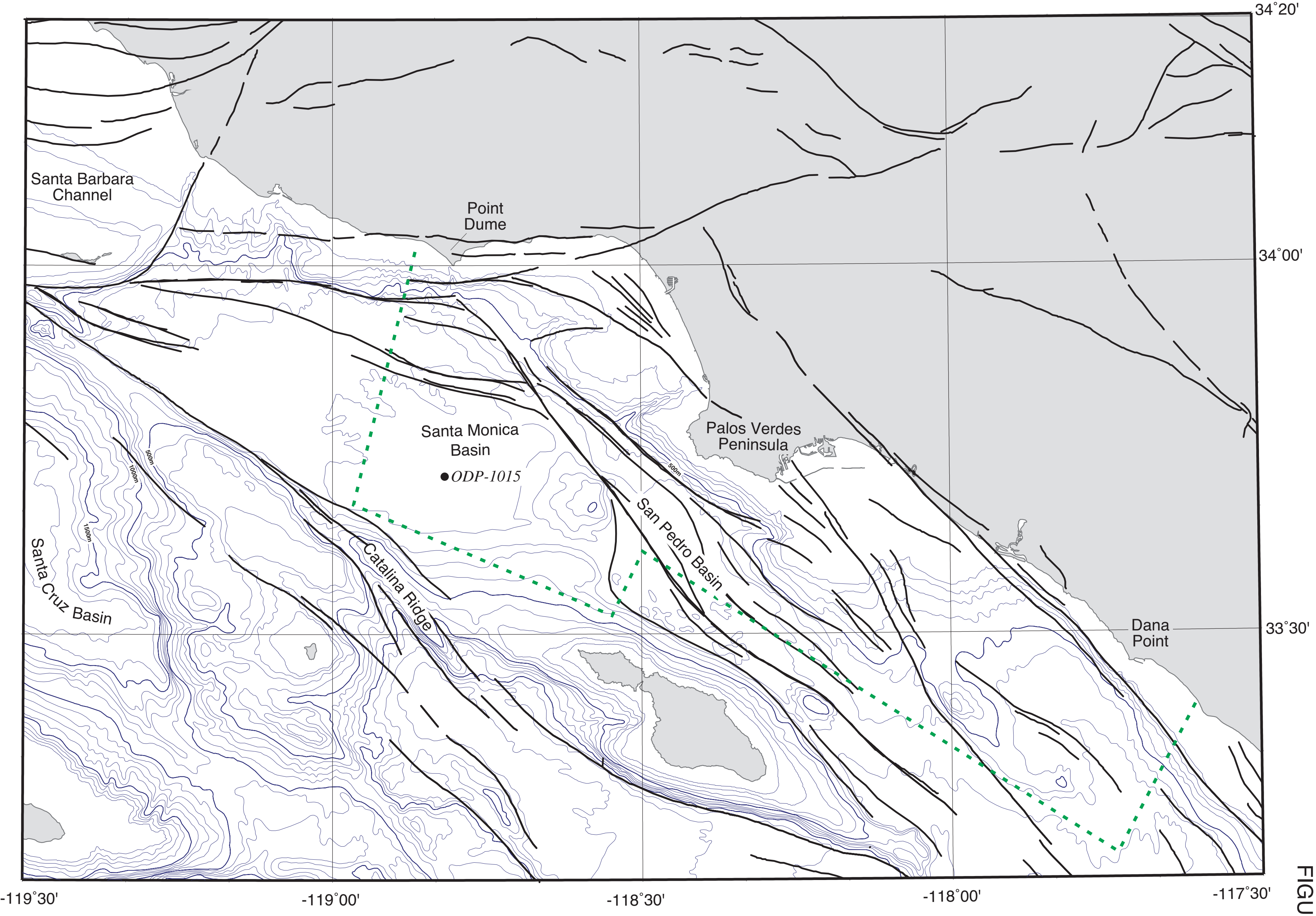
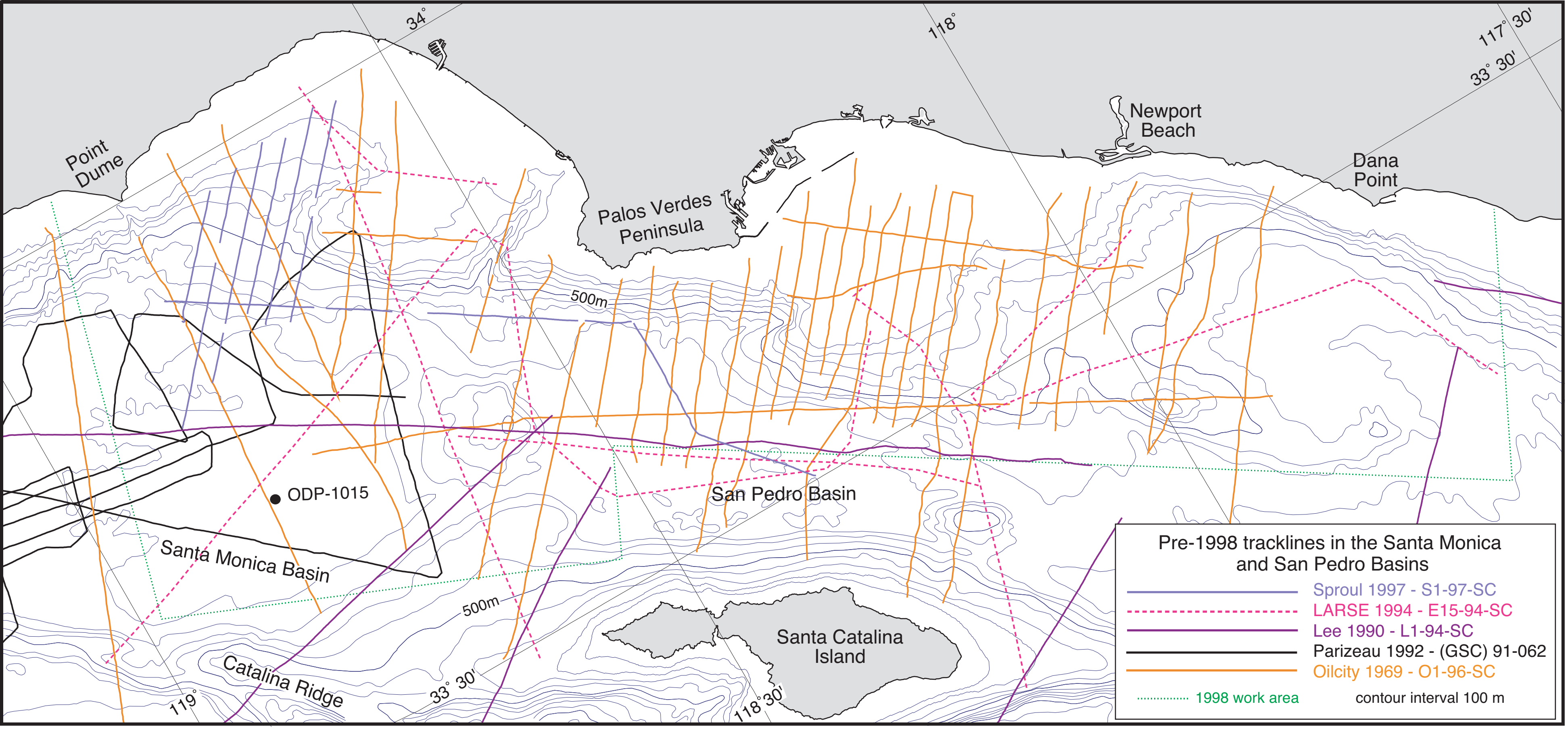

34°20'
34°00'
33°30'
Santa Barbara Channel
Point Dume
Santa Monica Basin
ODP-1015
Palos Verdes Peninsula
San Pedro Basin
Catalina Ridge
Santa Cruz Basin
Dana Point
500m
1000m
1500m
-119°30'
-119°00'
-118°30'
-118°00'
-117°30'

FIGURE 2



Pre-1998 tracklines in the Santa Monica and San Pedro Basins
Sproul 1997 - S1-97-SC
LARSE 1994 - E15-94-SC
Lee 1990 - L1-94-SC
Parizeau 1992 - (GSC) 91-062
Oilcity 1969 - O1-96-SC
1998 work area
contour interval 100 m
Point Dume
Palos Verdes Peninsula
Newport Beach
Dana Point
San Pedro Basin
Santa Monica Basin
ODP-1015
Santa Catalina Island
Catalina Ridge
500m
500m
34°
118°
117° 30′
33° 30′
119°
33° 30′
118° 30′


FIGURE 3A

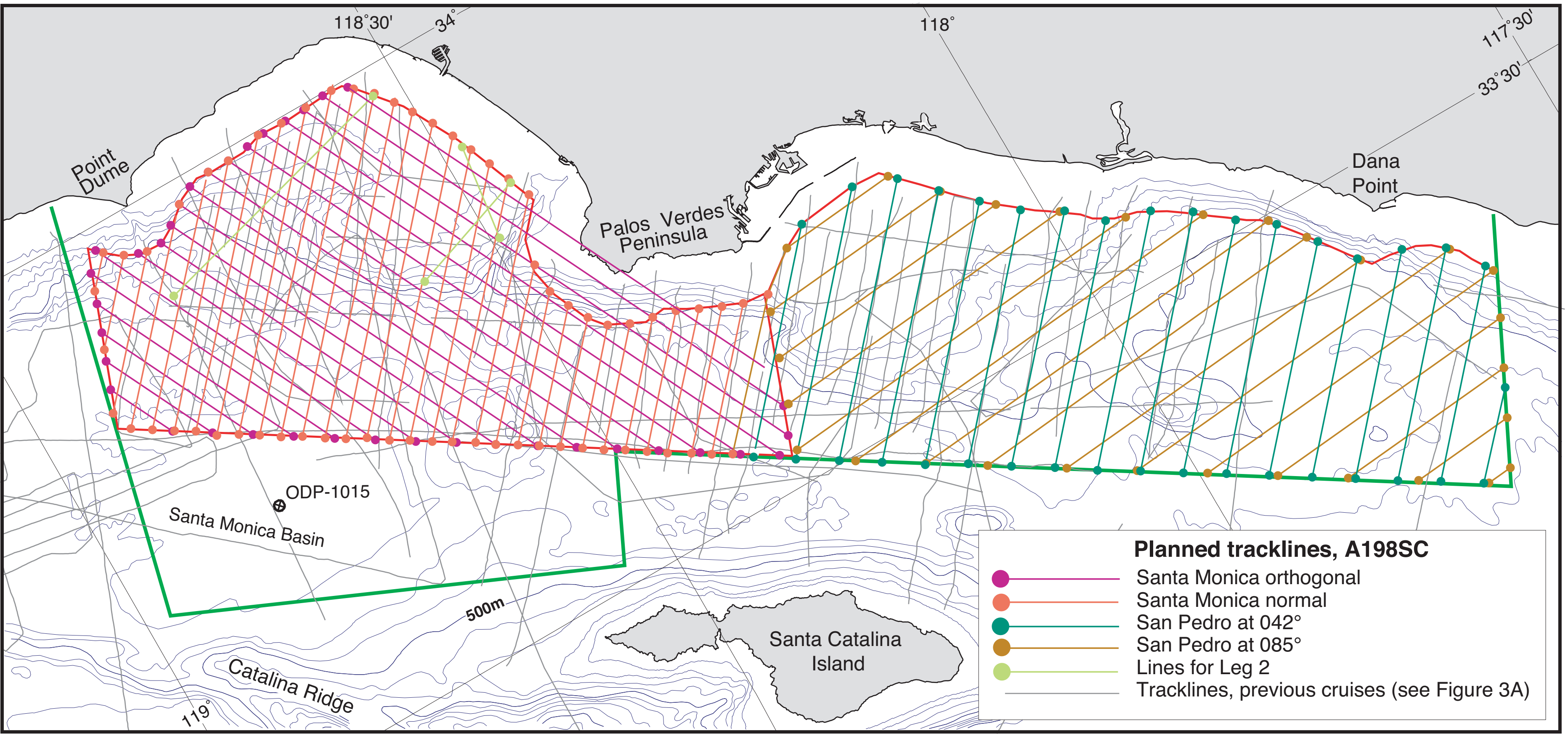
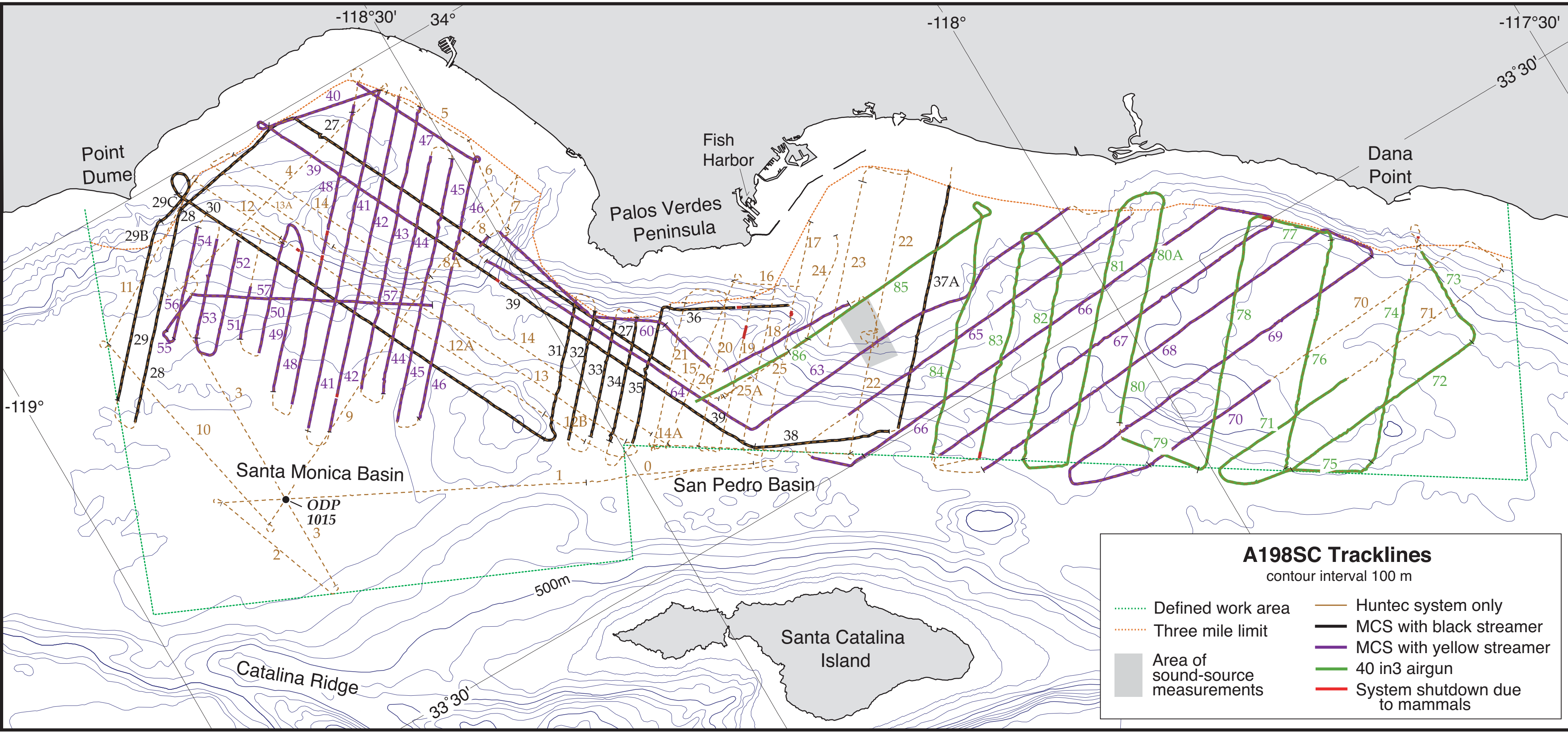

Planned tracklines, A198SC
Santa Monica orthogonal
Santa Monica normal
San Pedro at 042°
San Pedro at 085°
Lines for Leg 2
Tracklines, previous cruises (see Figure 3A)
118°30'
34°
118°
117°30'
33°30'
119°
Point Dume
Palos Verdes Peninsula
Dana Point
ODP-1015
Santa Monica Basin
500m
Catalina Ridge
Santa Catalina Island

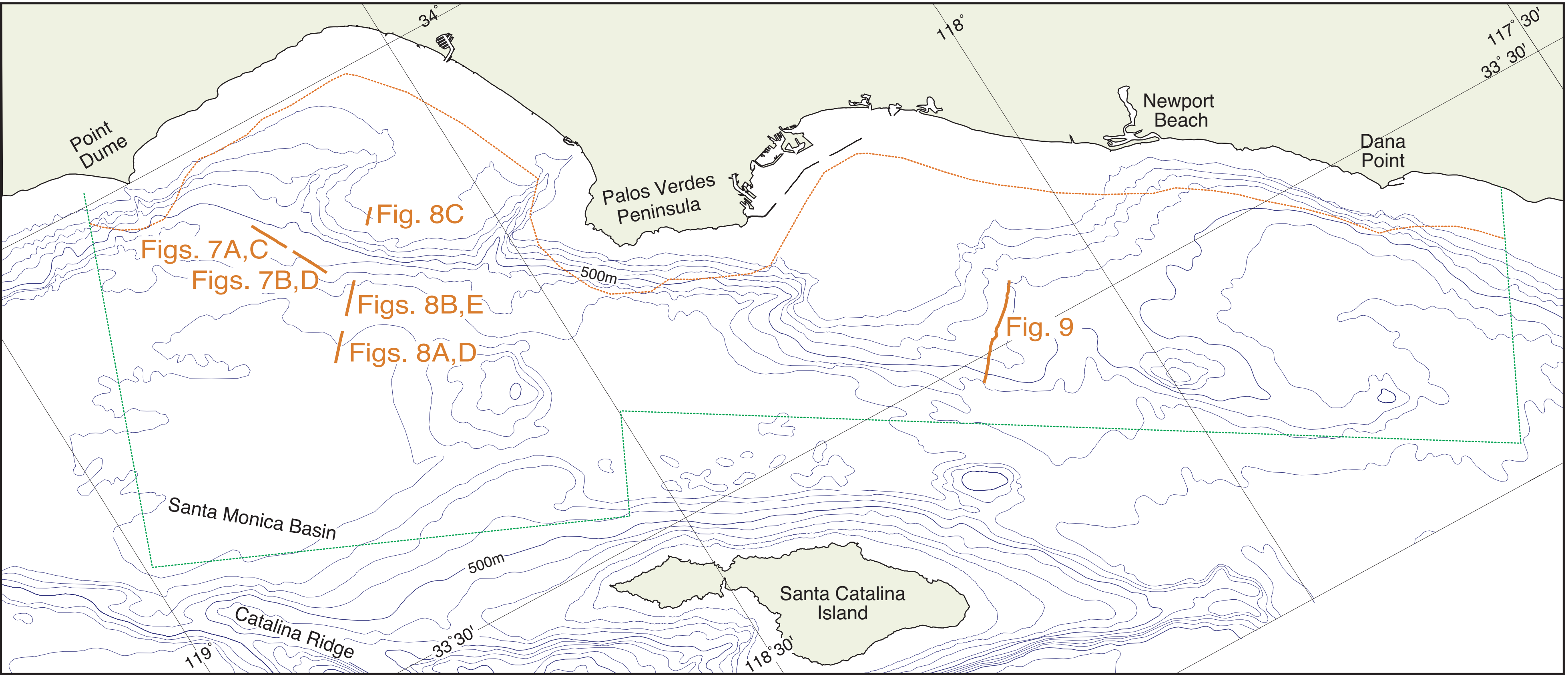
FIGURE 3B

FIGURE 4



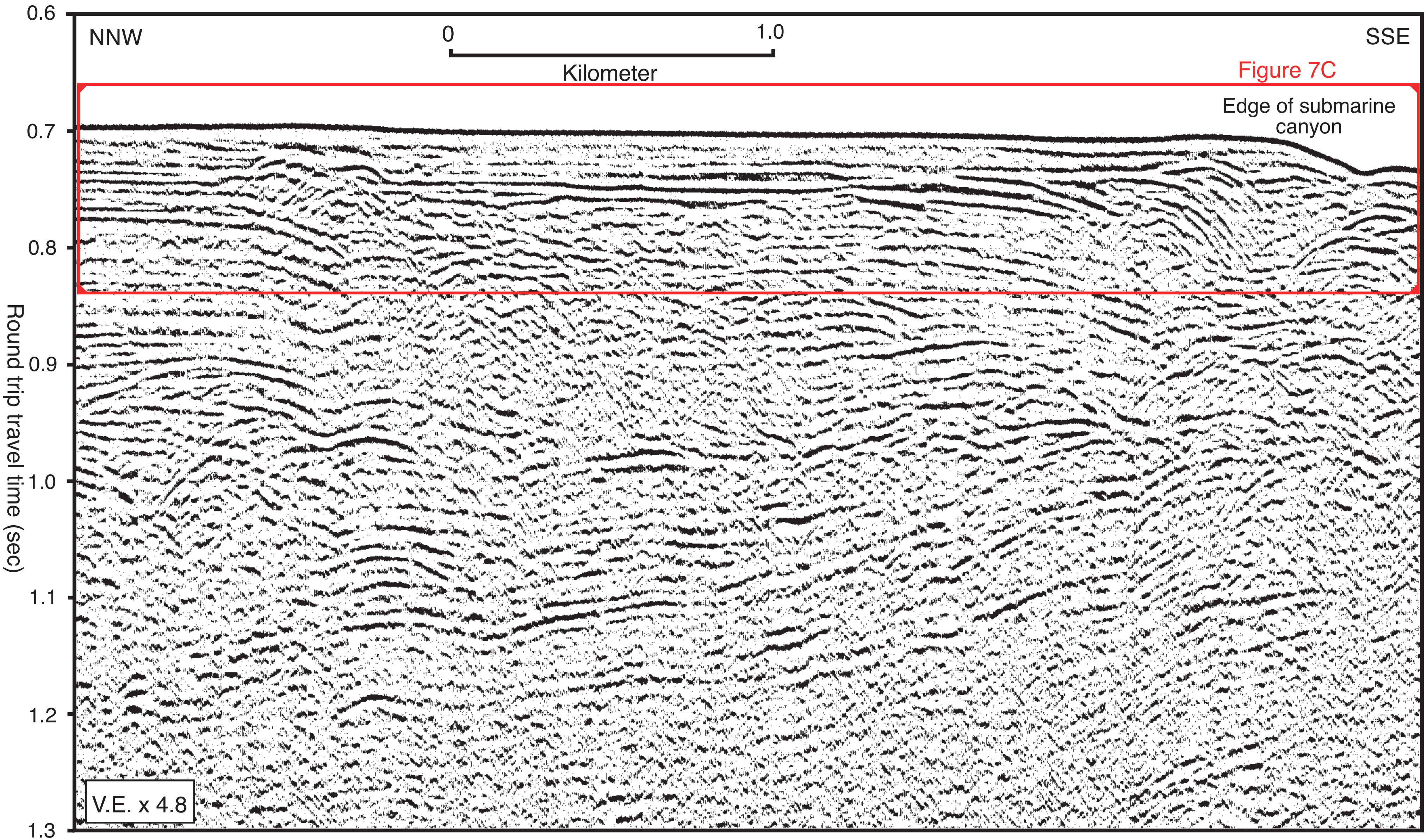
A198SC Tracklines
contour interval 100 m
Defined work area
Three mile limit
Area of sound-source measurements
Huntec system only
MCS with black streamer
MCS with yellow streamer
40 in3 airgun
System shutdown due to mammals
-118°30'
34°
-118°
-117°30'
33°30'
-119°
Point Dume
Fish Harbor
Palos Verdes Peninsula
Dana Point
Santa Monica Basin
San Pedro Basin
ODP 1015
500m
Santa Catalina Island
Catalina Ridge


FIGURE 5



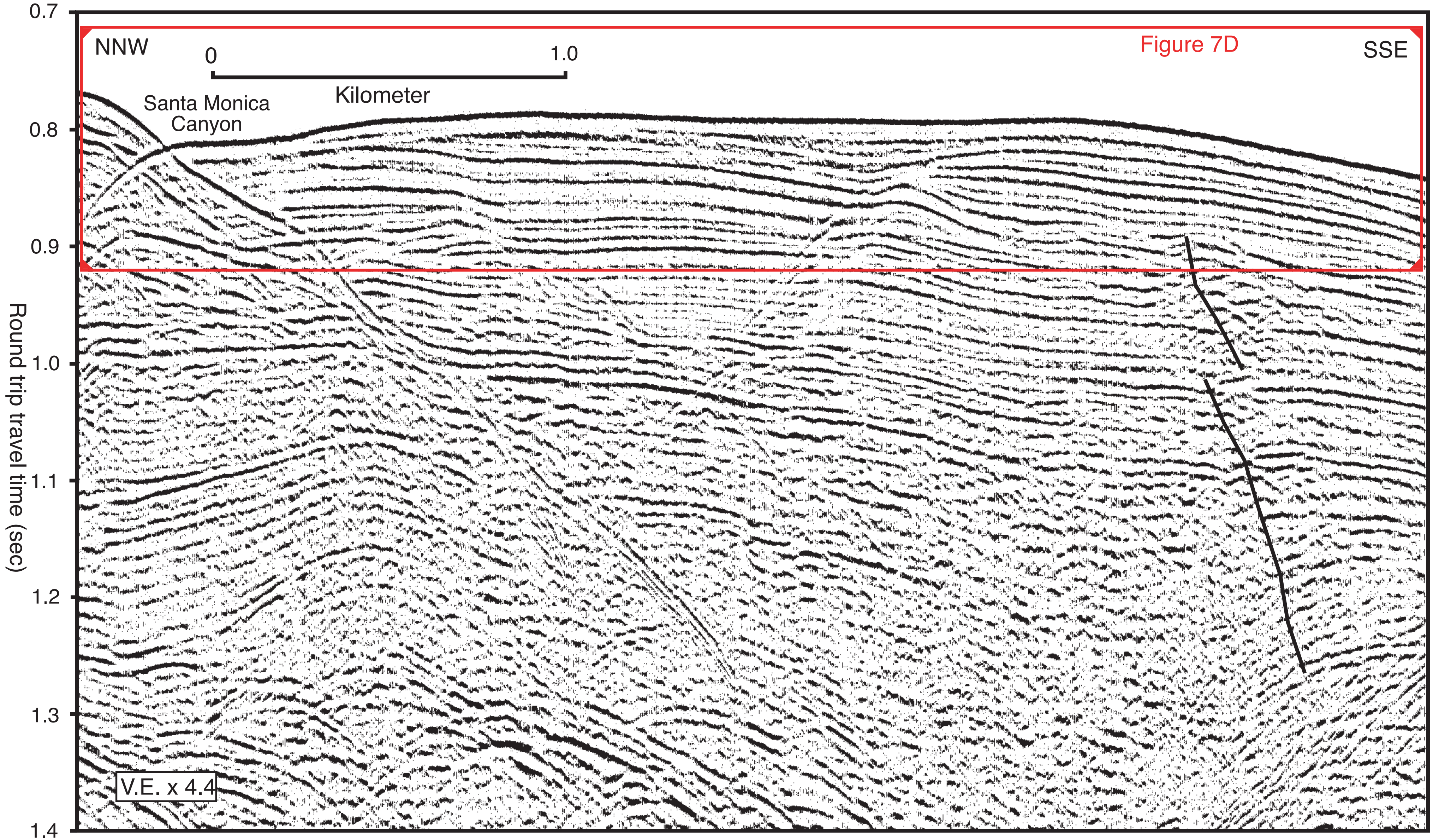
34°
118°
117° 30′
33° 30′
Point Dume
Newport Beach
Dana Point
Palos Verdes Peninsula
Fig. 8C
Figs. 7A,C
Figs. 7B,D
500m
Figs. 8B,E
Figs. 8A,D
Fig. 9
Santa Monica Basin
500m
Santa Catalina Island
Catalina Ridge
119°
33°30′
118°30′


FIGURE 6




line 30 part 1 ffid: 6244 - 6437
H time range: 226/2201-226/2235
V time range: 600ms - 1300ms
timing lines every 100 ms first line at: 700ms
24m shot interval = 1200m every 50 ffids
Variable area plot  bandpass = 20-40-200-250
agc window = 200ms

FIGURE 7A




line 30 part 2 ffid: 6446-6607
H time range: 226/2235-226/2313
V time range: 700ms - 1400ms
timing lines every 100 ms first line at: 800ms
24m shot interval = 1200m every 50 ffids
Variable area plot bandpass = 20-40-200-250
agc window = 200ms

FIGURE 7B

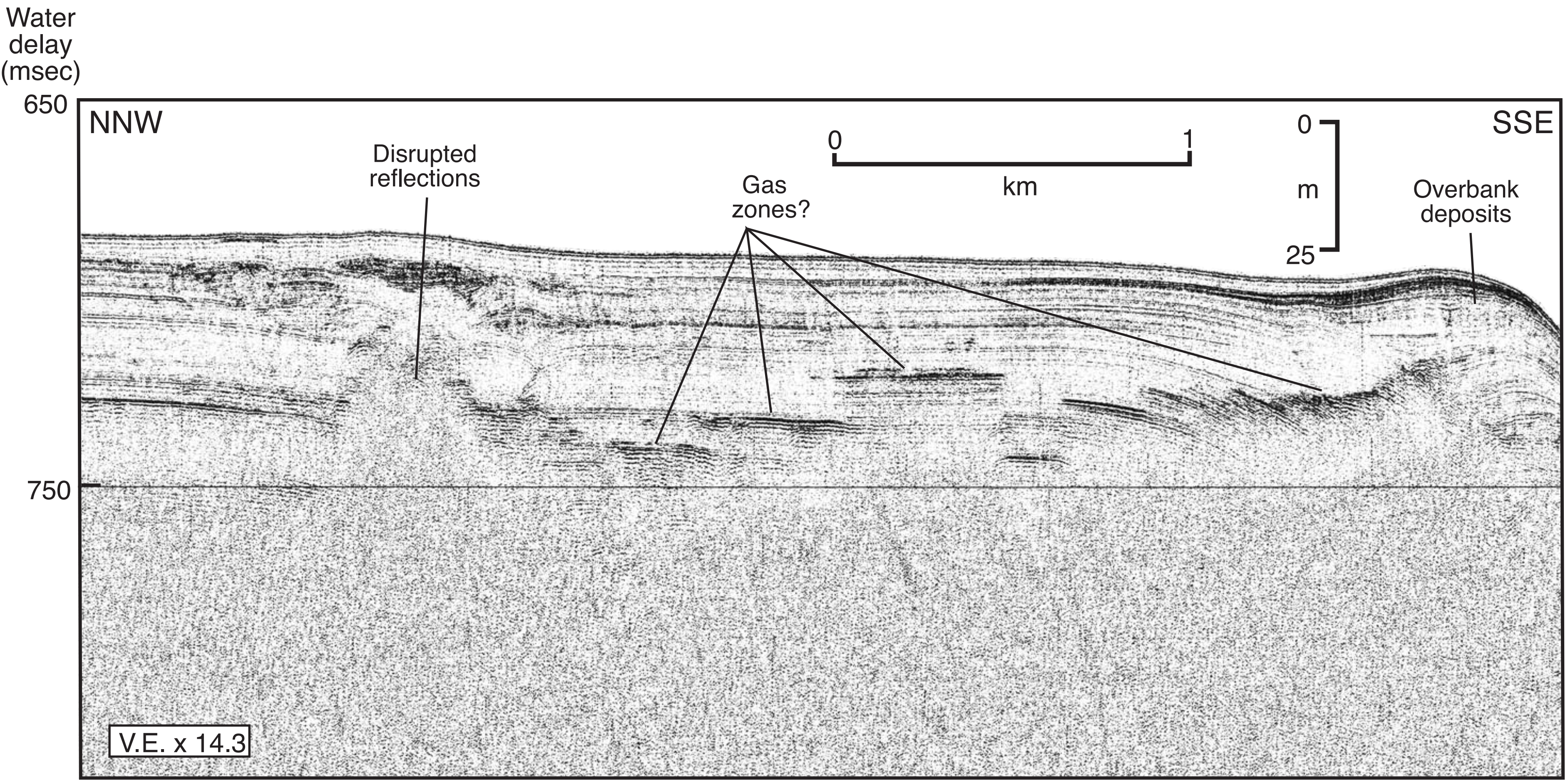
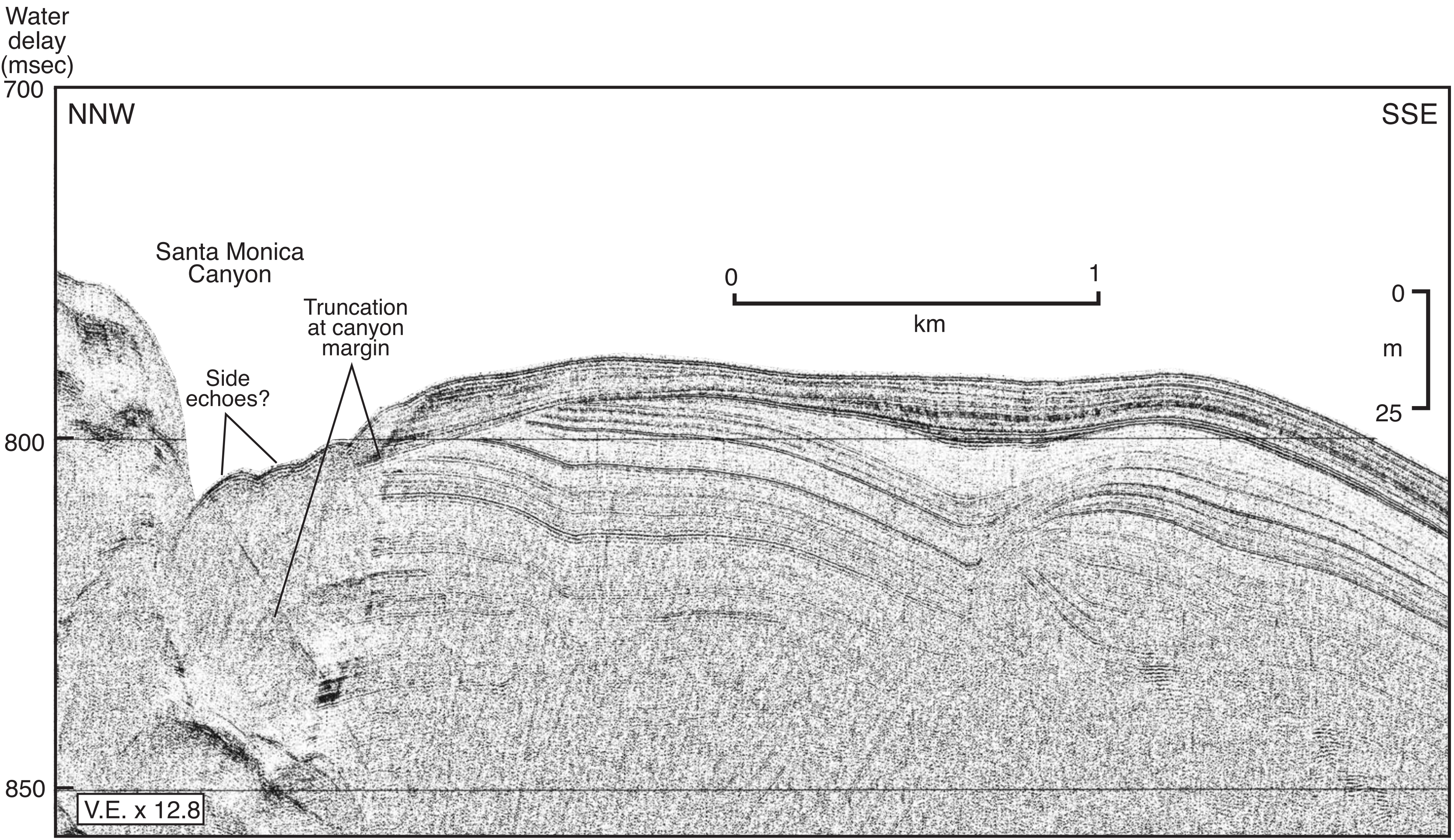
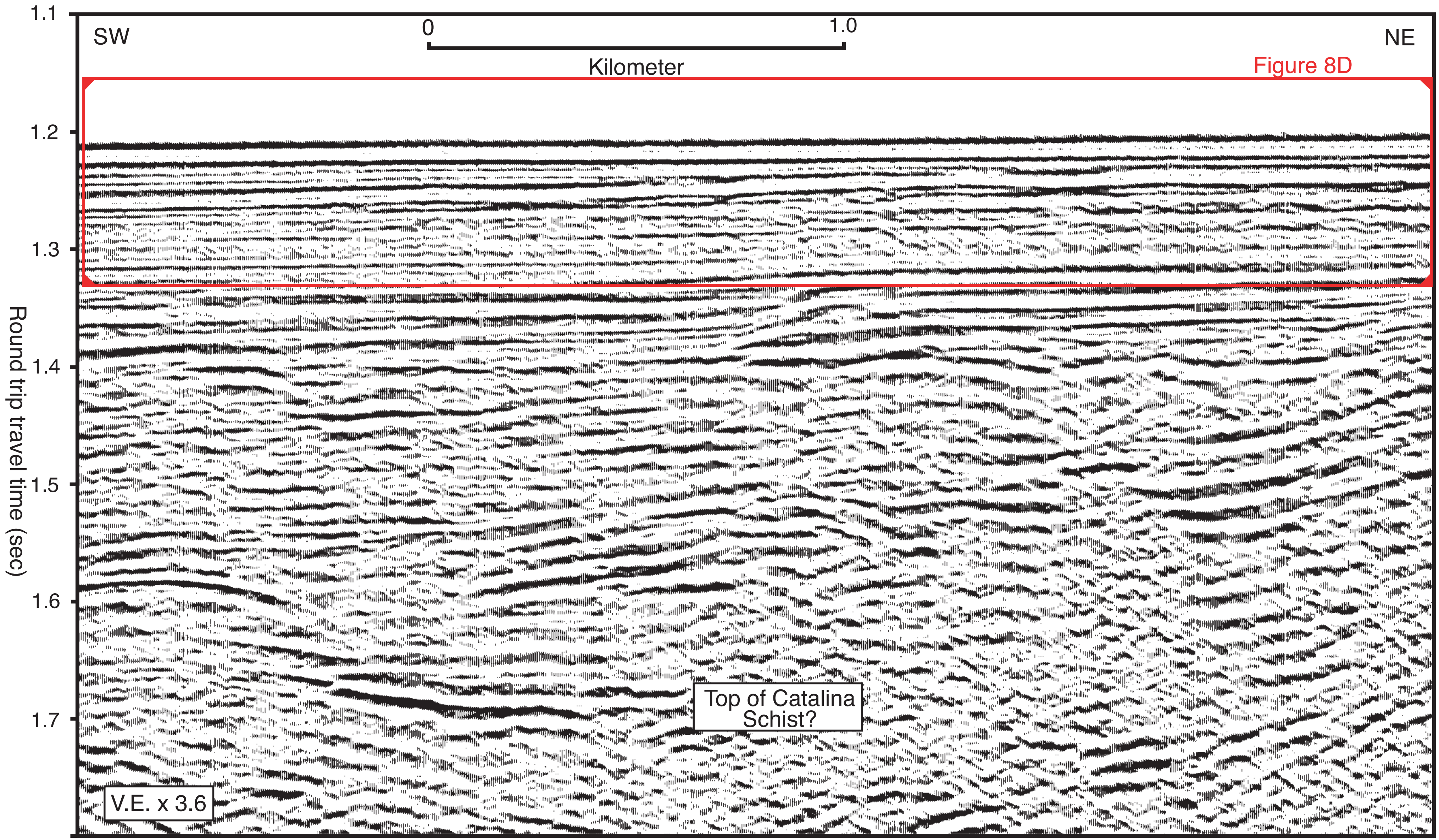

Water delay (msec)
650
750
NNW
SSE
Disrupted reflections
Gas zones?
0
1
km
0
m
25
Overbank deposits
V.E. x 14.3

FIGURE 7C



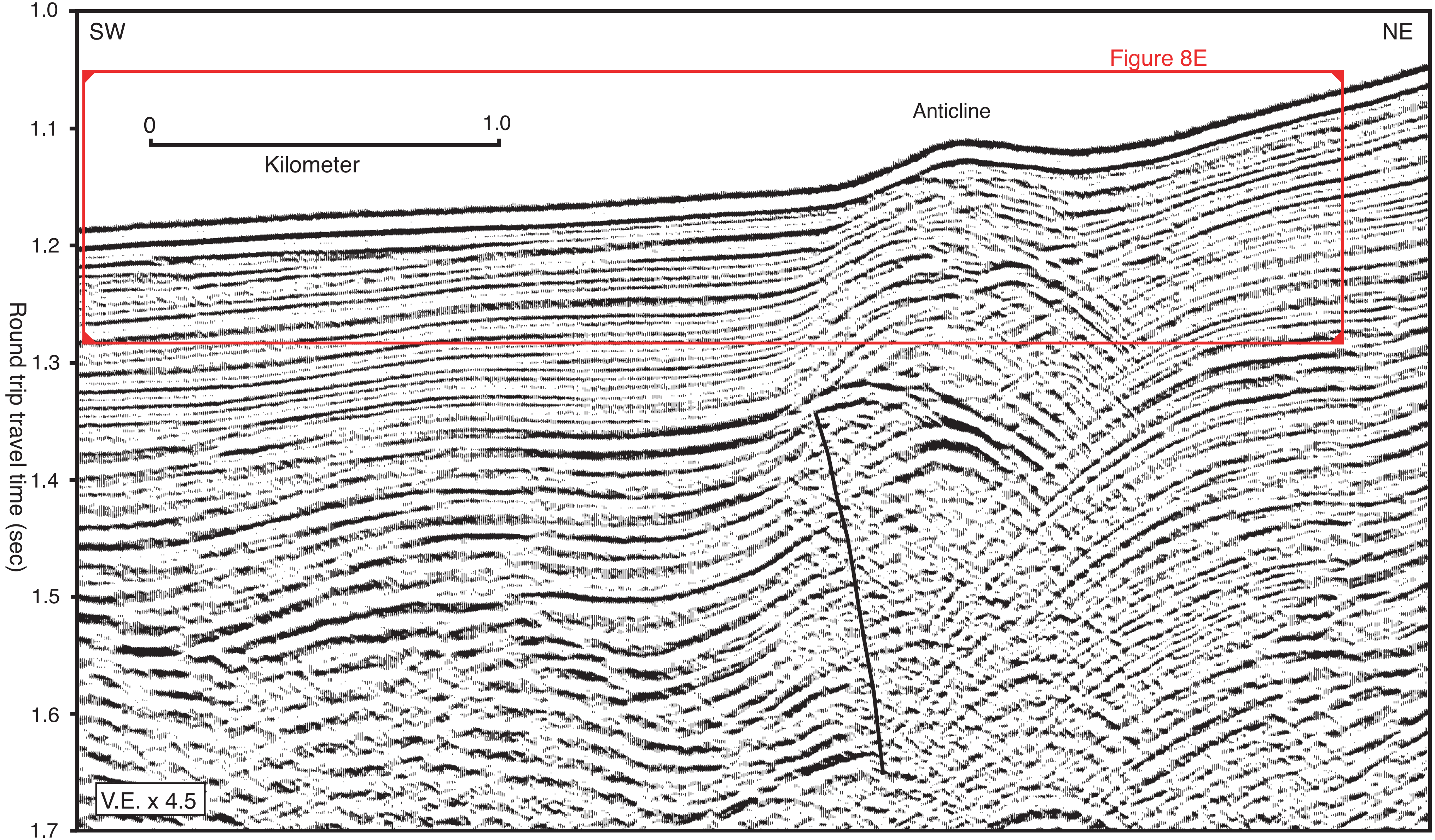
Water delay (msec)
700
800
850
NNW
SSE
Santa Monica Canyon
Truncation at canyon margin
Side echoes?
0
1
km
0
m
25
V.E. x 12.8


FIGURE 7D



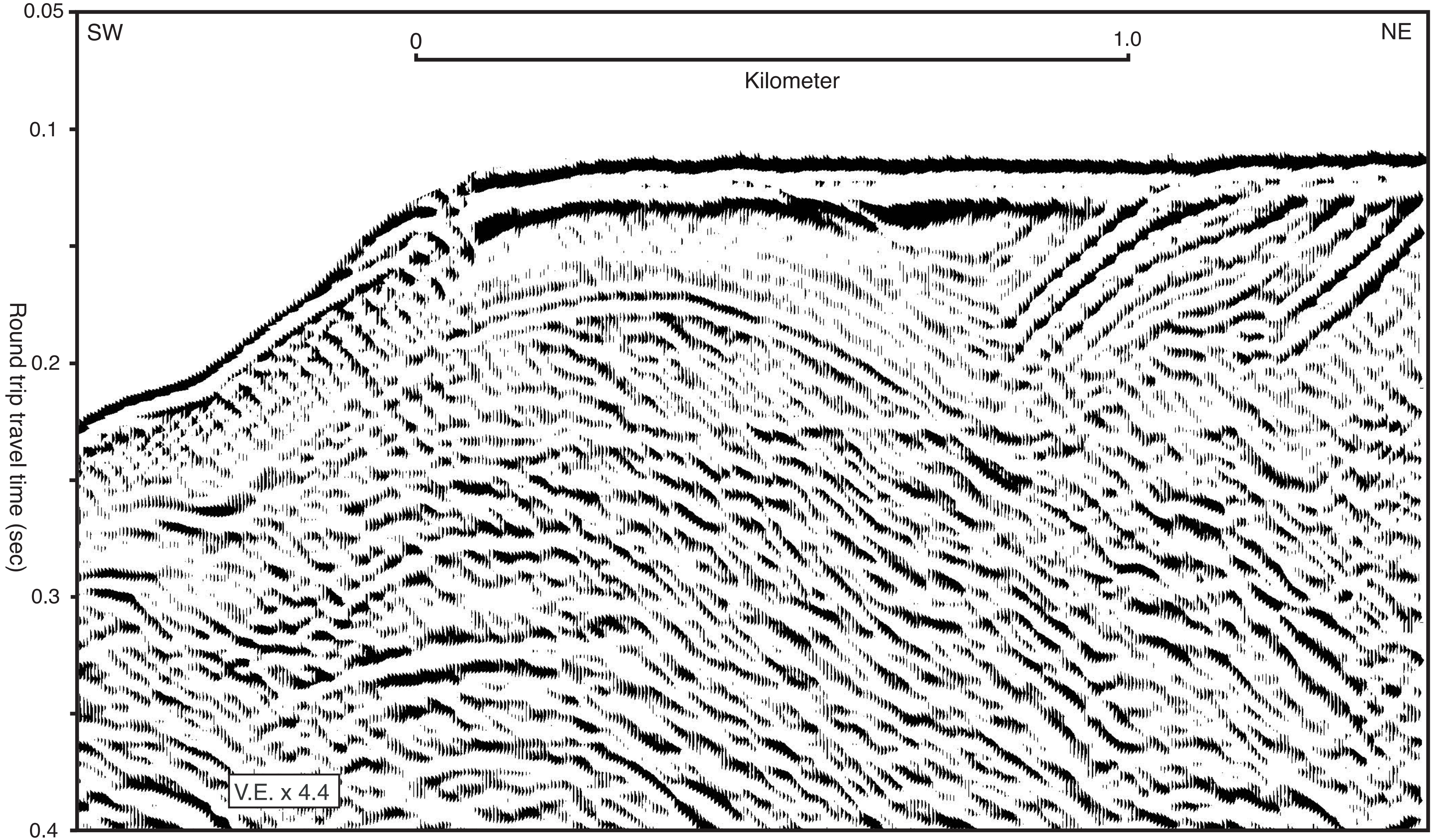

line 42 part 1 ffid: 1107 - 1241
H time range: 228/1635-228/1701
V time range: 1100ms - 1800ms
timing lines every 100 ms first line at: 1200ms
24m shot interval = 1200m every 50 ffids
Variable area plot  bandpass = 20-40-200-250
agc window = 200ms

FIGURE 8A




line 42 part 2 ffid: 1305 - 1454
H time range: 228/1714-228/1744
V time range: 1000ms - 1700ms
timing lines every 100 ms first line at: 1100ms
24m shot interval = 1200m every 50 ffids
Variable area plot bandpass = 20-40-200-250
agc window = 200ms

FIGURE 8B




line 42 part 3 ffid: 1679 - 1757
H time range: 228/1833-228/1848
V time range: 50ms - 400ms
timing lines every 100 ms first line at: 100ms
24m shot interval = 1200m every 50 ffids
Variable area plot bandpass = 20-40-200-250
agc window = 200ms

FIGURE 8C

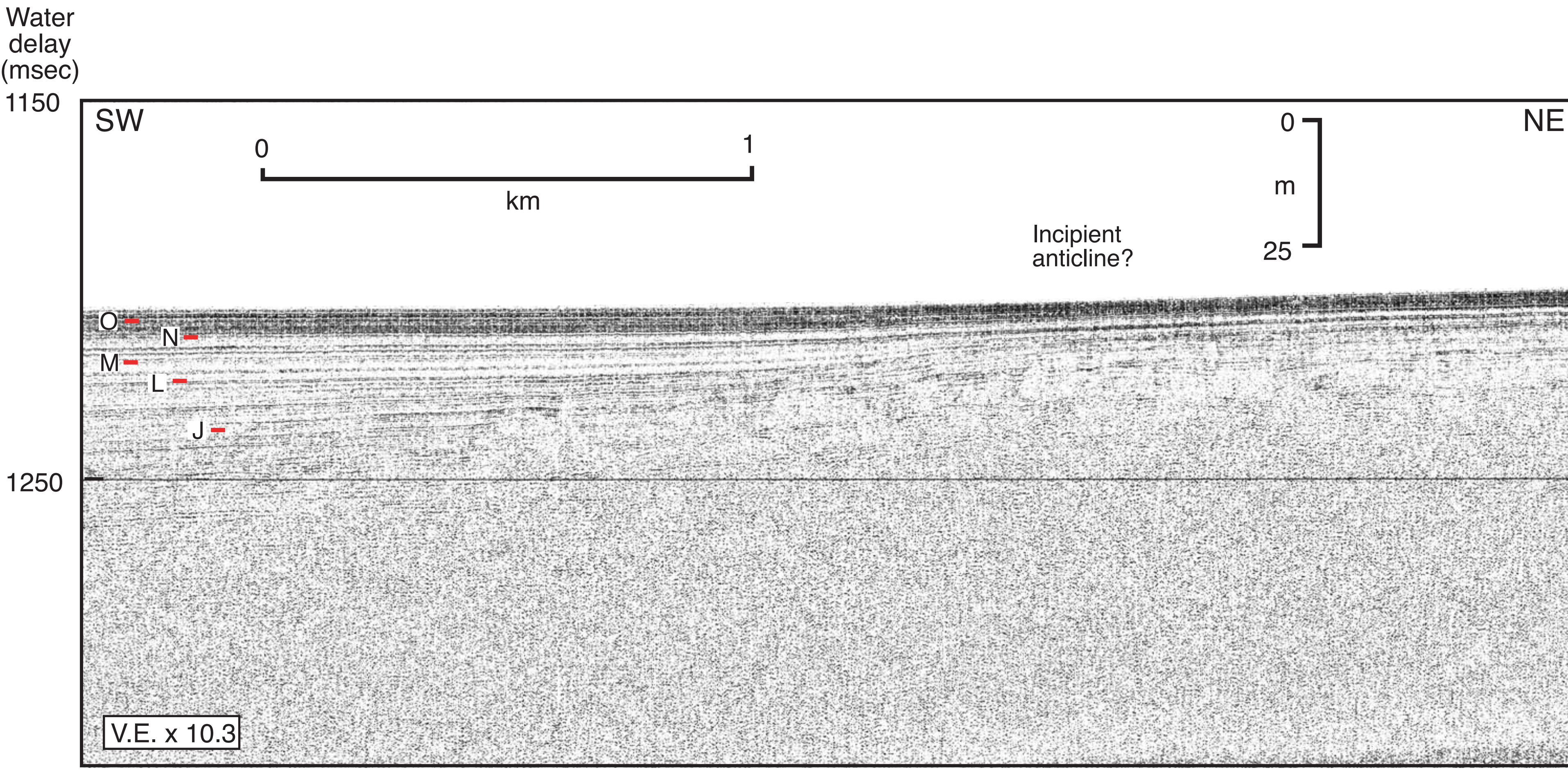

Water delay (msec)
1150
1250
SW
NE
0
1
km
0
m
25
Incipient anticline?
O
N
M
L
J
V.E. x 10.3

FIGURE 8D

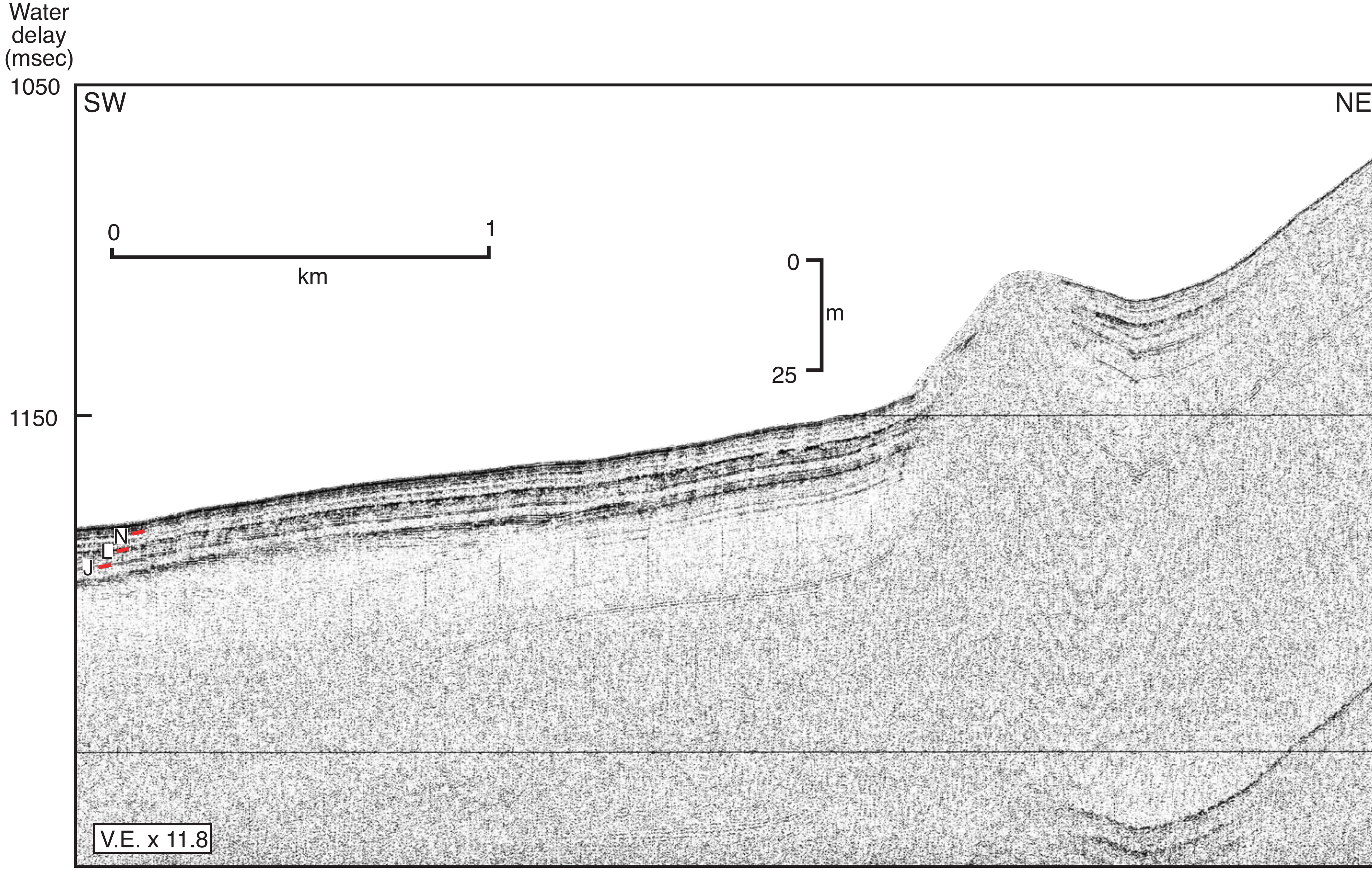
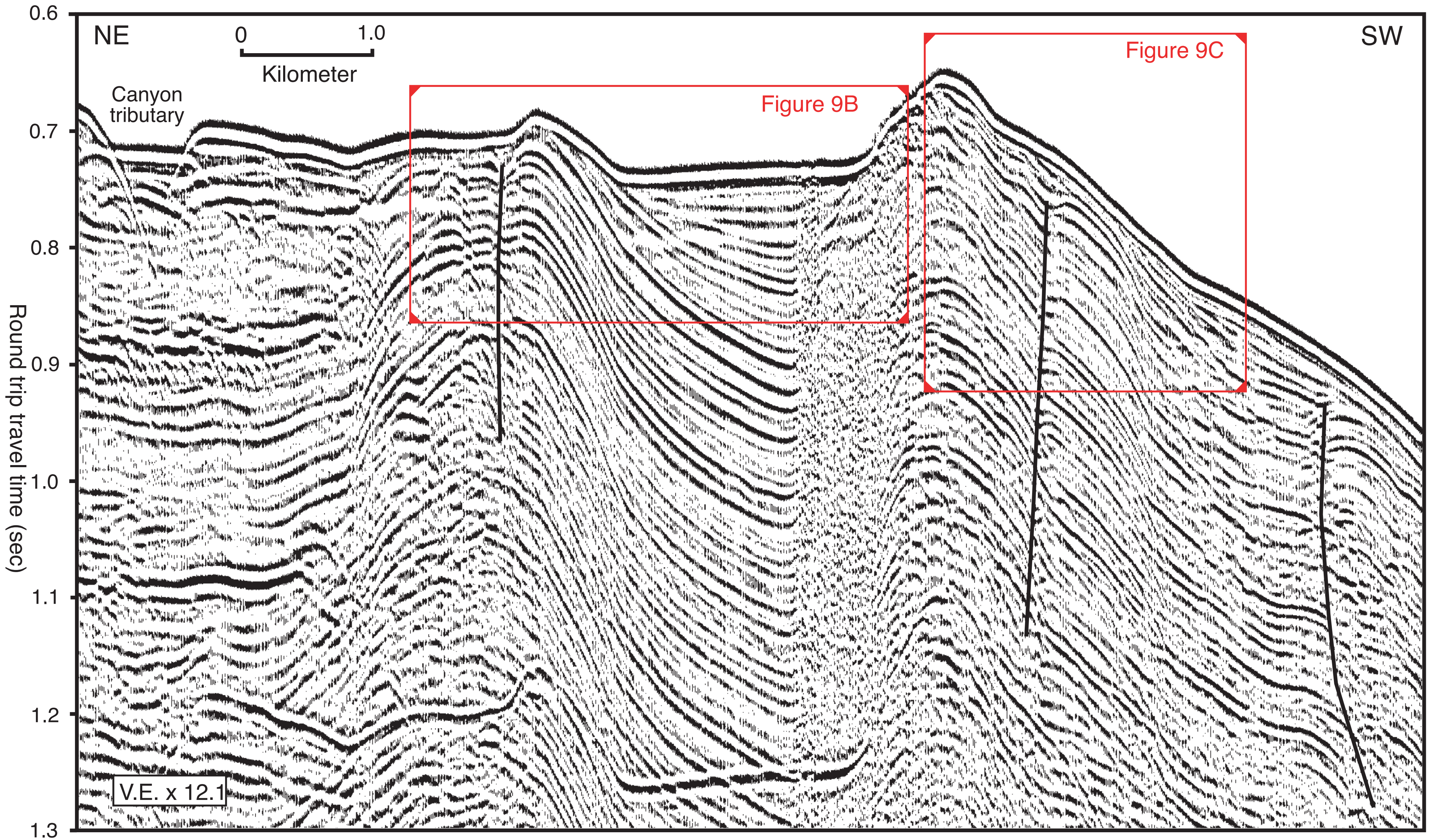



FIGURE 8E




line 83  ffid: 3154 - 4024
H time range: 234/1715-234/1844
V time range: 400ms - 1100ms
timing lines every 100 ms first line at: 500ms
12m shot interval = 600m every 50 ffids
Variable area plot  bandpass = 20-40-200-250
agc window = 200ms Adjacent traces stacked....2:1

FIGURE 9A

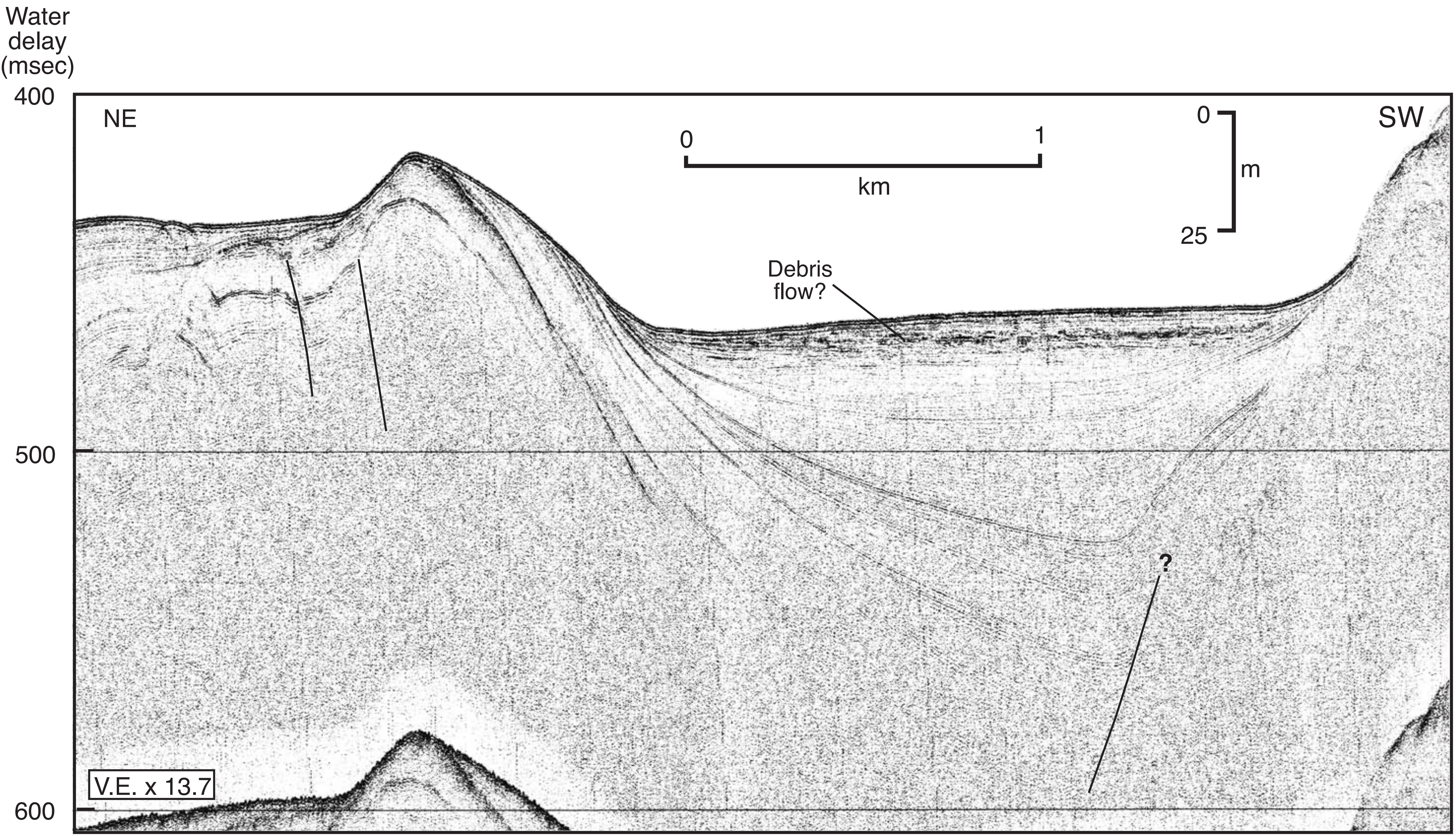

Water delay (msec)
400
500
600
NE
SW
0
1
km
0
m
25
Debris flow?
?
V.E. x 13.7

FIGURE 9B

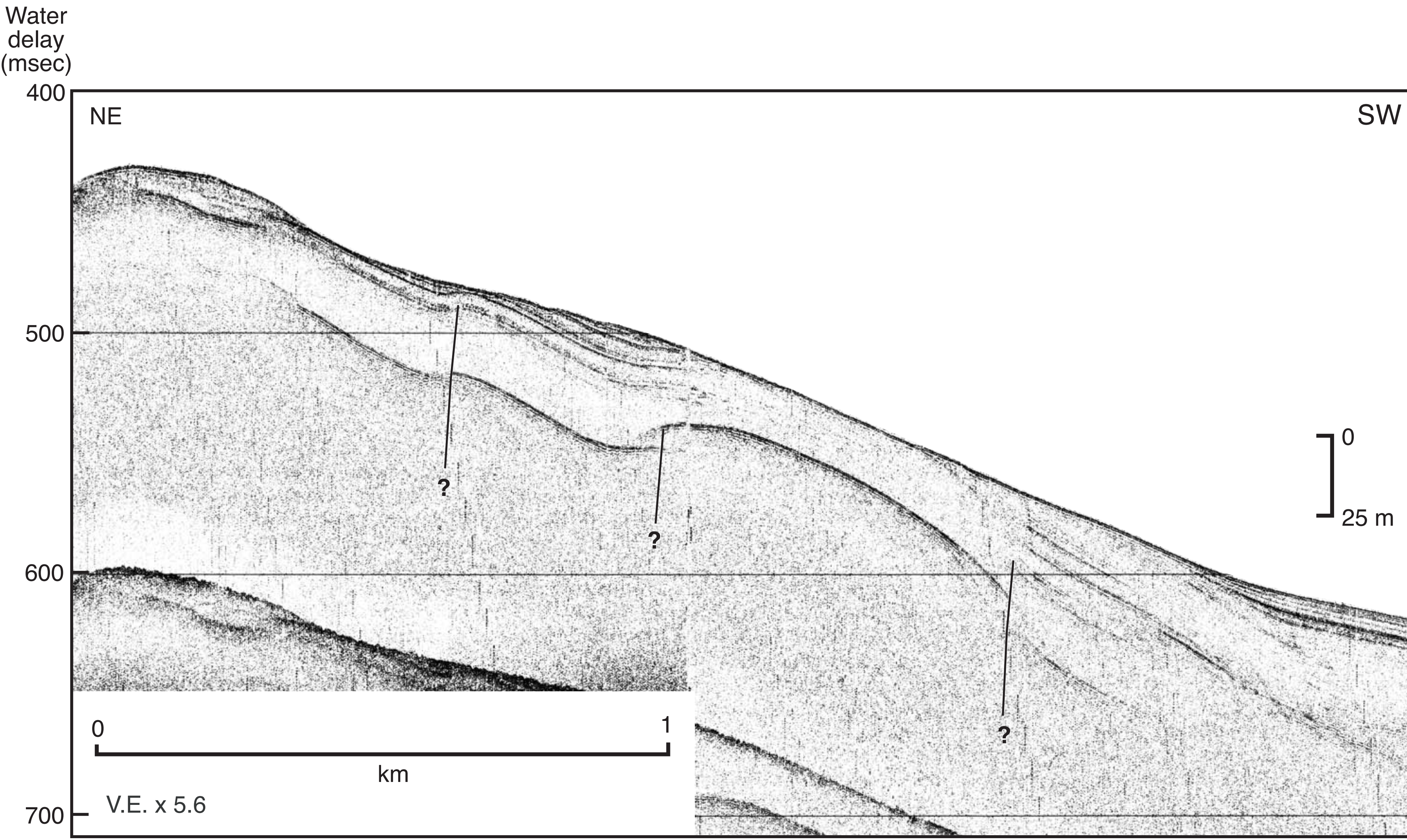



FIGURE 9C

## Table 1. Scientific Personnel

| Name | Affiliation | Responsibilities |
|---|---|---|
| Bill Normark | USGS, Menlo Park, CA | Chief Scientist |
| Bob Bohannon | USGS, Menlo Park, CA | MCS watchstander |
| Gita Dunhill | USGS, Menlo Park, CA | Navigator and general watchstander |
| Larry Kooker | USGS, Menlo Park, CA | Electronics Technician |
| Jane Laursen | Aarhus Universitet, Aarhus, Denmark; USGS volunteer, Menlo Park, CA | Navigator and general watchstander |
| Walt Olson | USGS, Menlo Park, CA | Mechanical Technician |
| Fred Payne | USGS, Menlo Park, CA | Electronics Technician |
| Jennifer Quan | Cascadia Research Collective, Olympia, WA (contracted activity) | Marine Biologist; marine mammal observer |
| Lisa Schlender | Cascadia Research Collective, Olympia, WA (contracted activity) | Marine Biologist; marine mammal observer |
| Dave Scholl | Scientist Emeritus, USGS volunteer, Menlo Park, CA | MCS watchstander |
| Ray Sliter | USGS, Menlo Park, CA | MCS watchstander |
| Graham Standan | Geoforce Consultants; Dartmouth, Nova Scotia, Canada (contracted activity) | Technical support for Huntec deep-towed boomer |
| Hal Williams | USGS, Menlo Park, CA | Mechanical Technician |

## Table 2. Operational Log

Local time is 7 hours behind GMT

| DATE/TIME JD/GMT | ACTIVITY |
|---|---|
| 221/~1700 | M/V AURIGA arrives at Fish Harbor (berth #261) |
| 221/~2130 | Depart Fish Harbor |
| 222/~0130 | Launch Huntec deep-tow boomer |
| 222/0225 | Begin slow speed holding pattern near SOL 01 while compressor repairs are initiated; logged as SOL 00 for Huntec data |
| 222/0645 | Initiate survey with Huntec only. Based on forecast that compressor repairs would take many hours, made decision to survey objectives in Santa Monica Basin for which MCS data are not critical |
| 222/0900 | SOL 01; Huntec only |
| 223/1422 | EOL 11; this completes tie lines to ODP Site 1015 and lines requested for cruise A2-98-SC; SOL 12 using planned survey grid (Fig. 3B) |
| 223/~1900 | Call to compressor specialists suggests that we will need to return to port for repairs; set JD224/1600 (12 Aug./0900) |
| 224/1405 | EOL 16; pull in Huntec fish; underway to Fish Harbor |
| 224/1530 | Docked at Fish Harbor (berth #261) |
| 224/1930 | Depart Fish Harbor |
| 224/2000 | SOL 17; resume survey with Huntec only |
| 225/1733 | EOL 23; stop surveying and return to Fish Harbor for compressor repairs |
| 225/~1830 | Tie up at Fish Harbor, berth #261 |
| 225/~1930 | Depart Fish Harbor |
| 225/~2000 | Launch GI gun and start firing; work on tuning GI gun bubble suppression (see Appendix 1) |
| 225/2050 | Launch streamer; tow points for GI gun and streamer are too close to Huntec tow point, which is from middle of A-frame; change tow points for GI gun and streamer to outside of bulwarks |
| 225/2140 | Huntec back on; the change in tow points provides a satisfactory window for scope of Huntec tow cable. No seismic signal is received from the MCS streamer and the Geometrics recording system also isn't operational. After ~2.5 hours, it is discovered that extensive corrosion in a connector box at one end of the deck cable is the cause; connections to the preamps in streamer are gone. Bottom line: ITI did not repair streamer despite assurances of a quality-control check and a $10k charge. |
| 226/0018 | SOL 24; again with Huntec only. During this operation, modifications in the MCS recording system allow data to be stored on magneto-optical discs. Problem: not enough discs for both MCS and Huntec for rest of cruise. |

| DATE/TIME JD/GMT | ACTIVITY |
|---|---|
| 226/0526 | While underway on Line 26, start collecting multi-channel data using the backup streamer (see section on Equipment Review). Operational plan modified to reduce data rate: go to 1 ms sampling rate and limit to 3 sec data (pre-cruise plan was 0.5 ms and 4 sec.) |
| 226/1500 | Decide that we will have to return to port again; there are not enough optical discs and CDs on board to continue collecting multi-channel data, even with the reduced data rate. Geometrics system won't write to tape drives, therefore, data are not compatible with ProMax |
| 227/1521 | EOL 36; slow and pull gear to transit to Fish Harbor again. |
| 227/1625 | Arrive Fish Harbor. A good Samaritan, Fred Payne's supervisor while he worked for the FAA, agreed to pick up our Federal Express packages and deliver them to Fish Harbor. Unfortunately, the packages included only the items provided by Marine Facilities; the additional optical discs shipped from the manufacturer were not received. |
| 227/1742 | Depart Fish Harbor |
| 227/1902 | On station; slow to stream gear |
| 227/1931 | SOL 37 using both Huntec and multi-channel systems. Repairs started on the deck cable for the primary streamer. This repair requires a total rebuild of the connector box on the deck cable. |
| 228/~0600 | Slow ship to retrieve the backup streamer; deploy primary streamer; see section of Equipment Review for descriptions of streamers. Primary streamer works well; at this point, the survey begins utilizing the equipment planned for the cruise. |
| 228 | 'Standard' operations - survey with Huntec and multi-channel systems |
| 229 | 'Standard' operations until temporary shutdown of multi-channel system; compressor 4th-stage temperature sensor shuts down operation. Multi-channel system is off for about 1 hour. |
| 230/1500 | EOL 57. Pull in all gear; change to flank speed to meet Jon Childs for the sound-source parameter measurements. |
| 230/1720 | Change to steerage on station. J.Childs radios that he sees AURIGA; gear transfer for the sound-source measurements is completed by JD230/1800 (1100 18 Aug). |
| 230/2120 | GI gun source measurements completed. Launch Huntec for next experiment |
| 230/2150 | Complete Huntec source-parameter measurements |
| 231/0106 | Resume standard survey operations with Huntec and multi-channel system |
| 232/~2100 | Temporary shutdown of multi-channel system; compressor 4th-stage temperature sensor shuts down operation. Multi-channel system is off for about 1 hour. |

| DATE/TIME JD/GMT | ACTIVITY |
|---|---|
| 233/0142 | GI gun literally blew apart; Changed to Bolt 40 $in^3$ air gun with wave-shape kit; several hours lost because changeout included new hose packages and first air gun failed after brief operation; problem is failure of shaft-seal parts. |
| 233/0803 | Resume operations with the second Bolt air gun. |
| 233/1541 | Air gun broke --- also a shaft seal part; change to third air gun. |
| 233/1657 | New Bolt gun in use; resume multi-channel survey |
| 235/0403 | EOL 86; pull in gear for last time. |
| 235/0610 | Dock at berth #147 - West Basin, Terminal Island |
| | A1-98-SC scientific party disembarks |

## Table 3. Menus and preferred system settings for GI gun operation
(from Sureshot Program Control menus)

FN1-Changes system modes and info at bottom of screen
FN2-Changes Q/C parameters and graphic scales
FN3-Changes system timing info
FN4-Changes individual Gun parameters
FN5-View line statistics for each Gun

| | | |
|---|---|---|
| **Q/C Parameters FN2** | | |
| Delta Error Q/C | 1.0 +/- msec | "Window around Aim Point that sensor return should fall" |
| Min Vol Q/C | 48 | "Minimum volume of shot" |
| Trace Start | 15 msec | "Number of msecs after trigger where sensor display begins" |
| Graphic Scale | 10 +/- volts | "Full scale values for sensor graphics" |
| Error Count Q/C | 3 | "Number of bad shots before trace turns from yellow to red" |
| Print Errors | OFF | "Off/On for error printing at each shot" |
| Trace Length | 180 msec | " Number of msecs of sensor to display" |
| **Timing Parameters FN3** | | |
| Aiming Point | 50 msec | "Time in msec after trigger when sensor signature will be aligned" |
| S.P. Interval | 1 | "Shot point increment value" |
| Peak Look Window | 10 +/- msec | "Window around aim point to look for signature" |
| Fire Pulse Width | 60 msec | "Width in msec of solenoid fire pulse" |
| Peak Threshold | 1.5 volts | "Voltage level sensors must cross to detect a sensor return" |
| Bubble Look Window | 40 +/- msec | "Window around aim point to look for signature" |
| Number of Guns | 1 | "Number of Gun sensor channels" |
| Gun Type | G I | "Norm (one chamber) or GI (two chamber)" |
| Peak Detection Method | Peak | "Method of sensor time pick; *Peak*, *Zero* crossing or threshold *Level*" |
| Auto/Fire Threshold | 4.0 volts | "Voltage level sensor must cross to declare an auto fire" |
| Bubble Threshold | 1.5 volts | "Voltage threshold for bubble detection" |
| **Gun Parameters FN4** | | |
| Mode | auto | "*Off*-no detection, *Spare*- no firing but autofire detection. *Manual*-firing but gun delay is not automatically adjusted. *Auto*-firing and gun delay is automatically adjusted" |
| Delay | 12.4 | "Time before the aim point at which the solenoid (Generator-GI Mode) will be Activated" Operator sets initially then program adjusts as needed. |
| Offset | 0.0 | "Deviation from aim point" |
| Gain | 3.0 | "Linear gain constant applied to sensor signal" |
| Invert | Invert | "Select *Norm* or *Invert* to invert sensor signal" |
| Volume | 35 | "A gun volume is defined here in whatever units you desire" |
| Injector Delay | 25 | "Delay in msecs after aim point when Injector solenoid will fire" |
| Bubble Period | 70 | "Delay after aim point where mid-point of bubble look window is found" *Note- GI manual says this delay should be ~ 42 msecs for 35/35 cu in @ 3000psi* |

Some values were changed mid cruise before the GI gun self destructed. Bubble threshold set to 2.5 volts, injector delay set to 23 msec. Next time out we will have to play with the bubble period to see if GI manual is really correct.

# Table 4. Locations of cruise data

**Web sites:**

| | |
|---|---|
| General cruise operational information: | http://walrus.wr.usgs.gov/infobank/a/a198sc/html/a-1-98-sc.meta.html |
| Survey line information: | http://walrus.wr.usgs.gov/infobank/a/a198sc/nav/a-1-98-sc.nav_lines |
| Navigation data: | http://walrus.wr.usgs.gov/infobank/a/a198sc/nav/a-1-98-sc.065 |
| Equipment shutdown | http://walrus.wr.usgs.gov/infobank/a/a198sc/nav/a-1-98-sc.nav_lines |

**Within this report:**

| | |
|---|---|
| Table 1 | A1-98-SC scientific party |
| Table 2 | Operational log |
| Table 3 | Sureshot control settings |
| Appendix 1 | Cascadia Research Collective report on mammals |

# Appendix 1

USGS OF 99-152

Report prepared by

Cascadia Research Collective

Under contract to the USGS in support of

Cruise A1-98-SC

Cascadia Research Collective
a non-profit research organization

Research: (360) 943-7325
Computer counsulting: (360) 943-7640
FAX: (360) 943-7026

**FINAL REPORT**

# MARINE MAMMAL OBSERVATIONS AND MITIGATION ASSOCIATED WITH USGS SEISMIC SURVEYS IN THE SOUTHERN CALIFORNIA BIGHT IN 1998

**Prepared for**

**U.S. Geological Survey**
**345 Middlefield Rd.**
**Menlo Park CA 94025**

**Prepared by**

**John Calambokidis**
**Lisa Schlender**
**Jen Quan**

**Cascadia Research**
**218½ W Fourth Ave.**
**Olympia, WA 98501**

**December 1998**

Waterstreet Building 218½ West Fourth Ave. Olympia, Washington 98501

# INTRODUCTION

From 9 to 22 August 1998, the U.S. Geological Survey conducted seismic surveys in the Pacific Ocean just off Los Angeles to investigate earthquake hazards. Details on the purposes and specifications of the equipment used are described below. 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. We report here the results of this marine mammal mitigation and monitoring program conducted in conjunction with the USGS Los Angeles surveys.

# BACKGROUND ON OVERALL PROJECT AND SOUND SOURCE DESCRIPTION

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

The focus of the Southern California Earthquake Hazards project is to identify the landslide and earthquake hazards and related ground-deformation processes that have the potential to impact the social and economic well-being of the inhabitants of the Southern California coastal region. The primary objective is to help mitigate the earthquake hazards for the Southern California region by improving our understanding of how deformation is distributed (spatially and temporally) in the offshore with respect to the onshore region.

The active field program for the project focuses on those areas with the greatest impact potential on the Southern California populace:

1) The coastal strip (coastal zone and continental shelf) between Los Angeles and San Diego, where much of the hazard appears to be associated with strike-slip or oblique-slip faults;
2) Active faults within the Santa Monica, San Pedro, and San Diego Trough basins, where more extensive sedimentation has left a greater stratigraphic record;
3) The offshore extension into the Santa Barbara Channel of the fold and thrust belt;
4) The boundary (Channel Islands region) between the inner California Borderland (strike-slip dominated deformation) and the Santa Barbara Channel (thrust and fold deformation).

Tracklines were planned at a 2 km spacing aligned perpendicular to the shelf break and basin slope and on an "orthogonal" set aligned to intercept major structural features that are oblique to the trend of the basin slope and shelf edge.

The FY 1998 field program was conducted using a leased vessel, the 156-ft-long M/V AURIGA, owned and operated by F/V North Wind, Inc. Two sound transmissions were used:

Huntec: A high-resolution Huntec DTS boomer system, towed between 6 m and 160 m below the sea surface (depending upon the water depth), was used to image the upper few tens of milliseconds of strata with a resolution of better than 0.5 ms (0.4 m). Power output was 350 Joules (540) with a firing rate that was also dependent on water depth, ranging in 0.25 sec intervals from 0.75 sec over the shelf and upper basin slopes to 1.25 sec over the deeper parts of the basins. Returning signals were received with a 5-m-long Benthos 10-element hydrophone array. Signals were filtered at 800-6000 Hz and recorded at a 0.25 sec sweep. The data were recorded both on paper using an EPC recorder and on magneto-optical disc. The average survey speed of about 3.8 kt (7 km/hr) resulted in a shot spacing between 1.5 and 2.5 m for the deep-tow boomer profiles.

Multichannel seismic-reflection system (MCS): As a result of equipment problems, the multichannel seismic-reflection (MCS) profiling activity during the cruise used two different sound sources and two different streamers to receive the signals. The primary sound source was a 35/35 $in^3$ double-chamber GI gun firing every 12 seconds at a pressure of about 3000 psi. A Sureshot system was used 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. The most efficient settings for the Sureshot control are given in (Table 3). The GI gun was towed 5 meters behind the vessel and suspended from a float to maintain a depth of about 1 meter. Catastrophic failure of the gun resulted in changing to the backup sound source, a 40 $in^3$ Bolt airgun, which was deployed for the last 48 hours of data collection. This airgun, which had a wave-shape kit to reduce the effect of the bubble pulse, was towed at a depth of about 4 meters using 2000 psi air pressure and fired at a six-second shot rate.

The primary streamer for the mcs operation was a 24-channel ITI streamer with 10-m-long groups and 3 phones per group. This streamer was unusable for the first part of the survey because of extensive corrosion of the wiring in the termination box of the deck cable. The backup receiving system, a 24-channel ITI streamer with 6.25 m groups and 1 phone per group was used initially until repairs could be effected on the primary streamer. Failure of the GI gun late in the survey as noted above meant that three combinations of sound source and streamers were used during the operation: primary sound source with backup streamer, primary sound source and streamer, and backup sound source with primary receiver.

Data was collected using a STRATAVIEW digital recording system and a Geometrics marine controller. Shots were triggered by the YoNav system. Data was recorded in SEGD format on 2-gbyte DAT tapes using a 1 msec sample rate and a three second record length. A 60-Hz notch filter was used, otherwise all frequency bands were passed. A total of approximately 250 hours (20 gigabytes) of data were collected.

## OBJECTIVES

The objectives of the marine mammal study were as follows:

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

2. Mitigate impacts by identifying potentially sensitive areas to marine mammals that should be avoided or surveyed only during daylight hours.

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

4. Evaluate the reactions of marine mammals to the sound transmissions at different distances from the air gun array.

## METHODS

### General Approach

The research effort consisted of observations made directly from the seismic vessel (*Auriga*) to provide mitigation, document marine mammals exposed to the air guns, and monitor reactions of marine mammals close to the seismic survey vessel. Observations were conducted from a platform in front of the bridge that put the observers eye level at 7.6 m above the water. This external platform provided excellent visibility to the front and sides and only slightly obscured visibility to the rear. The platform was near the front of the vessel 6.4 m behind the bow and 47 m from the stern of the vessel.

Observations were conducted from the seismic vessel (*Auriga*) 24 hours a day when seismic operations were underway. Two observers were placed about the seismic vessel to provide the mitigation described above and gather data on the species, number, and reaction o marine mammals to the seismic vessel. Each observer worked during six hours of daylight and six hours of darkness. During daylight observations, observers used *Tasco 7x50* binoculars with internal compasses and reticles to record the horizontal and vertical angle to sightings. Night-time operations were conducted with a commercial hand-held light magnification scope. Observers would search the area close forward and to either side of the ship for marine mammals.

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

Distances to sightings were calculated using the vertical angle to the animal (based on either the reticle reading through the binoculars or a hand help 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 safety zones

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

1. For pinnipeds and Odontocetes (toothed cetaceans) seismic operations would be shut down when an animal was seen close to a distance of 100 m or less.

2. For mysticetes (baleen whales), the safety zone was 200 m.

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

Observers were instructed to call for a shut-down when a marine mammal was seen inside the safety zone or close enough to the safety zone that given measurement-error, it could be within the safety zone. Shut-down was also considered when animals were ahead of the vessel path outside the safety zone, but it appeared likely that the direction of travel of the vessel would result in the marine mammal being within the safety zone shortly.

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

## RESULTS AND DISCUSSION

### Shut-downs for marine mammal mitigation

Seismic operations were requested to be shut down on eleven occasions related to the presence of marine mammals (Table 1). All requested shutdowns were because animals were in close proximity to the seismic vessel. Eight of the shut-downs were for common dolphins (five of them approaching to bow-ride) and three were for California sea lions.

Only 3 of the 11 shut-downs were requested at night. This likely reflected the poorer sighting conditions at night that made it hard to spot marine mammals even within the safety zones. Two of these three shut-downs were due the presence of dolphins riding the bow wave of the vessel.

### Sightings made by vessel

There were 133 sightings of 6,313 marine mammals not including the 98 re-sightings made from the *Auriga* during the surveys (Table 2). These represented at least eight species of marine mammals. Common dolphins and California sea lions were most frequently sighted. Other large whale species included humpback and minke whales and several sightings of blue and possibly fin whales made at long distances from the vessel. Other smaller cetaceans besides common dolphins included Cuvier's beaked whale, Risso's dolphin, and either a Dall's or harbor porpoise. The only other pinniped seen beside California sea lions was northern fur seals.

Sightings at night were far less common with only the three sightings close to the boat that resulted in shut-downs. These involved common dolphins bowriding that could be heard and a California sea lion.

### Orientation and behavior of marine mammals

A disproportionate number of marine mammals were headed away from the vessel as opposed to toward the vessel or perpendicular to the direction to the vessel (Table 4). For both sightings and resightings animals were headed away about twice as often as any of the other three direction quadrants. Most of the survey effort was conducted with either the Huntec operating or both the Huntec and airgun operating. This makes it hard to evaluate whether animals were reacting to the vessel or one or both of the sounds generated.

Marine mammals were sighted engaged in a variety of behaviors (Table 5). The majority of sightings and resightings were of animals judged to be either fast or slow traveling. The next most common behavior was hauled (many of the California sea lions). Animals were also seen milling, surfacing in the same area, and likely indicating feeding. Common dolphins were seen bowriding on six occasions. A number of less common behaviors were seen including a minke whale lunge feeding and a humpback that was seen breaching on five occasions. It was not possible to judge if any of these behaviors could have been related to survey activities.

## DISCUSSION

The species encountered during the surveys is consistent with what would be expected in the region. Both common dolphins and California sea lions are considered the most common marine mammals in nearshore waters of Southern California. Sightings of unidentified dolphins were also likely common dolphins seen at distances that did not allow species identification. Both Risso's dolphins and Cuvier's beaked whales, seen a few times in the study, are more typical of deeper waters off the continental shelf edge. The sighting of a potential harbor porpoise was surprising and was scored as a possible Dall's porpoise primarily because harbor porpoise are generally considered to not occur south of Point Conception.

The sightings of several large balaenopterid whales are of interest and indicate these species were present in the study area despite the proximity of the surveys to shore. Humpback, blue, and fin whales are the most common large baleen whales that feed off California. Recent photographic identification research conducted by Cascadia has indicated a population of about 800 humpback whales feeding off California each summer (Calambokidis et al. 1996, 1997). Most of these are generally concentrated from the Santa Barbara Channel north during the summer. About 2,000 blue whale are estimated to feed off California, one of the areas of highest blue whale density anywhere in the world (Calambokidis and Steiger 1995, 1997).

## CONCLUSIONS AND RECOMMENDATIONS

Overall, the surveys provided valuable information on the species of marine mammals present in the survey area. They also provided some protection from potential impacts through shut-downs when marine mammals were observed close to the survey vessel. Although sample size was small these surveys yielded data on the reactions of several species to a survey vessel. Night-time operations were of limited value in sighting marine mammals or making observations of reactions of marine mammals. The few sightings made at night resulted in three shut-downs, which provided some mitigation of impacts. The low number of sightings and shut-downs at night, however, indicated these observations were of only limited effectiveness. In the future it would be more effective to better staff daylight shifts and not risk compromising these observations for the limited effectiveness of night observations.

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Table 1. Cases where air gun/Huntec shut-downs were requested due to marine mammal occurrence.

| Date | Time | Resume firing | Firing | Reason for request | Comments |
|---|---|---|---|---|---|
| 08/11/98 | 9:31:00 | 9:36:00 | Huntec | Proximity of California sea lion | |
| 08/12/98 | 3:16:00 | | Huntec | Bowriding dolphins | Auth. shut-down personnel not in lab |
| 08/12/98 | 18:50:00 | 18:59:00 | Huntec | Bowriding common dolpins | |
| 08/15/98 | 2:06:00 | 2:09:00 | Huntec | Proximity (<100m) of California sea lion | |
| 08/15/98 | 21:55:00 | 21:57:00 | Huntec/Airgu | Bowriding dolphins | |
| 08/16/98 | 9:32:00 | 9:35:00 | Huntec/Airgu | Proximity of California sea lions | |
| 08/17/98 | 11:34:00 | 11:40:00 | Huntec/Airgu | Proximity of common dolphins | |
| 08/17/98 | 11:59:00 | 12:07:00 | Huntec/Airgu | Proximity of common dolphins | |
| 08/21/98 | 9:18:00 | 9:26:00 | Huntec | Proximity of common dolphins | |
| 08/21/98 | 17:58:00 | 18:04:00 | Huntec/Airgu | Bowriding common dolpins | |
| 08/22/98 | 12:12:00 | 12:16:00 | Huntec/Airgu | Bowriding common dolpins | |

Table 2. Summary of sightings and resightings of difference species during daylight and night observations.

| | Daylight observations | | | | Night obs. | | Total day and night | |
|---|---|---|---|---|---|---|---|---|
| | Sighting | | Resighting | | Sightings | | Sightings | |
| Species | Sight. | Anim. | Sight. | Anim. | Sight. | Anim. | Sight. | Anim. |
| Humpback whale | 1 | 1 | 6 | 6 | | | 1 | 1 |
| Minke whale | 4 | 4 | 2 | 2 | | | 4 | 4 |
| Large Balaenopterid (blue or fi | 3 | 3 | 4 | 4 | | | 3 | 3 |
| Cuvier's beaked whale | 1 | 1 | | | | | 1 | 1 |
| Unidentified whale | 1 | 1 | | | | | 1 | 1 |
| Common dolphin | 32 | 3,981 | 48 | 6,555 | | | 32 | 3,981 |
| Risso's dolphins | 1 | 8 | 1 | 8 | | | 1 | 8 |
| Unidentified porpoise | 1 | 5 | 1 | 5 | | | 1 | 5 |
| Unidentified dolphin | 22 | 2,155 | 18 | 1,746 | 2 | 4 | 24 | 2,159 |
| California sea lion | 61 | 144 | 18 | 43 | 1 | 2 | 62 | 146 |
| Northern fur seal | 2 | 2 | | | | | 2 | 2 |
| Unidentified pinniped | 1 | 2 | | | | | 1 | 2 |
| Grand Total | 130 | 6,307 | 98 | 8,369 | 3 | 6 | 133 | 6,313 |

Table 3. Daytime sightings (not including resightings) by operational status of airgun and Huntec.

| Species | None firing | | Huntec only | | Airgun only | | Huntec & airgun | | Total | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sight. | Anim. | Sight. | Anim. | Sight. | Anim. | Sight. | Anim. | Sight. | Anim. |
| Humpback whale | | | | | | | 1 | 1 | 1 | 1 |
| Minke whale | | | 1 | 1 | | | 3 | 3 | 4 | 4 |
| Large Balaenopterid (blue or fin) | | | 2 | 2 | | | 1 | 1 | 3 | 3 |
| Cuvier's beaked whale | | | | | | | 1 | 1 | 1 | 1 |
| Unidentified whale | | | | | | | 1 | 1 | 1 | 1 |
| Common dolphin | 3 | 498 | 11 | 1620 | 2 | 95 | 16 | 1768 | 32 | 3981 |
| Risso's dolphins | | | | | | | 1 | 8 | 1 | 8 |
| Unidentified porpoise | | | | | | | 1 | 5 | 1 | 5 |
| Unidentified dolphin | 1 | 40 | 9 | 652 | | | 12 | 1463 | 22 | 2155 |
| California sea lion | 28 | 101 | 16 | 21 | 1 | 2 | 16 | 20 | 61 | 144 |
| Northern fur seal | | | | | | | 2 | 2 | 2 | 2 |
| Unidentified pinniped | | | | | | | 1 | 2 | 1 | 2 |
| Grand Total | 32 | 639 | 39 | 2296 | 3 | 97 | 56 | 3275 | 130 | 6307 |
| Hours of daylight operation | | 19.8 | | 61.4 | | 0.6 | | 101.4 | | 183.2 |

Table 4. Headings of marine mammals sighted from survey vessel in relation to sighting type and firing status.

| | Heading relative to direction to boat | | | | |
|---|---|---|---|---|---|
| **Firing status** | **away** | **left** | **right** | **toward** | **Total** |
| | **Sightings** | | | | |
| None | | | | 1 | 1 |
| Airgun only | | | | 2 | 2 |
| Huntec only | 11 | 4 | 6 | 7 | 28 |
| Huntec & airgun | 16 | 10 | 9 | 7 | 42 |
| Total for sight. | 27 | 14 | 15 | 17 | 73 |
| | **Resightings** | | | | |
| None | 2 | | | | 2 |
| Airgun only | | | | | 0 |
| Huntec only | 6 | 1 | 4 | 2 | 13 |
| Huntec & airgun | 22 | 8 | 5 | 9 | 44 |
| Total for resight. | 30 | 9 | 9 | 11 | 59 |
| Grand total | 57 | 23 | 24 | 28 | 132 |

Table 5. Behavior of marine mammals sighted or resighted during daylight hours during surveys. Behaviors were clasified based on primary behavior seen during observation.

| | Sightings | | | | | Resightings | | | | | Both |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **Behavior** | Firing status | | | | | Firing status | | | | | **Total** |
| | **Airgun** | **Huntec** | **A&H** | **None** | **Total** | **Airgun** | **Huntec** | **A&H** | **None** | **Total** | |
| Fast travel | | 13 | 16 | 1 | 30 | | 11 | 23 | 1 | 35 | 65 |
| Slow travel | 1 | 14 | 19 | 1 | 35 | | 3 | 11 | | 14 | 49 |
| Hauled | | 3 | 1 | 25 | 29 | | | | 8 | 8 | 37 |
| Milling | | 5 | 8 | 1 | 14 | | 2 | 13 | | 15 | 29 |
| Stationary | | 2 | 3 | | 5 | | | 2 | | 2 | 7 |
| Bow riding | 2 | | | 2 | 4 | | 1 | | 1 | 2 | 6 |
| Breaching | | | 1 | | 1 | | | 4 | | 4 | 5 |
| Pec slaping | | | | | 0 | | | 2 | | 2 | 2 |
| Surface lunge-feed | | | 1 | | 1 | | | | | 0 | 1 |
| Feeding | | | | 1 | 1 | | | | | 0 | 1 |
| Total | 3 | 37 | 49 | 31 | 120 | 0 | 17 | 55 | 10 | 82 | 202 |