Offshore Seismic and Geology Survey
Portuguese Bend, California

conducted
October 20 to 25, 1994

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final version submitted
June 30, 1995

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Appendix A. Seafloor Bathymetry off Portuguese Bend Landslide

Appendix B. Isopach map of sediment thickness over bedrock seaward of Portuguese Bend Landslide

Appendix C. Geology and bedrock topography seaward of Portuguese Bend Landslide

Appendix D. Profiles of sediment thickness over bedrock on three NS traverses seaward of the Palos Verdes Landslide. Scale 1 inch to 100 feet.

Project Summary and Recommendations

This report presents the results and recommendations from an offshore geological survey conducted between October 20 and 26, 1994, along the south shore of Palos Verdes Peninsula, California. Continuous line recordings of subbottom reflections from a 3.5KHz and a Boomer seismic system designed by EcoSystems Management, Inc. and a Klein side-scan system were interpreted to provide seismic stratigraphy and possible evidence of present or ancient landslides beyond the present shoreline of Portuguese Bend Landslide. Survey lines were located so as to overlap seismic transects made on an earlier 1989 survey conducted off Abalone Cove by Dill GeoMarine Consultants for the City of Rancho Palos Verdes (Dill, 1989; Dill and Slosson, 1990).

Thirty seven north-south lines were made between Abalone Cove on the west and the point of land that forms the eastern boundary of Portuguese Bend Bay. Twelve east-west cross-tie traverses were made, along with 3 diagonal lines, to check for accuracy of soundings at traverse crossings and to check the continuity of features seen in north-south profiles. Seismic traverse lines extended 2 miles offshore to a point where it became clear that the geology was not related to landslides onshore. Traverses parallel to the shore were run from the eastern side of Abalone Cove to an area of hard rock outcrops approximately one mile southeast of Inspiration Point (see Figure 1). A total of 35.6 statute miles of seismic line were made in an area, concentrated off the Portuguese Bend Landslide as defined in maps provided by Dr. Perry Ehlig and Charles Abbott Associates, Inc. Seismic data were used to construct an accurate offshore bathymetric map of the region (Fig. 1 and Appendix A), an isopach map of the thickness of overburden (Fig.2 and Appendix B), chart-profiles showing thickness of Holocene sediments along nearshore lines and a geological interpretation map based on the seismic stratigraphy and side-scan profiles of the region (Fig.3 and Appendix C) and three north-south profiles showing sediment thickness over bedrock at a scale of one inch equals 100 feet.

Our basic conclusions and recommendations are:

1. There is no evidence in the seismic profiles or the side-scan records that indicate the presently active Portuguese Bend Landslide has displaced offshore Holocene sediments blanketing the Miocene bedrock, seaward of its present shoreline toe.

2. The Holocene sediments directly off the landslide have lenticular acoustic reflectors that indicate abundant cobble beds, similar to those found on the 1989 seismic and side-scan surveys off Abalone Cove and verified using vibrocores.

3. These cobble beds would make vibrocoring in the area seaward of Portuguese Bend Landslide extremely difficult or impossible. It is therefore **not** recommended that vibrocoring be used to determine the internal nature of the Holocene sediments covering bedrock on the next phase of this study. These same cobbles could make coring by rotary drilling to obtain rock samples difficult.

4. Sediment eroded from the exposed toe of the landslide by storm waves have been carried both seaward and to the east, forming a lobe of sediment blanketing an irregular eroded bedrock surface. Bedding within the bedrock has been truncated by an erosion surface which forms a distinct boundary between overlying Holocene sediment and underlying bedrock. Although this interface surface has irregularities, it has a gentle slope to the south. The erosion surface probably formed in the surf zone during both the regressive and transgressive periods of sea level fluctuations during the last ice age. In water depths less than 30 feet cobble beds above bedrock have a gentle dip seaward or are flat lying. They show no evidence of their being displaced by landslide movements. This

would indicate that the seafloor seaward of Portuguese Bend Landslide has been stable and sediment buildup has not been interrupted by landslides or tectonic movements for at least the last 2,000 years, a period of relatively stable sea level following a rapid Holocene rise and the flooding of the Continental Shelf.

5. Seismic evidence strongly suggests that there is solid bedrock beneath a thin Holocene sediment cover directly seaward of the landslide within Portuguese Bend Cove. In many nearshore areas sediment thickness is less than 5 feet. However, the records do not provide a means to determine the physical competence of bedrock under the sediment cover to support buttress structures. It is therefore strongly recommended that drilling to obtain rock samples be done at the present shoreline to determine the nature and structural strength of bedrock on the seaward side of the toe of the landslide.

6. The basalt sill that protects the seaward margin of Inspiration Point extends to the east as exposed bedrock forming a resistant structural restraint to landslide movement. Seismic profiles indicate that a layered bedrock formation underlies the basalt sill and gently dips to the south in most areas of the survey.

7. The basalt and dolostone outcrops within the surf zone just east of the presently active landslide extend to the west and provide a bedrock buttress to inhibit landslide movement on the eastern margin of the landslide.

8. A well developed fault zone in the bedrock, strikes diagonally across the survey area towards the southwest. It can be traced on land to a zone of contorted beds in the cliffs that form the southeastern boundary of the survey area. The important implication to this study is that none of the reflective acoustic lenses, interpreted as cobbles or bedding, within the Holocene sediments are displaced or contorted, indicating the area has been stable since marine sedimentation started with the flooding of the area following the last ice age.

9. If shoreline erosion of the toe is allowed to continue there will be further smothering of rocky habitats and destruction of a highly productive ecosystem both east and west of the presently active landslide.

Background

This study is part of a response to recommendations made in a May 1994, Initial Project Management Plan (IPMP) by the City of Rancho Palos Verdes, California and the US Corps of Engineers to determine the feasibility of protecting the shoreline and an environmental restoration project at the seaward boundary of the City of Rancho Palos Verdes. For a complete description of project objectives, historical data, and construction details one should refer to the complete reconnaissance report's main text and technical appendices, dated May, 1992 (rev) which is available at the Los Angeles District Office of the Corps of Engineers.

Prior to 1956, shoreline erosion and sediment transport from eroding cliffs on the southern shore of Palos Verdes Peninsula had not become an environmental issue or attracted the attention of the general public or local residents. Historically, the Peninsula was utilized primarily for agriculture and had a low population density. Increased urban use following the rapid development of the peninsula after World War II and with the advent of freeways and the southward spread of the populous of Los Angeles created a new network of roads to support housing projects in this previously rural area. Loading from road construction and ground water from septic tanks and runoff from a newly created road system apparently triggered the reactivation of ancient landslides along the southern terraced shore of Palos Verdes (Ehlig, 1982.; Anderson, J. L. 1987; Slosson, J. E. and Havens, G. W., 1987). The steep cliffed bluffs facing the sea slipped into the surf zone exposing their previously stable seaward margin to wave erosion. Eroded sediment was then suspended and carried seaward and along the coast by wave-generated longshore currents. Continual erosion of the toe had a domino effect and triggered a headward movement of the slide blocks creating unstable land masses unfit for urban utilization.

The unique rocky intertidal habitat of the area, particularly at Portuguese Bend has been severely impacted by landslide debris. As erosion continues, the increased sedimentation precludes the restoration of the natural environment of the area without some structural protection to stabilize the landslide. Determining the feasibility of such a construction effort is the main objective of the IPMP.

Under present conditions, continued seaward movement of the landslide pushes the toe berm into an area of wave erosion, preventing it from counteracting the landslide's driving force. Erosion of the landslide material also provides a source of sediment to longshore currents that carry it up and down the coast smothering the highly productive rocky habitats of the area. One of the options for prevention of erosion is to protect the toe by a man made structural buttress anchored to bedrock. If successful, such a structure would protect

the toe of the landslide from wave erosion, stabilizing its seaward movement so that it no longer is a source of environmentally damaging sediments.

One of the main concerns in stabilization of a landslide by a buttress, is if an unstable subsurface or prior slump zone weakness exists in the underlying bedrock. If a potentially unstable substrate exists, it could be reactivated. Continued wave erosion and structural damage could greatly compromise the protection provided by the stabilizing structure. Because of this concern, this study was designed to determine;

1) if the unstable conditions creating the landslide extend offshore;
2) if there is a continuation of the basaltic sills outcropping at Inspiration Point to the east that could act as a stable bedrock surface to anchor a buttress structure; and
3) if there is any displacement of beds within the Holocene sediment fill over bedrock that would indicate modern landslide activity has disturbed these sediments beyond the present shoreline.

Following initial discussions with Charles Abbott Associates, Inc., (CAA) and Dr. Perry Ehlig, City Geologists for Rancho Palos Verdes, and representatives of the U.S. Corps of Engineers (COE), Dill GeoMarine Consultants formed a Joint Venture with EcoSystems Management, Inc. to provide high resolution seismic profiles and side-scan images that would define the nature of the offshore geology seaward of the Portuguese Bend Landslide. The design of the survey was guided by a series of memos and a preliminary letter of agreement between the City of Rancho Palos Verdes, COE and geological recommendations made by Dr. Perry Ehlig. The major objectives of this survey were to produce:

1) a detailed bathymetric map of the survey area with a 5-foot contour interval;

2) an isopach map of Holocene sediment thickness above bedrock, at a scale of 1-inch to 500 feet;

3) three profiles of sediment thickness and internal structure of the Holocene sediments over bedrock. These will be made at the same scale as land profiles provided by CAA and Dr. Perry Ehlig (1 inch = 100 ft.);

4) an interpreted side-scan sonar map of bottom features and outcrops; and

5) this report on the offshore geology of the area related to the possible offshore extension of the Portuguese Bend Landslide.

Charles Abbott Associates, Inc. and Dr. Ehlig defined the areas to be studied by our offshore seismic and side-scan survey. Priority was given to the area seaward of active landslides in Portuguese Bend. In addition, the areas immediately adjacent to the landslide

and off Abalone Cove were studied in less detail to obtain a reconnaissance picture of the relationship of landslides to the geology along the southern shore of Palos Verdes Peninsula. Dill GeoMarine Consultants and EcoSystems Management had previously conducted a study with similar objectives seaward of the adjacent Abalone Cove Landslide in 1989 (Dill, 1987, Dill and Slosson, 1989, Slosson and Dill, 1990). Records and coring from this prior survey were used in preparing maps of the offshore geology of both areas and presented in the charts, maps and profiles in this report. A summary of the results of previous studies relevant to this one, are presented in the Comparative Studies section of this report.

Seismic stratigraphy and evidence of present and ancient landslides were examined by interpreting continuous line recordings of subbottom reflections from 3.5KHz and Boomer seismic systems designed by EcoSystems. Survey lines were located so as to overlap seismic transects made on the previous 1989 surveys conducted off Abalone Cove. During this survey (October 20 to 26, 1994), thirty seven north-south lines were made between Abalone Cove on the west and the point of land that forms the eastern boundary of Portuguese Bend Bay. Twelve east-west cross-tie traverses were made along with 3 diagonal lines to check for accuracy of soundings at traverse crossings and to check the continuity of features seen in north-south profiles. Seismic traverse lines extended 2 miles offshore to a point where it became clear that the geology was not related to landslides onshore. Traverses parallel to the shore were run from the eastern side of Abalone Cove to an area of hard rock outcrops approximately one mile southeast of Inspiration Point (see Fig. 1). A total of 35.6 statute miles of seismic line were run in the area , concentrated off the Portuguese Bend Landslide as defined in maps provided by Dr. Perry Ehlig and CAA.

Seismic data was used to construct an accurate offshore bathymetric map of the region (Fig.1 and Appendix A) and an isopach map of the thickness of overburden (Fig. 2 and Appendix B). An offshore geological interpretation map, based on the seismic stratigraphy of the region and input from the literature and Dr. Perry Ehlig was also prepared to support the conclusions and recommendations coming from this study (Figure 3 and Appendix C). We also constructed a series of profiles based on seismic lines showing the thickness of sediment in representative key areas related to the Portuguese Bend Landslide. A chart showing seaward extensions of land profiles was also constructed to provide a one inch equals 100 ft. true scale chart of the sediment thickness over bedrock along three profiles seaward to ones constructed by Dr. Perry Ehlig for land areas (Appendix D).

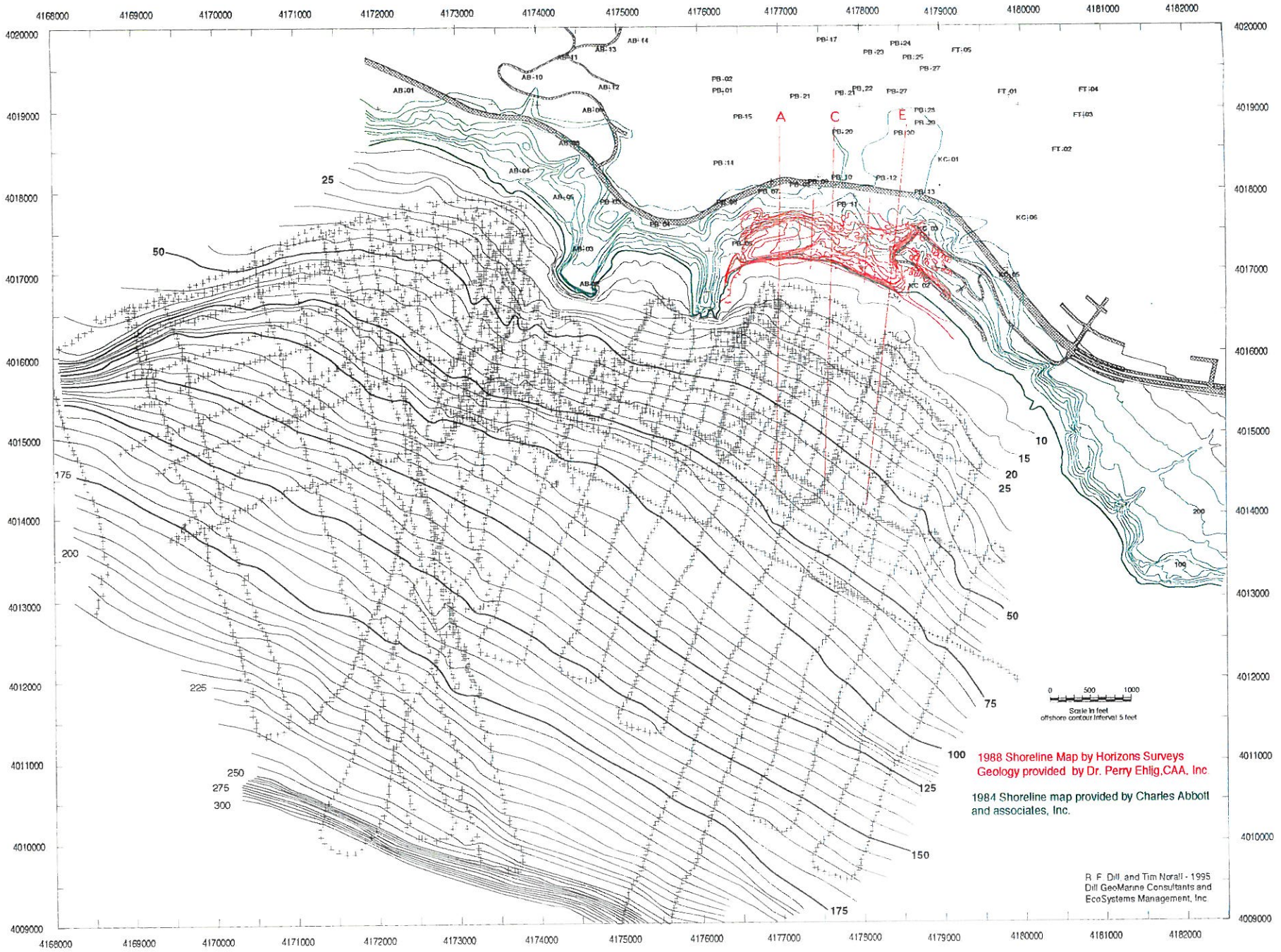


Figure 1. Bathymetry of the seafloor off Portuguese Bend and Abalone Cove Landslides on the southern shoreline of Palos Verdes, California. This is a composite map from surveys made for the City of Rancho Palos Verdes in 1989 and a 1994 survey for the City of Rancho Palos Verdes and the U. S. Corps of Engineers. A larger scale map is included in Appendix A. Depth contours are in feet. Locations were by GPS plotted in California Coordinates (ft), Zone 7, datum is NAD-27.

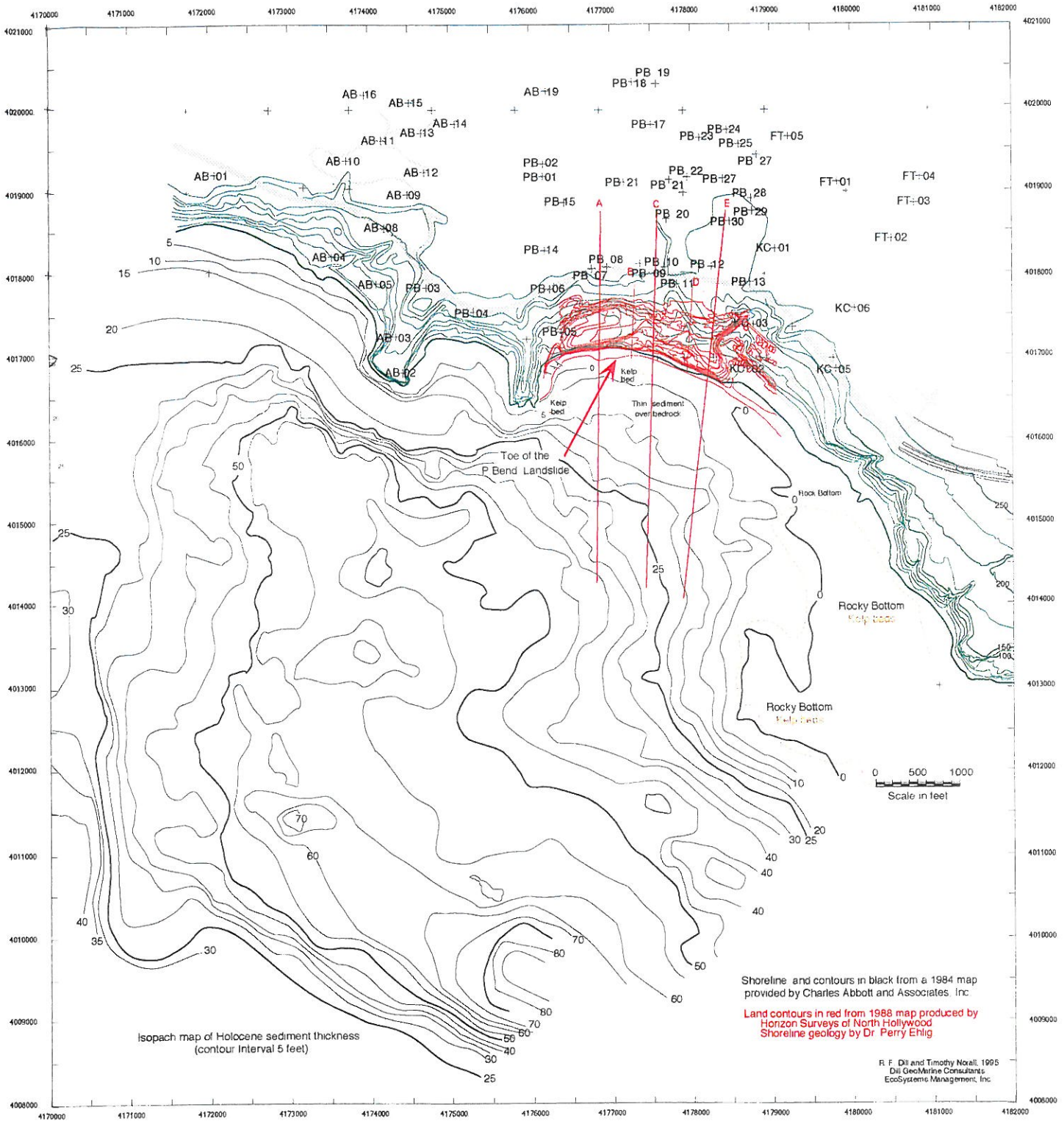


Figure 2. Isopach map of sediment thickness seaward of Portuguese Bend and Abalone Cove Landslides on the southern shoreline of Palos Verdes, California. A larger scale map is presented in Appendix B. Sediment thickness in feet was determined acoustically using a 3.5KHz and "Boomer" (200 to 1100) seismic system. Computer drawn contours were made using Surface III™ software. Data were from a 1989 survey and one conducted between October, 20 to 26, 1994 for the City of Rancho Palos Verdes. Red lines A. C. and E are offshore extensions of profiles across the Portuguese Bend Landslide prepared by Dr. Ehlig and are shown in Appendix D.

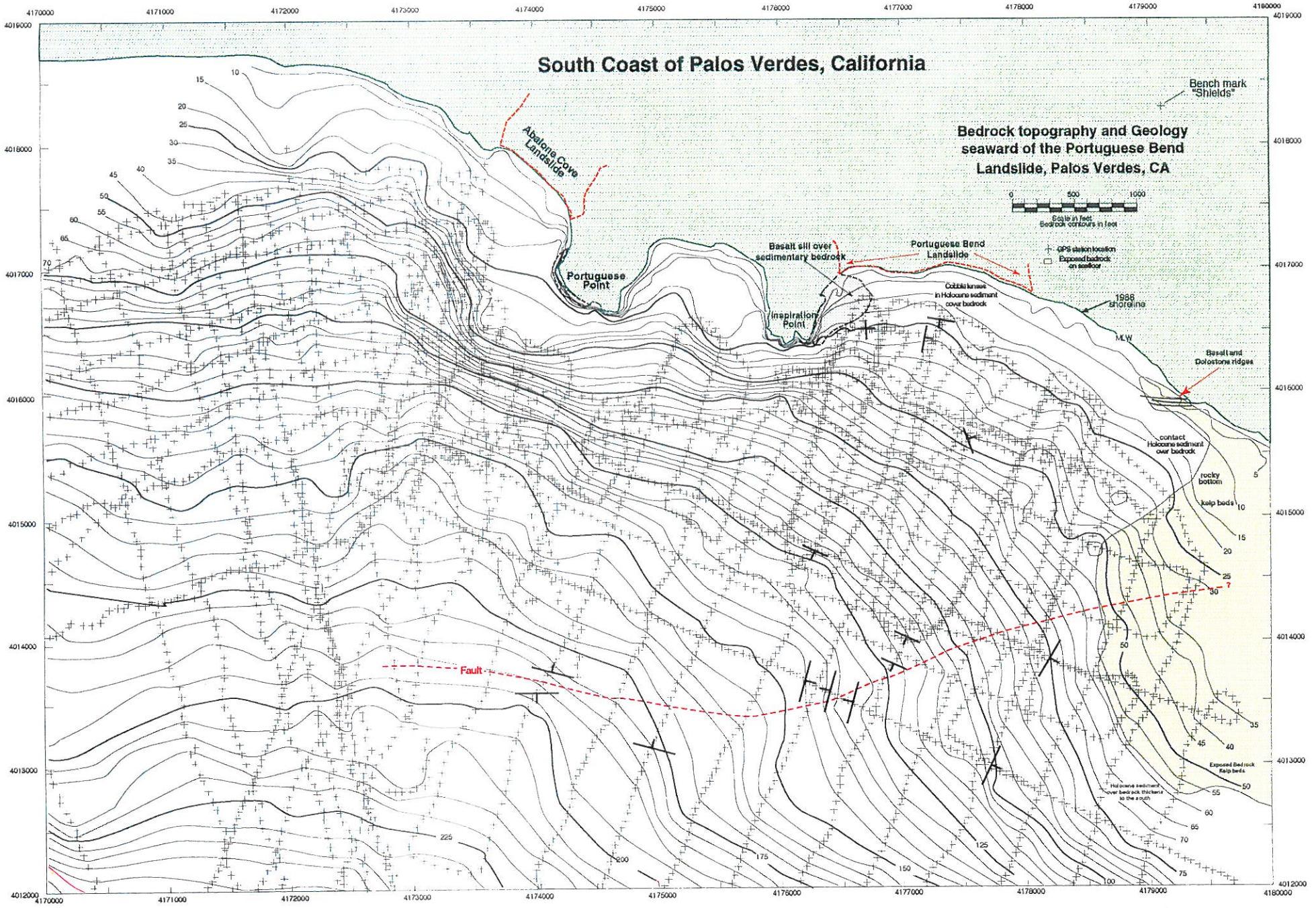


Figure 3. Geological interpretation of the seismic and side-scan surveys seaward of the Portuguese Bend Landslide, Palos Verdes, California (see Appendix C for large scale) Dip and strike symbols are apparent values from seismic track lines.

A side-scan sonar survey was conducted to determine the surface topography of the seafloor using an instrument with a 330 ft. horizontal range on either side of the survey vessel. The survey grid was laid out so that all of the bottom between Inspiration Point and the rocky bottom forming the eastern side of the survey would be covered between the surf zone and the 120 foot depth contour. Side-scan records locate and define acoustic reflections from rock outcrops and irregularities on the bottom such as ripple marks and sand channels. Overlapping paths permit construction of an acoustic picture of the bottom, similar to radar on land. Rock structures protruding above the bottom form patterns that can be related to the acoustic topography seen in seismic records. Orientation and size of microtopography can provide a record of oceanographic conditions and an indication of the type of sediment forming the seafloor. For example coarse grained sand forms larger ripples than fine grained sand and muddy bottoms are usually smooth with little relief.

Navigation was controlled using a modified Motorola *"six-gun"* Differential Global Positioning System (DGPS) with shore and vessel satellite receivers to provide a differential signal allowing an navigational accuracy of ± 6 feet. Positions were automatically recorded on a floppy disk in the ECO-NAV computer aboard the survey vessel. Simultaneous to each DGPS position recorded, the navigation software sent an event mark to the seismic record that automatically annotated seismic and side-scan records with a navigation ID number, time and date. A dual frequency seismic system designed by EcoSystems Management was used for determining the acoustic stratigraphy of the region. High resolution 3.5 KHz and lower frequency 200 to 2000 Hz "Boomer" acoustic signals were plotted simultaneously on the same record so that features seen on the high resolution shallow penetration 3.5 KHz record could be compared with the low frequency deep penetration "Boomer" records.

Our survey equipment included the following instrumentation:

Motorola "six gun" DGPS
3.5 kHz Sub-bottom High Resolution Seismic System
EPC dual channel Mod. 9600 Digital Recorder
1000 Joule "Boomer" Sub-bottom Seismic System, filters set for 270-1100 Hz.
A 100 /500 KHz Kline Mod. 590 side-scan sonar system
200 KHz echo sounder for depth measurements on the side scan survey

All equipment was mounted on our 25 ft. survey boat (Fig. 4) which was launched from the Cabrillo Park boat ramp in San Pedro Harbor. The DGPS differential shore station was placed directly over the County bench mark "Shields," (Fig. 5) identified by Dr. Ehlig on the hill north of the survey area (located at Northing 4018302.94 , Easting 4179107.25 : 33° 44' 29.11024 "N; 118° 21' 33.07934" W). Survey lines were preplotted using EcoSystem navigation software and loaded into the computer system aboard the boat.

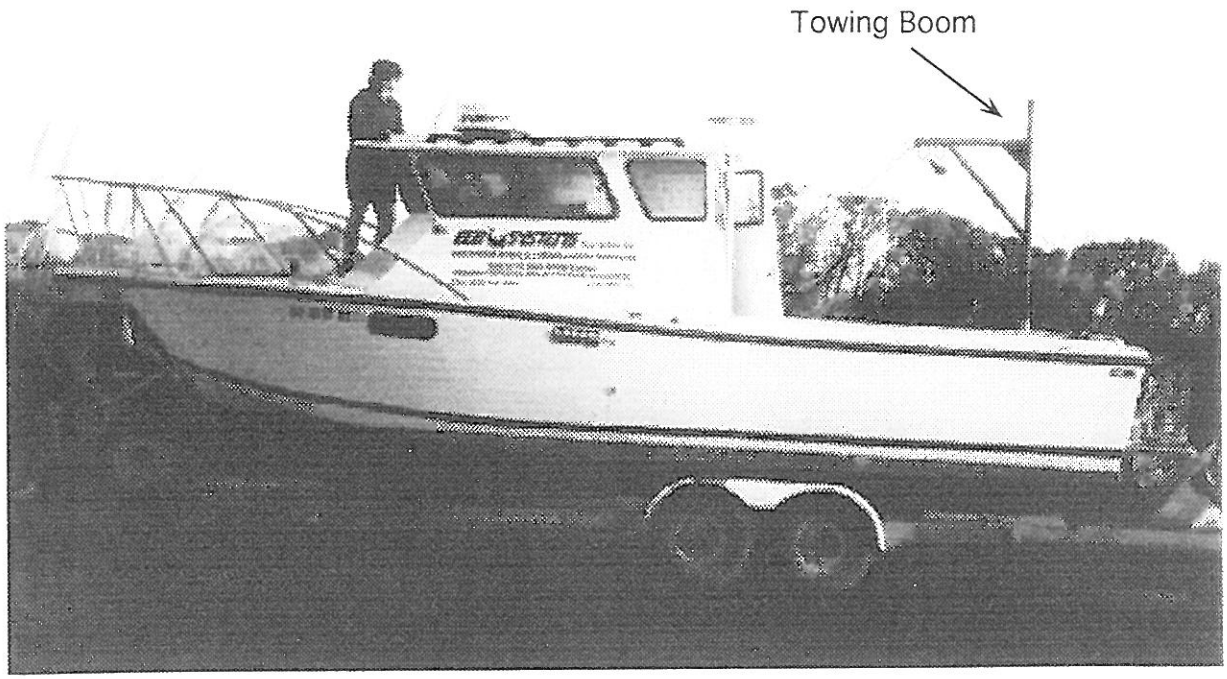


Figure 4. Twenty five foot vessel used on the Portuguese Bend Landslide survey. Aboard was the GPS navigation station, seismic and side-scan instruments with their recorders. Transducers were towed from the boom at the aft end of the boat.

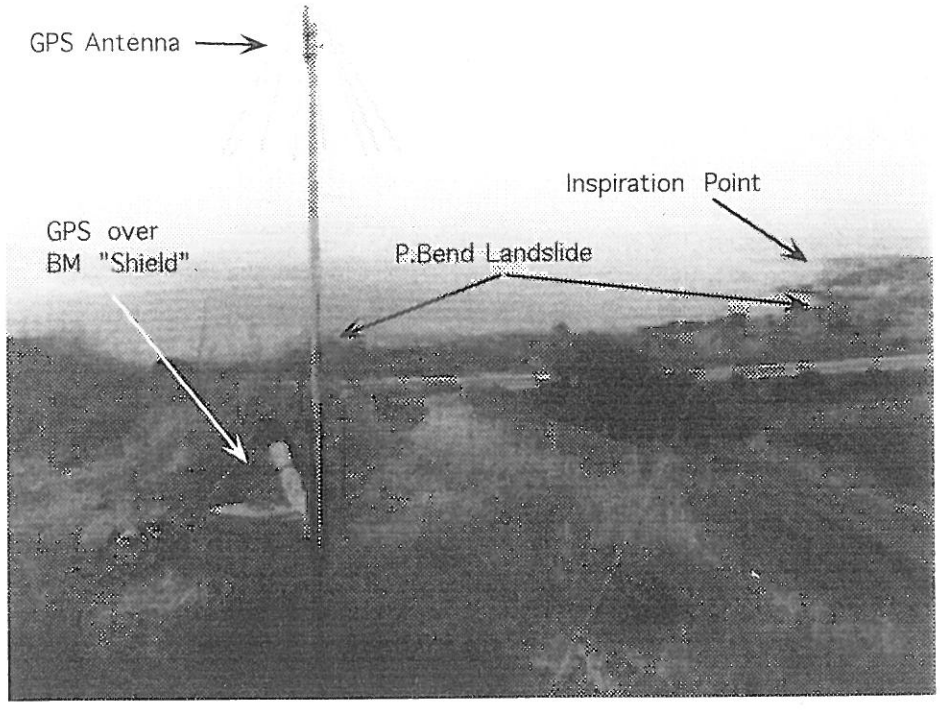


Figure 5. Looking south from the shore GPS station located 310 feet abovePortuguese Bend Cove. Inspiration Point is on the far right. The active landslide involves all the area below and to the right of the GPS station.

Preplot presentations were used to guide the vessel on track lines with a north-south and east-west track separation of approximately 250 feet. All traverse data and records have a time designation every 15 seconds and a location identification number printed on the original record so that they can be related to their position on traverses plotted on a regional chart for correlation.

Because of conflicting frequencies between the seismic and side-scan systems it was necessary to make two survey passes over the area. The side-scan sonar survey was done first, followed by the seismic survey. Precise navigation allows us to superimpose the two charts to compare seafloor surface features found on the side-scan survey with sub-seafloor geology seen on the seismic records to prepare the geological map of the survey area.

Side-Scan sonar survey

The side scan-survey covered all of the area seaward of the landslide out to a depth of 120 ft. (Fig.6 and Appendix C). Bedrock is exposed on the sea floor on the eastern side of the surveyed area. This rocky area supports a thick kelp forest. Irregular elevations of individual beds within the rock formations show that there is considerable variability in rock resistance to erosion. Rock exposures have relief of up to 6 feet. Folding and fault displacement are evident in the reflections from outcrop bedding planes in this eastern margin of the survey area. The zones of tectonic deformation can be projected onto land and tie in with deformed areas exposed in the cliffs along the shore to the east of the landslide. The trend of this deformation of the bedrock to the west, is approximately 2,000 feet seaward of the landslide and is probably not related to any present movements.

West of the rocky bottom forming the eastern boundary of the survey area, sediment blankets a relatively smooth bottom with little to no relief. There are no rock outcrops seaward of the 20 foot contour, only a relatively smooth sedimentary plane. This type of bottom extends all the way to the western boundary of the Abalone Cove survey of 1989. Dives over a similar seafloor topography during the 1989 survey showed the bottom to be composed of a silty, fine-grained sand with little or no relief. In shallow water directly seaward of the landslide toe at depths between the shoreline and the 20 foot contour, there are a few rock outcrops protruding through the Holocene overburden. These are colonized by kelp which is visible from the surface although the rocks themselves are not visible due to the turbidity of the water. The seismic profiles near these outcrops indicate they are part of the irregular eroded surface of the bedrock of the region and not eroded remnants of a previously active landslide. As will be discussed later the seismic lines verify this relationship in areas we could survey.

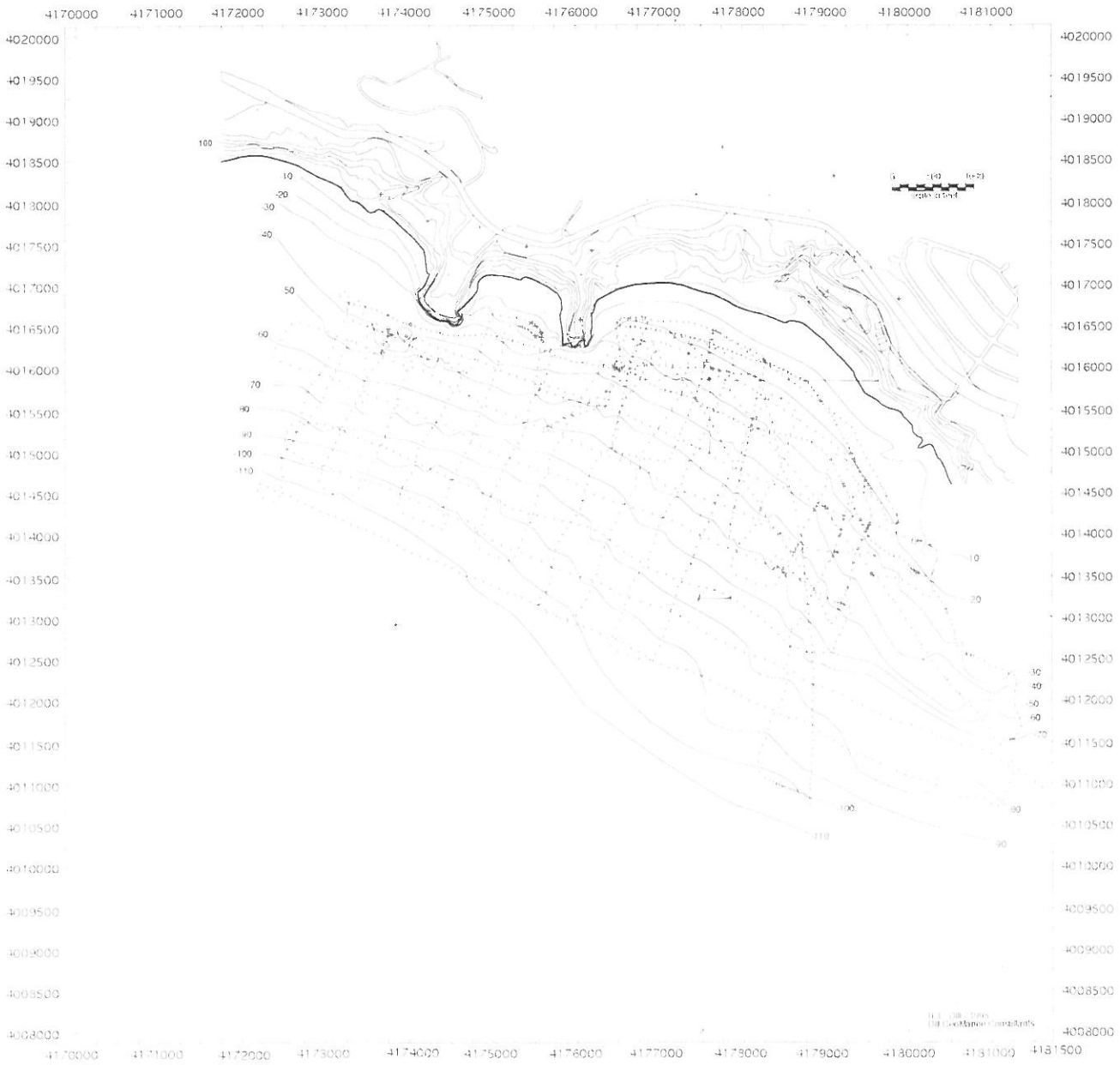


Figure 6. Side-scan survey vessel tracks and bathymetry off the Portuguese Bend Landslide. Land contours are in 25 foot intervals (provided by Dr. Perry Ehlig). Offshore contours are at 10 foot intervals and derived from a 200 KHz echo-sounder on the survey vessel. Navigational control was by a Motorola DGPS "six gun" system modified by EcoSystems

Bathymetry

The bathymetry of the area was measured in two ways. During the side-scan survey of the inner Cove, we utilized a high resolution 200 KHz echo sounder to continuously record depths. Navigational ID positions were keyed and printed on the record every 15 seconds. This continuous depth record was later read at the marked 15 second intervals using a digitizing board. Depth values were recorded in a Microsoft Excel™ spread sheet along with their ID station number and the Northing and Easting positions recorded at the same 15 second time interval using a Motorola Global Positioning System. Depths were then computer plotted using Surface III™ and Surfer™ software.

A "bar check" was taken at the beginning and end of each day's work to provide a correction for changes in sound velocity due to water density variations in the region and minor changes in the sweep rate of the sounding instrument. This is done by lowering a flat metal target attached to a calibrated wire to depths of 20, 30, and 40 feet below the transducer as the acoustic sounder is recording depth. Any deviation from the sounder tape grid lines is then applied along with a tidal correction to reduce the depth soundings to Mean Lower Low Water for constructing our final map of the bottom topography.

Depth soundings from our Excel™ spreadsheet were saved and read as a text file by Surface III™ V. 2.5, the software used for plotting positions and contouring depth. Geological interpretation of the side-scan records which show micro features of the sediment bottom and rock outcrops with macro-algal growth (kelp beds) are shown in Figure 6. Bottom types fell into two categories; sedimentary and rock.

Sedimentary Bottom. Most of the sea floor seaward of the active Portuguese Bend Landslide is blanketed by Holocene sediment deposited as sea level flooded the area following the last Ice Age, and subsequent sedimentation from the erosion of the shoreline and carried seaward as a prograding fill of bedrock irregularities. In general, the bottom has a gentle seaward slope all the way out to the Shelf Break at a depth of about 250 feet, approximately 1.5 miles offshore. There, the slope steepens and drops to the deep San Pedro Basin that separates Palos Verdes from Catalina Island and the Offshore California Borderland Basins and Ridges (Emery, K. O., 1960).

From shore to the drop-off at the shelf break there is very little micro relief or bed forms on the surface of this sedimentary blanket except near rock outcrops forming Inspiration Point, and the rocky bottom at the extreme south eastern part of the survey area (see Figs.2 and 3). In areas near rock outcrops there is a halo of coarse sand extending a short distance seaward from the steep rock walls that protrudes up thorough the Holocene overburden. Turbulence and increased swell induced currents in these areas winnow out the fine grains

and leave a coarser sediment with large rippled surfaces as a sediment halo usually with a high concentration of shell debris derived from organisms living on the rock surfaces. Within surge channels, swell induced bottom currents create giant ripple mark on the surface of the coarse lag gravel and sands occupying these high wave energy areas. This microtopography is well defined in the side-scan records. The basalt sill that protects the seaward edge of Inspiration Point forms a resistant rocky wall that rises almost vertically from a coarse grained sediment halo. A few scattered rock outliers with a dense cover of kelp were also sited on the side-scan records near Inspiration Point and along the shoreward margin of the survey area off the landslide.

During the survey (October 21 to 25, 1994) fine-grained sediment derived from the erosion of the landslide toe extended as a plume of dirty water all the way to the kelp beds on the eastern boundary of Portuguese Bend Cove. This sediment, held in suspension by wave induced turbulence and longshore tidal currents is visible on the 3.5 and 200 KHz records as a faint reflector above the strong bottom echo. The records show that the layer of turbid nearshore water thins as particles settle and it spreads seaward and down coast to the east. The suspended sediment from the toe of the slide is burying low rock outcrops which we will describe later in the report.

Near shore, the strong wave-induced currents sort the heterogeneous sediments from the face of the eroding landslide. Fine-grained sediments are held in suspension and moved by longshore currents away from the eroding face. The coarser grained component of landslide debris forms a lag deposit that is a source of the cobbles, coarse gravel and sands that form the beach along the toe of the landslide and along the shoreline to the east. These coarser sediments which are concentrated in the surf zone are slowly transported to the east until they encounter natural groins formed by low resistant basalt and dolostone bedrock ridges in the surf zone at the eastern margin of the landslide (Dr. Perry Ehlig, personal communication). Historical records of the position of the shoreline show that these rock ridges have been covered by landslide derived sediments; these sediments have been transported by longshore currents to the southeast to form a seaward prograding beach. Seismic and side-scan records show that prograding has covered the resistant linear rock ridges offshore as well as at the shore, smothering rocky habitat.

The topography reflects both a covering and diverting of longshore transported sediment seaward and over natural rock groins. The smooth bottom topography around rock outcrops reflects the active and dynamic movement of the sediments derived from the landslide. Upon reaching the zone of sediment transportation within the surf zone, landslide derived sediment fills in the natural irregularities of the rocky areas. We will

discuss this at greater length later when reporting the findings of the side-scan and seismic records.

Rocky bottom. There is a narrow exposure of rocky bottom around Inspiration Point and isolated outcrops along the eastern edge of the landslide. Contact between the resistant basalt wall defending Inspiration Point and the sediment is sharp. At the Point, basaltic bedrock abruptly rises from a coarse-grained rippled sand bottom that blankets the base of the rock terrace surrounding the point (Fig. 7). A much larger area of exposed bedrock forms the eastern boundary of the study area. Sediment-rock contacts in most areas are sharp except near the low rock ridges that extend across the shoreline at the cobble beach east of the landslide (see Fig.6). In this area the ridges form natural groins that are covered and exposed by seasonal cut-back and accretion of the beach. Offshore bottom contours near projections of the outcrops seaward, reflect a damming of sediment moved to the east by littoral currents

The rock bottom along the eastern margin has an irregular surface that reflects the bedding within the formations cropping out at the seafloor. Folds and faults can be seen in the side-scan records of reflections from the beds facing the sonar transducer. Bottom reflections from both echo sounder and side-scan records show that most of the rock exposures are covered with brown algae and sea grass. There are scattered rock outcrops nearshore that protrude through the sediment cover most of which are capped by the giant kelp (*Macrocystis*) and ribbon kelp (*Egregia*) (Fig. 7). The gas filled floats on the algae form excellent acoustic reflectors that provide a record on both the echo sounder and side-scan records. Previous diver observations provide a ground truth comparison with acoustic echoes that allows us to identify the type of algae growing on rock surfaces (Dill, et. al., 1989). The low standing algae which stands approximately 3 to 4 feet above the bottom is probably *Laminaria* and the high standing algae which reaches the surface forming a visible canopy is *Macrocystis*.

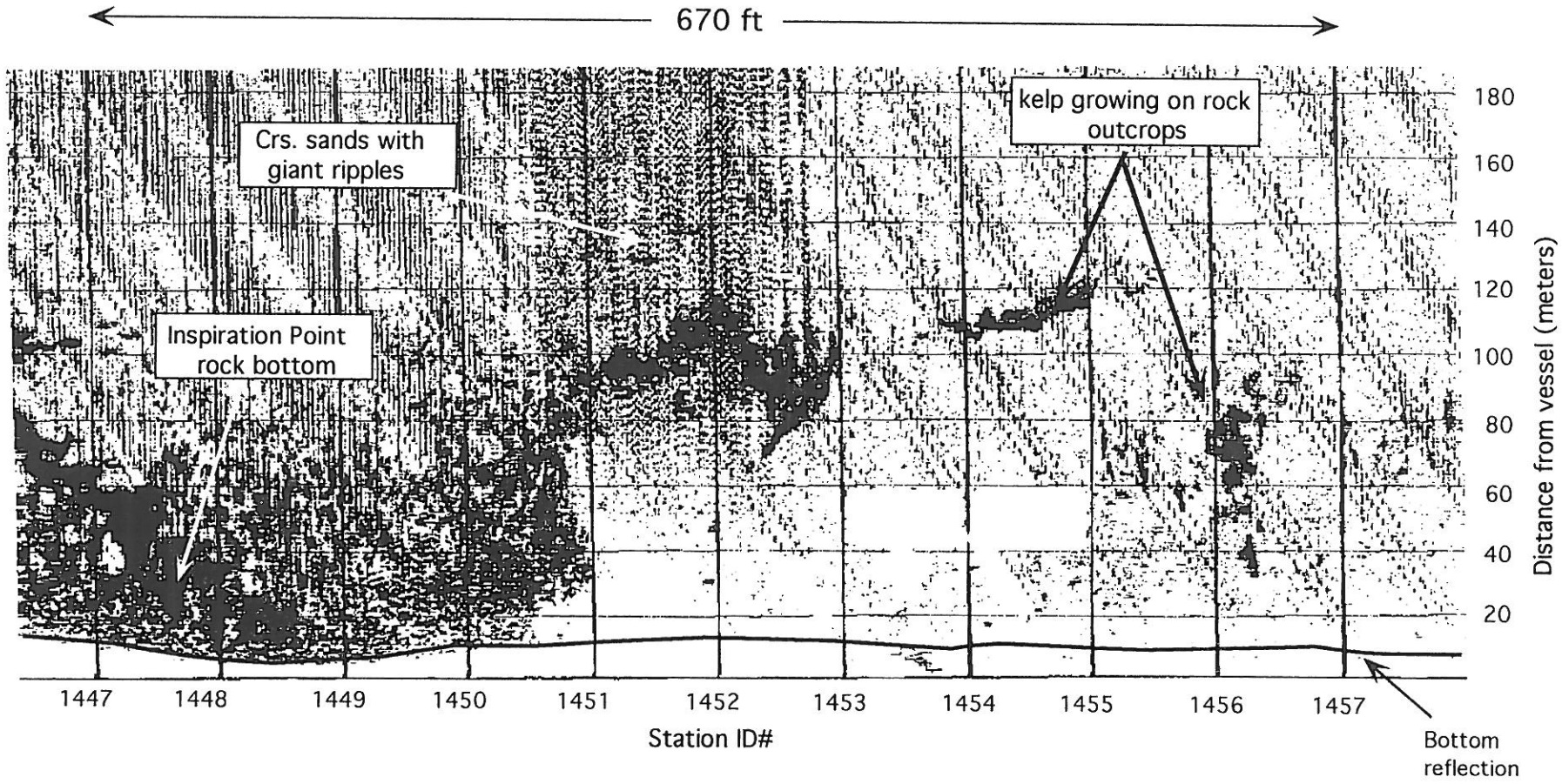


Figure 7. Right shoreward sweep of a west to east side-scan traverse just seaward of Inspiration Point. Dark areas are reflections from rock surfaces and kelp beds growing on rock outcrops. Coarse grained sand between Station #1451 and #1453 support a giant ripple marked surface. Diagonal streaks are instrument noise.

Seismic survey

Data from the two seismic systems were interpreted to show shallow stratigraphy within the survey boundaries. High resolution 3.5 KHz records were used primarily to record the thickness over bedrock and internal sedimentary structures within the Holocene sediment blanket. Our maximum penetration with the 3.5 KHz system in Holocene sediments was approximately 100 feet. However, in areas of what we interpret as cobble lenses and traverses over the basalt sill, high frequency acoustic energy is rapidly attenuated and acoustic penetration was much less. For this reason our system uses two acoustic sources, the higher frequency 3.5 KHz and a lower frequency (1,000 Hz) deeper penetrating but less definitive "Boomer" system for recording the structure of the bedrock underlying the sediments. Acoustic reflections from within the bedrock using the "Boomer" system at the power levels permitted by California State Law can define rock structures to depths of approximately 400 feet. In some areas the Holocene/bedrock boundary was indistinct or beyond the penetration range of the 3.5 KHz echoes, in those areas the deeper penetrating lower frequency "Boomer" records were used to determine sediment thickness.

Sediment thickness and bottom depth were measured on seismic records at each station ID and recorded onto a spreadsheet. Seismic data from the seismic records were read using a CalComp digitizing board. Water depth and sedimentary thickness over bedrock were then used to construct an isopach map of the Holocene sediments (Fig. 2 Appendix B). At the same time the records were being digitized, geological features relating to this study were recorded on a separate log for correlation with the side scan features, especially in areas of rock outcrops where formation structure could be interpreted from acoustic echoes.

Holocene Sediments

In general the Holocene sediments which overlay bedrock, increase in thickness towards the south all the way to the Shelf Break. There, at a depth of approximately 250 feet, sediment thickness decreases markedly with indications that in some places bedrock is exposed. Nearshore, in depths of less than 25 feet, thickness is variable but thin (usually less than 10 feet). Nearshore sediment thickness decreases to the southeast, away from the toe of the landslide. Projections seaward of linear shoreline basalt outcrops show that the bottom has exposed rock or is an area with only a thin sediment cover.

Most nearshore Holocene sediments have horizontal or gently, seaward-dipping acoustic reflectors, indicating coarse sand or cobble lenses within the sediment that blankets the bedrock (Fig. 8). Sediments are thin nearshore and are most probably derived from the toe of the landslide although there is undoubtedly some contribution from gully erosion by the ephemeral streams that carry sediments all the way to the shore during storm periods.

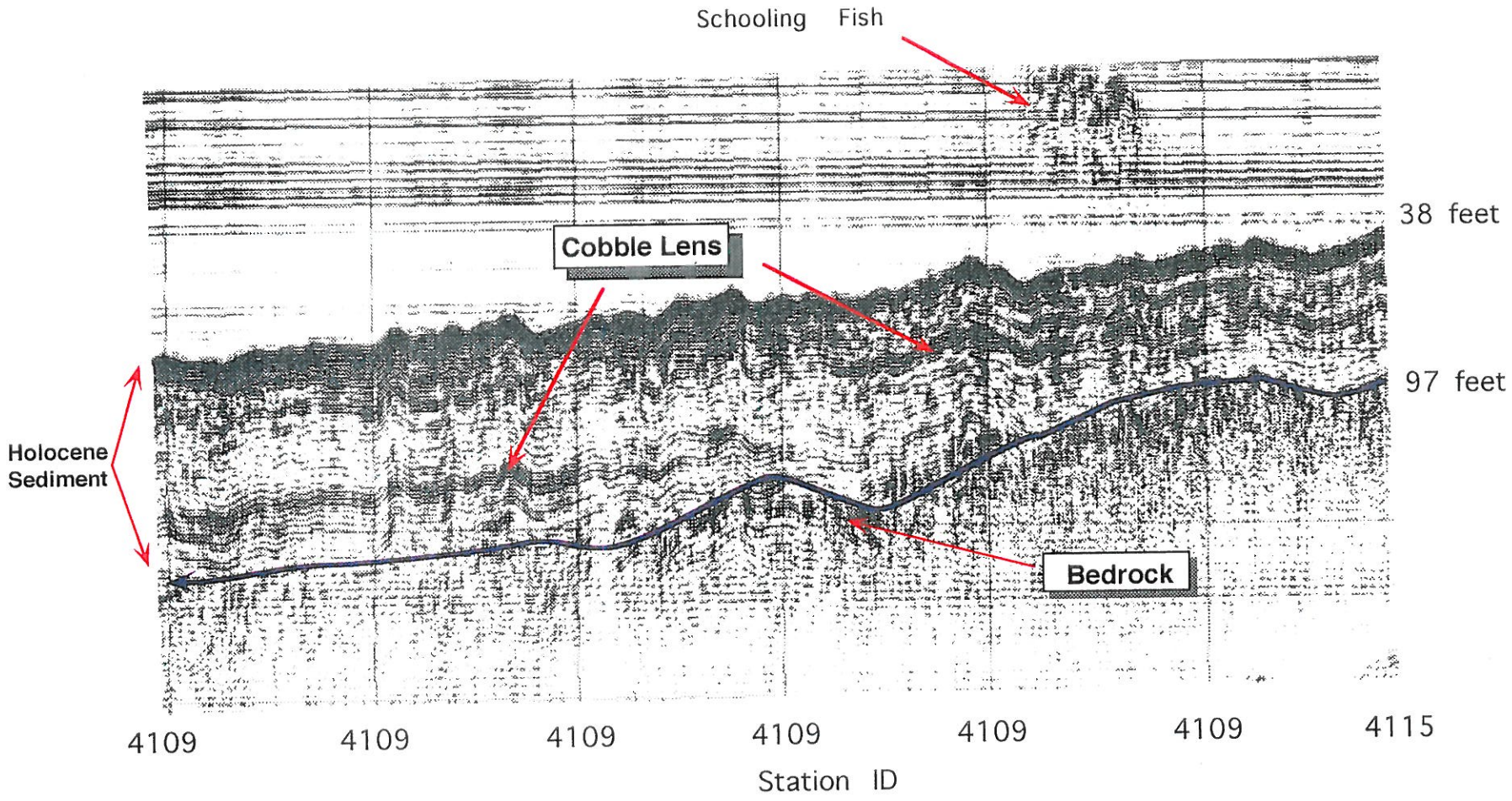


Figure 8. North-south 3.5KHz seismic profile showing sediment thickness and bedrock. Cobble lenses are not continuous. Bedrock surfaces below the Holocene sediment cover has considerable acoustic relief. A sediment thickness of 59 feet, shown on the right side of the figure, has been corrected to account for the increased sound velocity in sediments over its velocity in seawater. Irregularities in subbottom beds are due to variations in sea surface due to swells, in reality they are flat planes gently dipping to the south.

Beyond depths of 30 feet the sediment contains fewer lenses of reflective beds. Reflective lenses are seen through out the sediment column but most reflectors are concentrated just above the sediment-bedrock interface. Reflective beds are seen all the way to the shelf break just above linear bedrock elevation changes that could represent ancient shore lines and low shoreline cliffs.

It is important to stress that none of the horizontal lens of cobbles and coarse sand (?) show any displacement or tectonic folding which would indicate the sediments containing them has been stable since their emplacement as sealevel flooded the region in the Holocene, even though they are offshore of an unstable landslide area. This strongly indicates that Holocene sediments have not been affected by movements of the Portuguese Bend Landslide. This stability would represent a period of at least 2,000 years since the flooding of the Continental Shelf following the last ice age (Emery, K. O., 1960; Emery, K. O., 1967).

Sedimentary Thickness (isopach)

An isopach map showing the sediment thickness above the bedrock is presented in Fig. 2 and Appendix B and in profiles along characteristic seismic tracks in Figs. 9 to 15. The station ID numbers can be located on Chart #1 in Appendix D.

In general the Holocene sediment thickness in the survey area is less than 50 feet thick (Fig.2). Nearshore sediment over bedrock is less than 10 feet with some areas showing almost no cover. Near Inspiration Point bedrock forms the bottom with no sediment cover. The eastern side of the survey area is also an area with little to no sediment cover out to water depths of 20 feet. Seaward toward the south Holocene, sediments thicken out to near the shelf break where sediment cover thins to less than 10 feet. This type of sediment thickness pattern indicates that the sedimentary wedge over bedrock, is gradually prograding seaward as erosion of the cliffs and terraced coastal areas provide sediment to fill in offshore bedrock irregularities and topographic lows.

A section of the east-west profile closest to shore is shown in Fig. 9. Note the exposure of bedrock at the western boundary of the survey area. Holocene sediment laps up and covers bedrock in the central part of the profile and represents sediment and coarse gravels derived from the erosion of the toe of the Portuguese Bend Landslide. At the eastern edge of the area, just seaward to the active landslide, the basalt and dolostone outcrops seen on the beach extend seaward to the south forming a low relief linear rocky bottom. There are rock outcrops protruding through the nearshore sediments. Most of these rocky areas are covered with kelp.

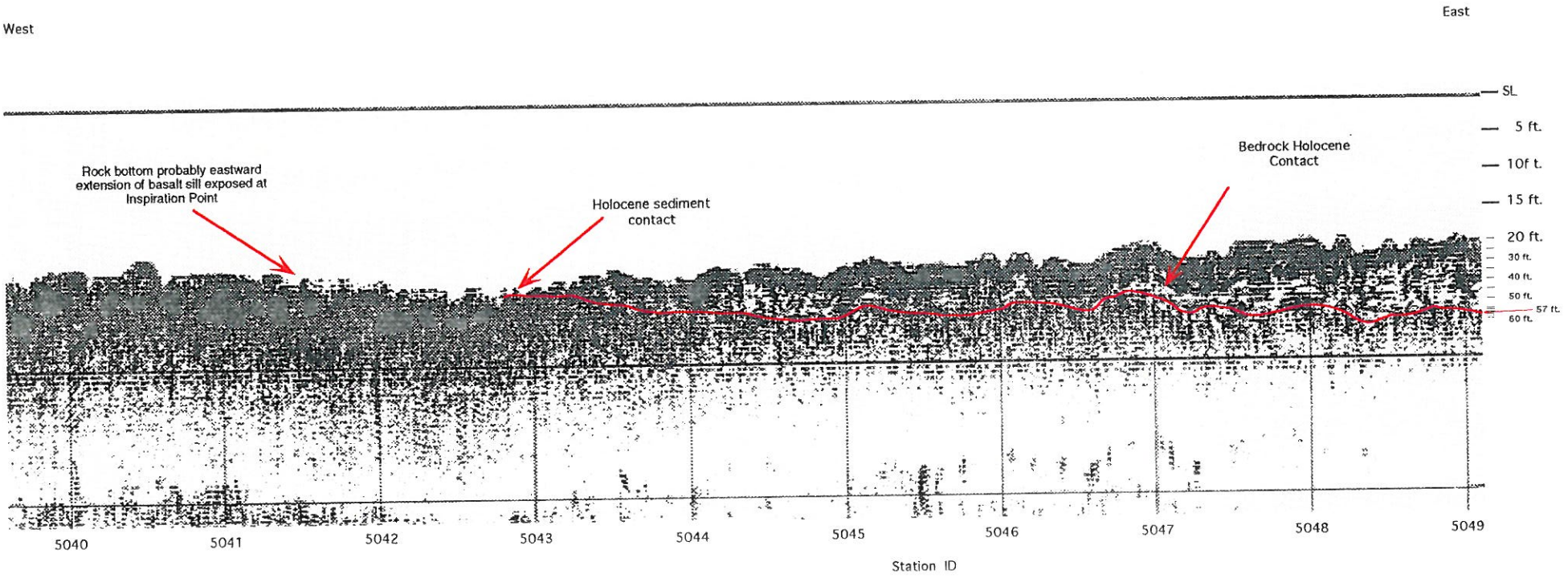


Figure 9. Scan of the 3.5 KHz seismic record along the 20 foot contour line. Station ID No. 5043 is at the contact with what we interpret to be an extension of the basalt sill exposed at Inspiration Point on the west side of the Portuguese Bend Landslide. Note how the acoustic energy is attenuated beneath the basalt layer. Holocene sediment thickness at Station ID No. 5049 is 37 feet. Note the depth scale change at the seafloor that reflects the increased sound velocity in the Holocene sediment.

Geological structures

Although the Holocene sediments appear to have been undisturbed for at least the last 2,000 years, the underlying Miocene bedrock show evidence of considerable tectonic movement and structural deformation. A well developed fault zone in the bedrock, strikes diagonally in a southwest direction across the survey area. It can be traced to a zone of contorted beds on land seen in the cliffs that form the southeastern boundary of the survey area.

East of the landslide, beyond the survey area, a major fault system on land associated with resistant hydrothermally altered sediments, trends seaward into the survey area. Along this trend seismic records show contorted bedding with an irregular topography on the bedrock erosional surface that could be attributed to faulting. Strata adjacent to the fault exhibit gentle folds as would be expected with tectonic movement along a fault. The important implication to this study is that none of the Holocene acoustic lenses or bedding overlying this fault zone are displaced, indicating the area has been stable for at least the last 2,000 years.

The southern part of the survey area near the shelf break, has well defined bedding dipping to the south. This probably represents well developed and acoustically definable beds of the Miocene Monterey Formation. These beds would be geologically younger than the beds seen under the Holocene cover near shore.

Basalt Sill

The basalt sill that protects the seaward margin of Inspiration Point extends to the east as exposed bedrock on the seafloor, forming a resistant structural restraint to landslide movement. Seismic profiles indicate that a layered bedrock formation underlies the basalt sill and gently dips to the southeast. The seaward faces of both Portuguese and Inspiration Points are defended by a resistant basalt sill (Fig. 10). One of the objectives of this study was to determine if this sill extended to the east seaward of the Portuguese Bend Landslide. Seismic records are not definitive, but there is a hard rock body with out bedding extending to the east under the Holocene sediments. This could be a eastward extension of the basalt sill that outcrops at Inspiration Point. Bedrock with distinct bedding underlies this massive rock body that we interpret to be basalt (?). Near the Point, Holocene sediment is thin or missing, however, it thickens eastward reflecting the sediment source formed by the erosion of the toe of the landslide (see Fig.9). These Holocene sediments have strong lenticular reflectors indicating cobble beds (Fig. 8). If present, cobble and boulder lenses would make vibrocoring impossible. Vibrocoring would not be effective in retrieving samples of volcanic or densely cemented bedrock. However, shoreline drilling should be

able to obtain bedrock samples to define the age, lithology, and structural competence of basalt and bedded formations.

The basalt and dolostone outcrops within the surf zone just east of the present landslide extend to the west under a thin blanket of Holocene sediment. Its eastward extent could not be determined in the seismic records. Coring at the shoreline should indicate if the basalt extends all the way to Inspiration Point or to the east beyond the landslide. If present, this rock type could form an excellent bedrock anchor for a protective structure to defend the landslide toe from future wave erosion. However, drilling is the only way to positively prove this possibility.

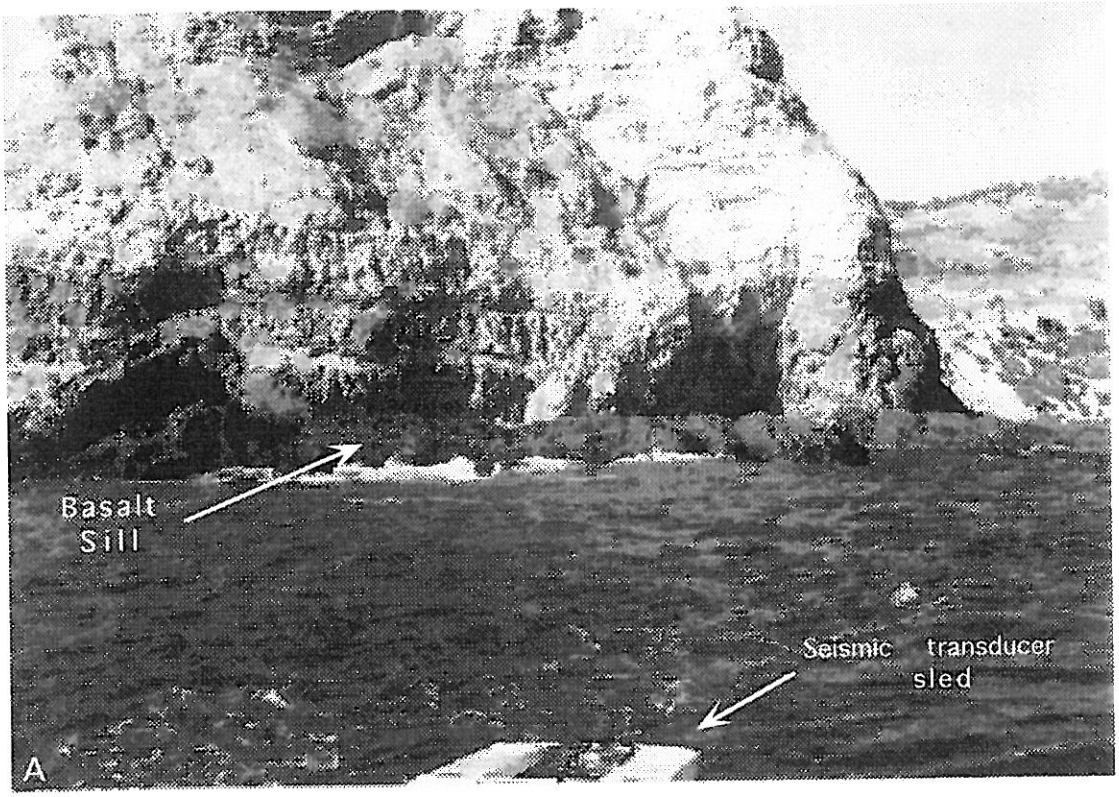
Side-scan records show that the contact between the basalt and the sediments covering it within Portuguese Bend Bay is sharp and near the present shoreline. This cover of sediment extends all the way to the shoreline exposures east of the active landslide. Visibility underwater is limited due to suspended sediment from the erosion of the landslide by wave action. Therefore, it is not expected that diving to determine if there are rock-outcrops protruding through the sediment cover would provide more information than the sides-scan records. Because of this limited visibility and a low likelihood of encountering bedrock exposures on diving traverses, we do not recommend a diving program to obtain bedrock data in the next phase of this project.

Folds

Seismic profiles and side-scan reflections from rock outcrops show that the bedrock within the survey has suffered tectonic folding. Many of these folds are associated with faults and take place over short distances (less than 100 feet). Bedding becomes more distinct south of the shoreline landslide toe as one approaches the shelf break at a depth of 250 feet approximately one and a quarter miles offshore. In this region beds dip to the south between 10 and 20°.

Portuguese Tuff

There are no distinct marker beds within the acoustic stratigraphy that could be interpreted as representing reflections from the Portuguese Tuff. Therefore, it is recommended that drilling be done at the shoreline to determine whether the Tuff extends offshore and if it is below the seaward dipping beds seen in the seismic profiles. Stratigraphy would place the beds seen dipping to the southeast in our nearest seismic profiles ID# 5041 and 5048 (Fig.11) located approximately 600 feet south of the tuff in the toe of the landslide and in a southerly direction in profile ID# 4117 to 4122 (see Fig. 8), to be stratigraphically above the tuff. Therefore, if the tuff extends offshore it should be seen in cores at the shoreline which would be stratigraphically below the offshore southeasterly dipping beds seen in our seismic records



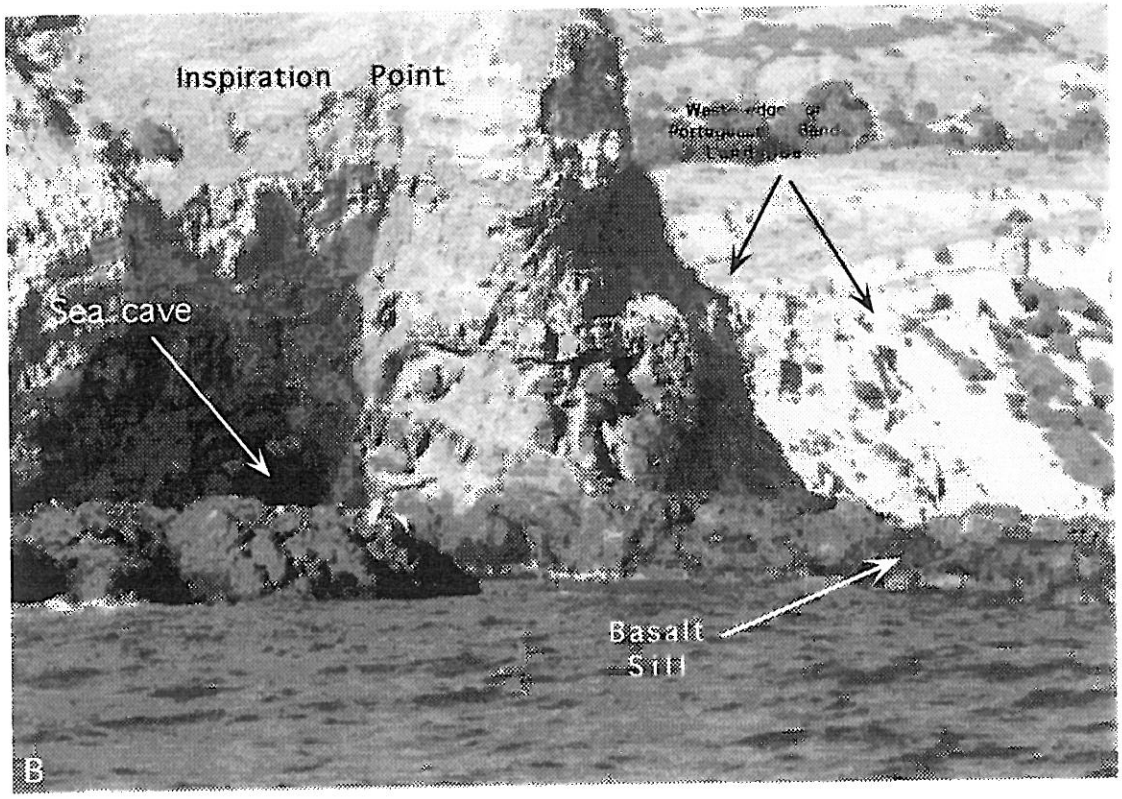


Figure 10. Looking north at Inspiration Point showing basalt sill and associated metamorphic rocks that defend the point from wave erosion. In background of B are the slump scars of the Portuguese Bend Landslide.

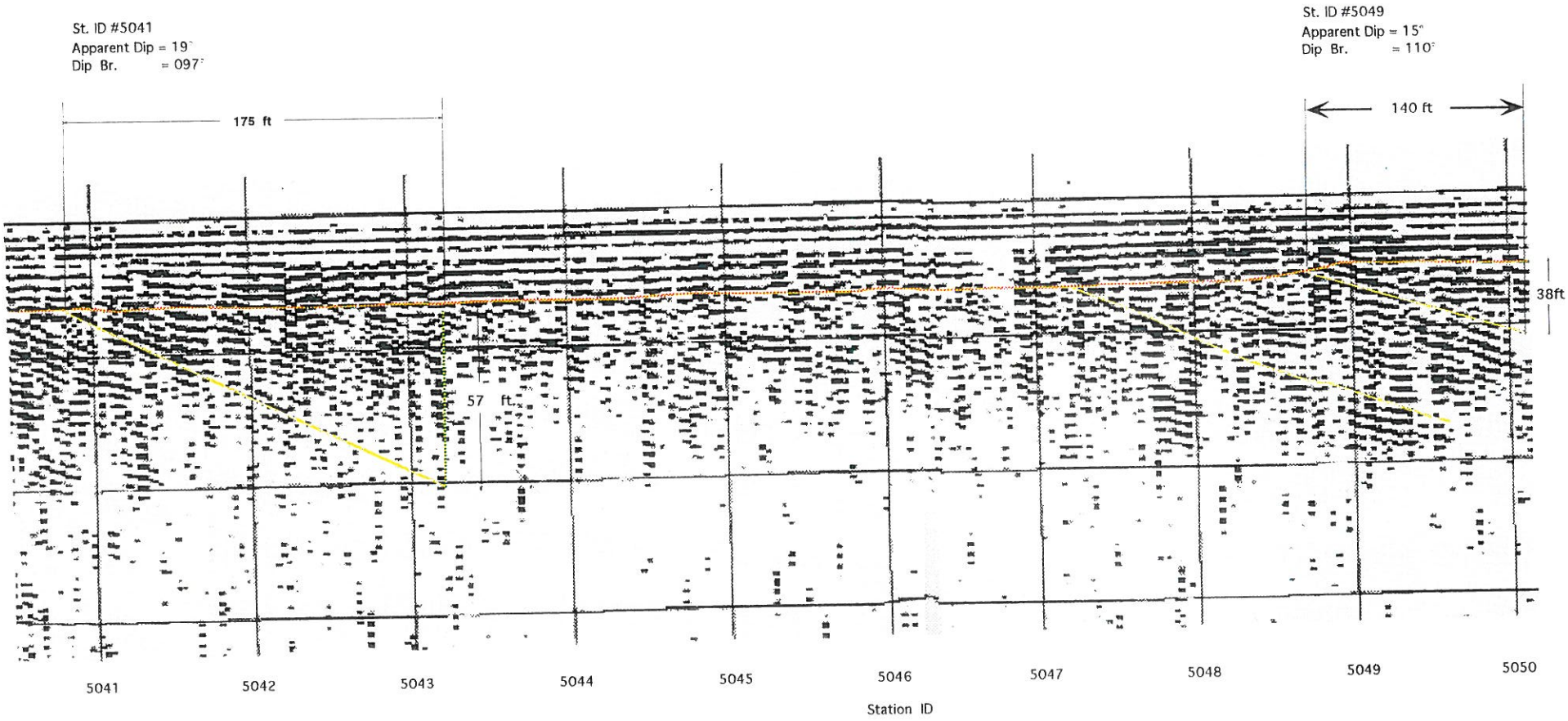


Figure 11. Station No. # 5041 to #5050 a "Boomer" seismic profile along the 20 foot contour line. ApparentDips are calculated using a rock velocity of 2110 m/sec (6920 ft./sec). Dip Bearing is calculated using the track trace on a 360° plot. This figure can be alined with Figure 10 which covers the same track.

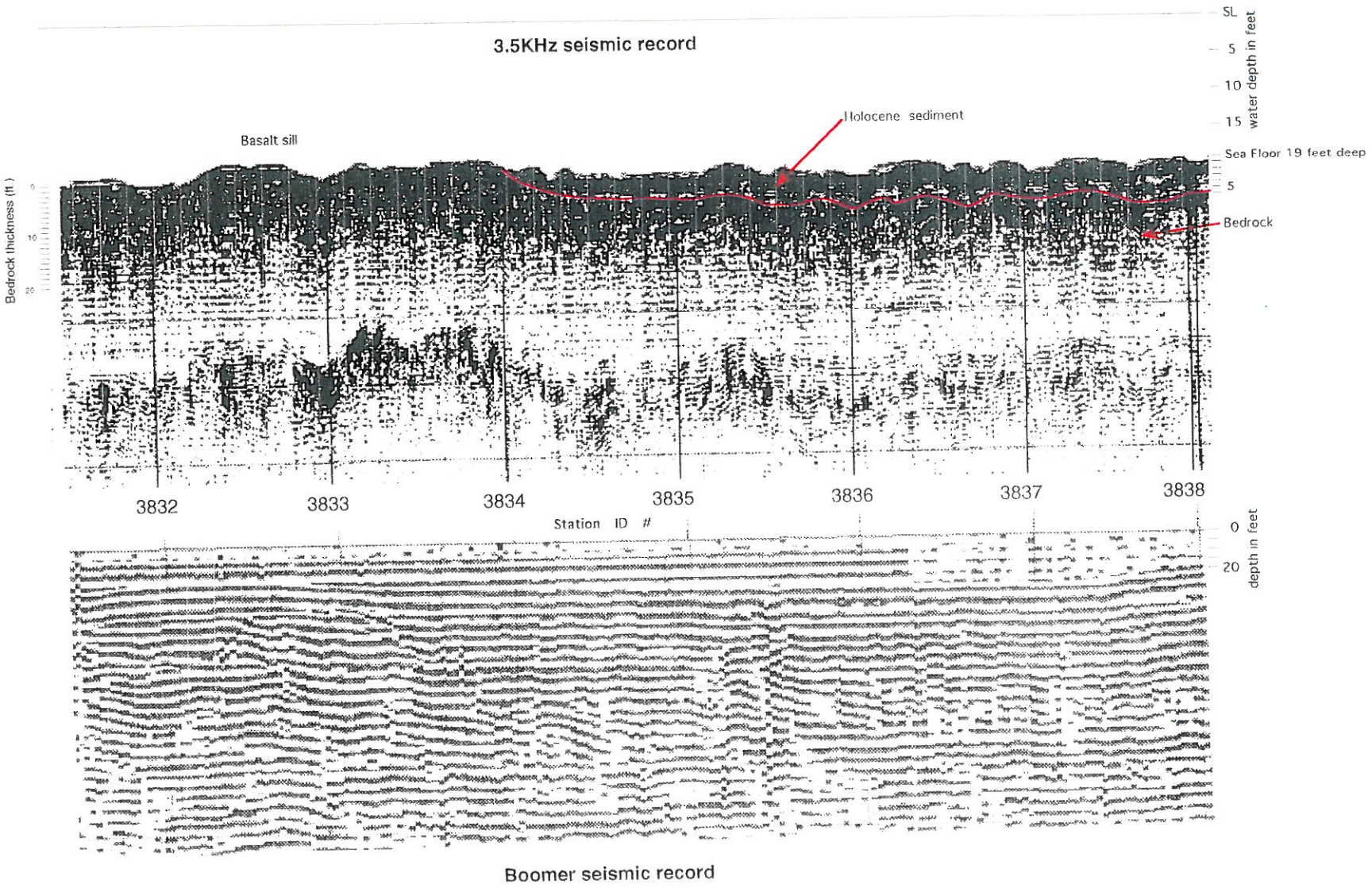


Figure 12. West to east traverse approximately 300 feet seaward of the toe of the landslide. Apparent dip of beds is zero indicatine the vessel was going along the strike of bedrock bedding. A traverse 90° to this one (Fig. 11) showed beds had an apparent dip of 13° to the north. True Dip Bearing would be 015° at a dip of 13°.

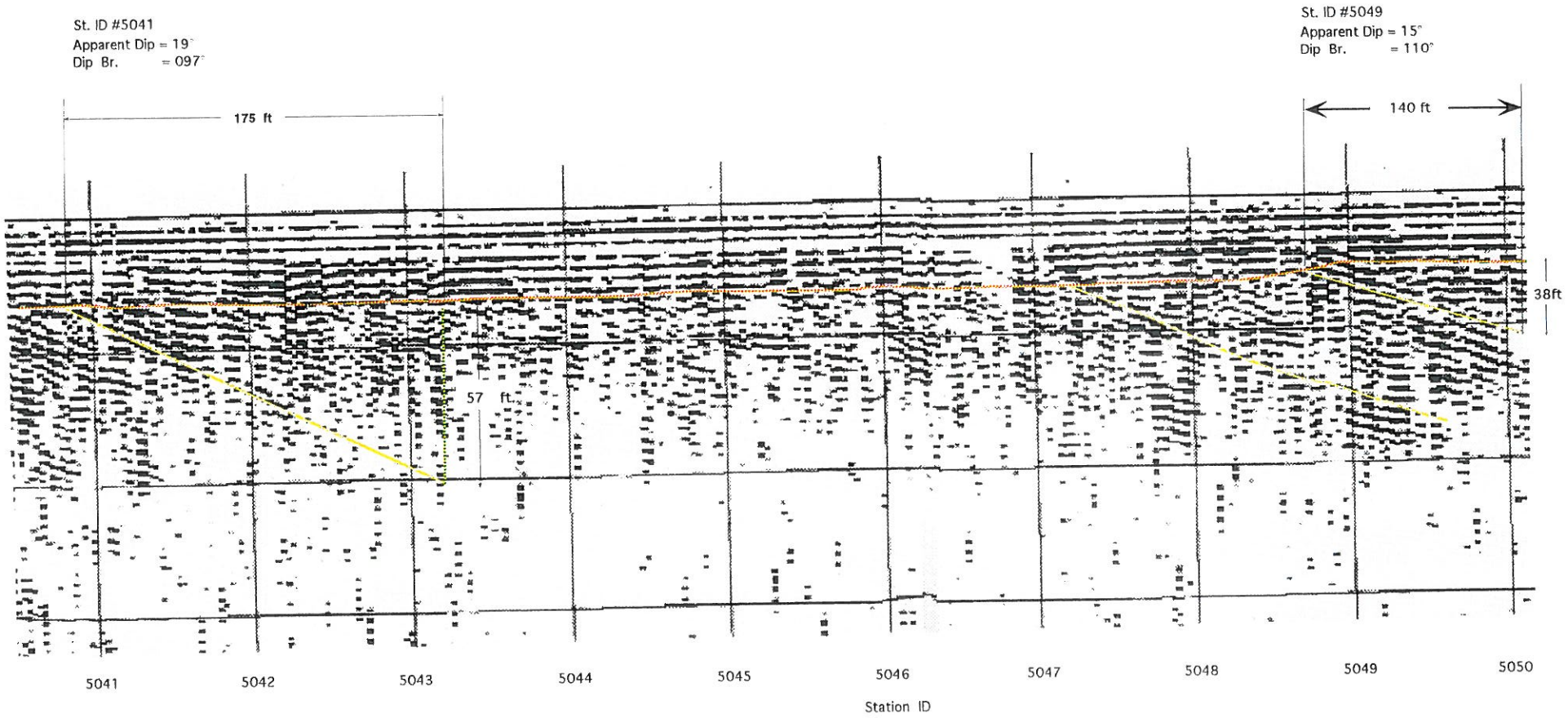


Figure 11. Station No. # 5041 to #5050 a "Boomer" seismic profile along the 20 foot contour line. ApparentDips are calculated using a rock velocity of 2110 m/sec (6920 ft./sec). Dip Bearing is calculated using the track trace on a 360° plot. This figure can be alined with Figure 10 which covers the same track.

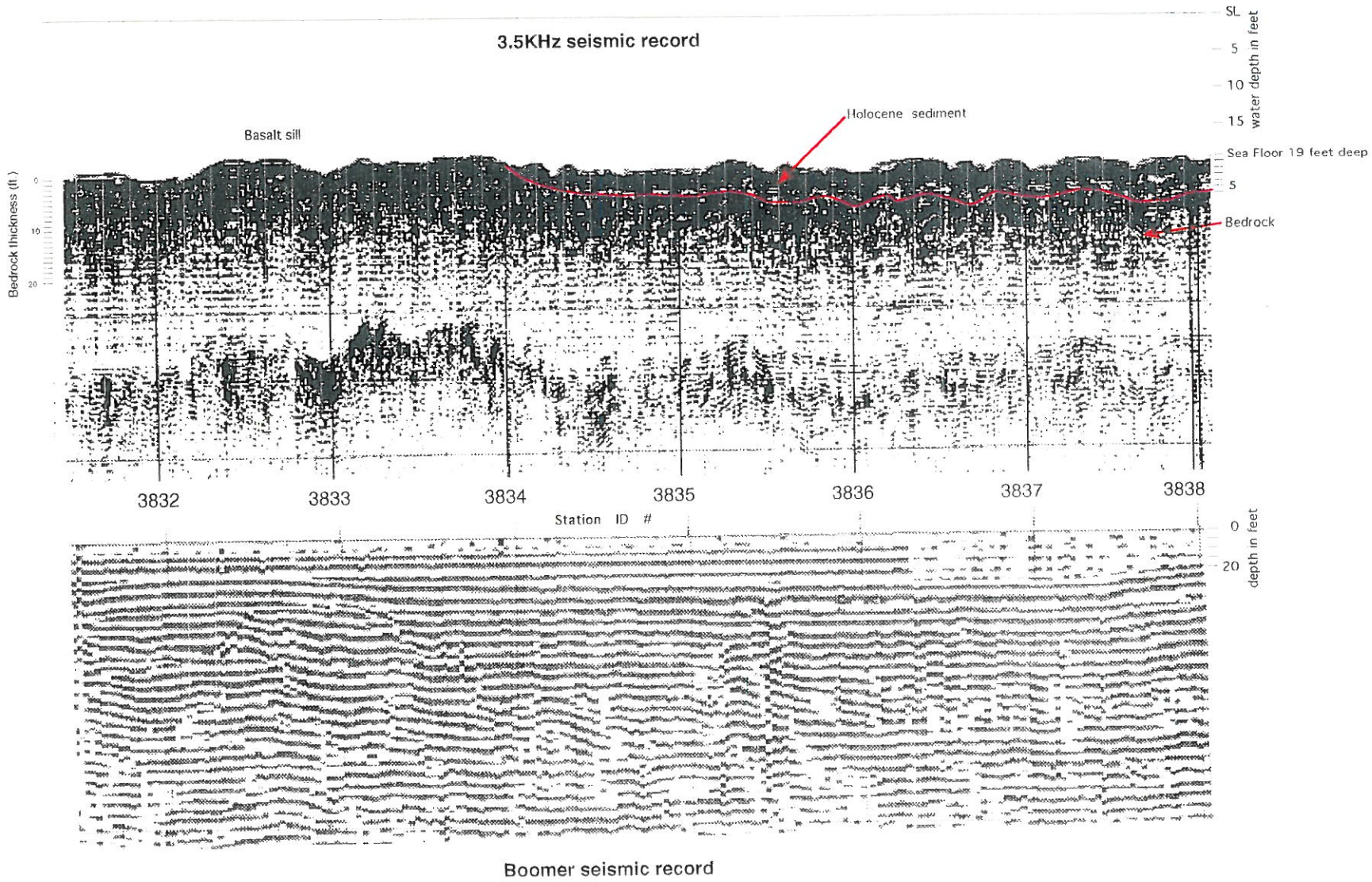


Figure 12. West to east traverse approximately 300 feet seaward of the toe of the landslide. Apparent dip of beds is zero indicatine the vessel was going along the strike of bedrock bedding. A traverse 90° to this one (Fig. 11) showed beds had an apparent dip of 13° to the north. True Dip Bearing would be 015° at a dip of 13°.

Nearshore Seismic Line

The shallowest seismic line closest to shore off the landslide skirts the eastern side of Inspiration Point and traverses to the east (#3832 - 3838) (Fig. 12). This figure shows a scanned record from both the 3.5KHz and "Boomer" records for comparison of geological features. The original records of the 3.5 KHz profile are much better in showing definition within the overburden due to difficulties in scanning the original records.

Bedrock probably basalt and associated hydrothermally altered shales and limestones form the seafloor with little to no sedimentary cover. Rock bottom extends to the east to #3834 where Holocene sediments overlap the bedrock as it looses relief, possibly due to a change in rock type and resistance of bedrock to erosion. The Holocene sediments have highly reflective internal bedding indicating cobble lenses. Bedrock internal reflections along this easterly traverse are flat lying indicating the vessel was following the strike of the beds. This would indicate that the beds have a east-west strike. Traverses perpendicular to this one show a shallow dip to the south (see Fig. 11).

Representative Profiles of Sediment Overlying Bedrock

Because of the large number of crossing track lines and their similarity, it would be confusing to present each as a separate profile showing depth, sediment thickness over bedrock and underlying geological structure. We have, therefore, chosen a few profiles that contain features that represent the western, central and eastern sides of the seafloor seaward of the active landslide. The length of seismic profiles running north-south relative to the thickness of sediment mandates that we show these profiles with a high vertical exaggeration in order to place them within the written report and still be able to see the Holocene sediments.

It is important to point out that the spacing between Station ID locations is not a constant distance but a constant time between navigation locations, a period of 15 seconds. However, the survey vessel was kept at a constant engine RPM which provides a nearly constant distance between Station ID locations. In general, the distance is approximately 125 feet as the vessel averaged a speed of about 4 nautical miles per hour during the survey. Exact distances can be obtained by measuring the distance between stations located on the large scale map showing station ID numbers in Appendix D.

Two profiles running parallel to the shore. One is a composite of east-west, nearshore tracks as we traversed to the next north-south line. The other is the closest track-line traversed along the 20 foot contour line, just south and seaward of areas of isolated rock outcrops that made a continuous vessel traverses closer to shore hazardous. Kelp beds attached to the rocky bottom also prevented us from towing our seismic gear closer to shore

than this long traverse parallel to shore (Fig.13). One diagonal traverse was made to cross check north-south and east-west traverse lines. The location of the traverses are shown on the nearshore map of the shoreline and land features with *northing* and *easting* coordinates. All distances and depths are in feet.

Nearshore Profile (Fig.13)

Profile ID #5040 to #5081 runs in a west to east direction parallel to the shoreline along the 20 ft. contour line, approximately 600 feet offshore. Parts of this traverse are shown in Figure 9, which is a scanned image of the seismic record showing internal structures in the Holocene sediments and the irregularly eroded surface of bedrock. Sediment covering bedrock varies in thickness between 0 feet and 8 feet.

Diagonal Profile (Fig. 14).

The diagonal line running from the southwest side to the northeast side crosses the survey area from near the shelf break to the nearshore corner of the survey area (Profile ID #3488 to #3532). Sediment thickness thins toward the shore. Internal reflections indicating cobble or coarse-grained sediment become more numerous as one approaches the shore or northeast side of the survey.

There are no rock outcrops along this traverse. Bedrock surface beneath the Holocene cover is irregular, indicating variability in rock resistance to erosion when this surface was exposed to subaerial erosion prior to the Holocene rise in sea level. Nearshore submarine erosion and waves have also caused differential bedrock erosion within the surf zone as its surface was flooded by rising sea level. Only a thin sediment covers the bedrock at the end of the traverse and in places there are rock exposures. The traverse ends approximately 300 feet offshore at 4178232 east and 4015939 north at a water depth of 36 feet. The sedimentary seafloor has a gentle seaward slope of 1.1 degrees and has almost no relief along the entire traverse.

Composite Near shore Profile (Fig. 15).

This profile is a composite of the inner west to east portions of three north-south traverses. We were able to make the nearshore traverses in these areas because they avoided kelp beds growing on rocky bottom and missed bedrock highs that were a hazard to the boat towing seismic gear. Profiles start at the western side of the landslide and runs roughly parallel to the shore. Station ID numbers are identified at the bottom of the profile and can be located in Appendix D, and on the profile location tracks plotted in gray on the location map at the top of the figure. Depth contours are given on the location map in feet at a contour interval of 25 feet. Water depths vary along the traverse but were all less than 20 feet and closer to shore than the traverse shown in this figure and in Figure 13, which ran along the 20 foot contour line. Note that there is no sediment cover between #2755 and

#2759. This is an area just seaward of the Portuguese Bend Landslide. Also sediment thickness is less than seven feet all along the traverse. High resolution 3.5KHz records did show there are strong layered and lenticular shaped horizontal bedding within the Holocene sediments covering the bedrock. These reflectors are probably cobble beds.

West side N/S Profile #2494 to #3760 (Fig. 16)

Starting nearshore this profile starts at the western edge of the landslide, skirts the eastern side of Inspiration Point and terminates approximately half way across the shelf at a depth of 140 feet. Nearshore Holocene sediment thins rapidly as one approaches Inspiration Point and skirts rock outcrops extending east of the Point. Kelp beds growing on isolated outcrops of bedrock or in areas with a thin overburden, extend eastward from Inspiration Point out to the traverse. Traversing seaward sediments thicken and loose internal reflectors, indicating a more homogeneous structure than the nearshore area. Sediment thickens all the way to the shelf break (not shown in this traverse but seen on adjacent profiles not presented) forming a featureless sedimentary seafloor.

Eastern side N/S Profile ID #3006 to #2902 (Fig.17)

This profile runs south from the eastern edge of the active landslide. The inner portion has a thin cover of Holocene sediment with numerous lenses of acoustic reflectors, interpreted as cobble beds. The traverse crosses the exposed bedrock ledges of the rocky bottom that forms the eastern margin of the survey area. The contact between the bedrock and the sediment lapping up on the bedrock high is sharp, with several reentrants and well developed surge channels. The bedrock has a well developed kelp forest attached to its stable surface. Seaward of the rocky bottom, the sediment thickens out to the shelf break at a depth of 320 feet. The sediment surface is smooth with almost no relief.

Center N/S Profile ID #6007 to #6095 (Fig. 18)

This profile runs south from the center of the active landslide shown in Figure 1 and Appendix A, out to the shelf break at 240 feet. Sediment thickens seaward from a thin blanket near shore to the center of the traverse and then thins toward the shelf break. The sediment surface is featureless with almost not relief. Bedrock under the Holocene cover has a low relief. A well defined fault zone cuts the traverse at Station ID #6042 to #6044. Bedding within the bedrock dips in opposite directions at the fault contact, probably representing drag folds.

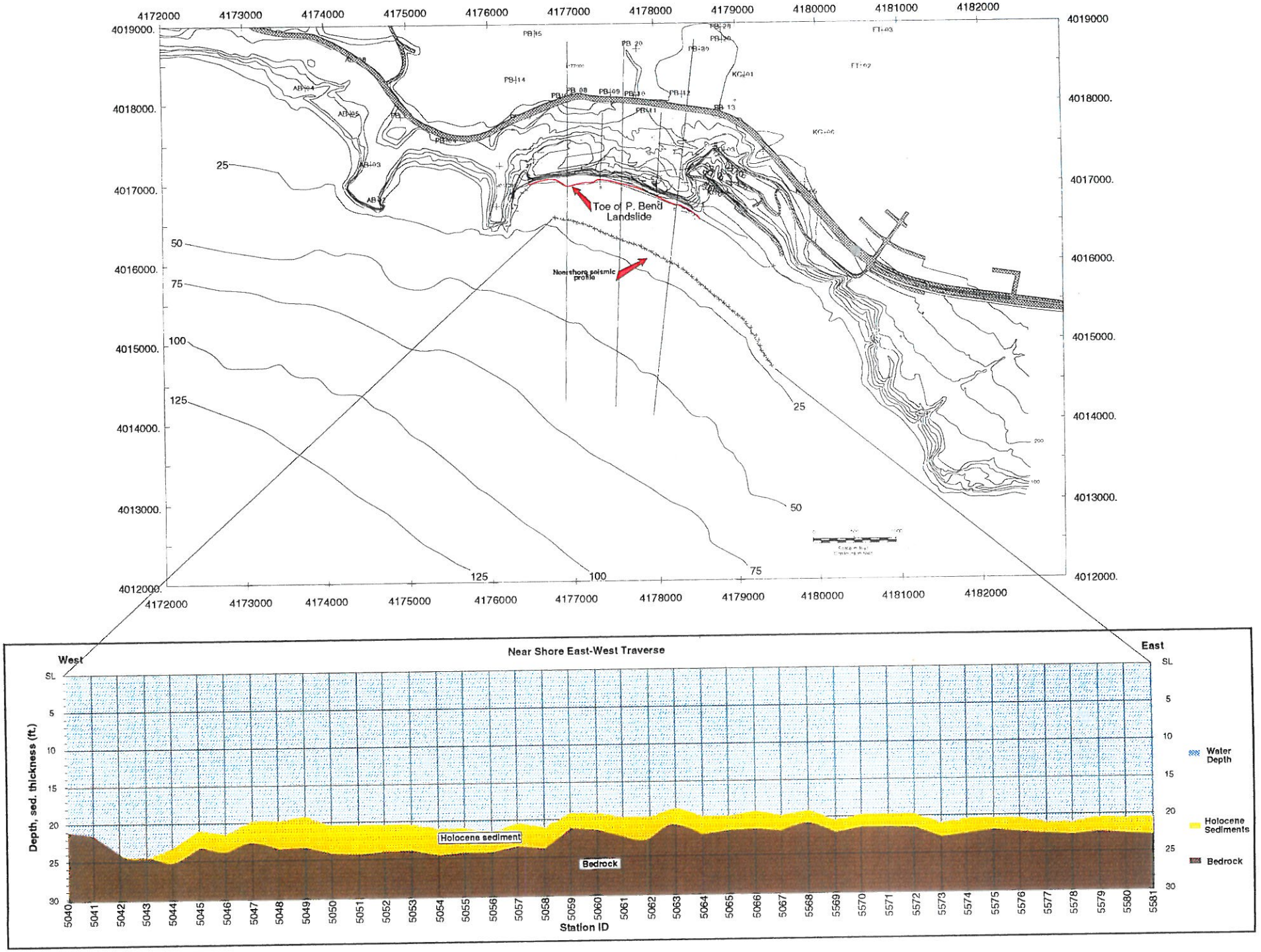


Figure 13. Offshore seismic profile ID # 5040 to 5081 showing Holocene sediment cover relative to the Palos Verdes Portuguese Bend Landslide. Holocene sediments, contours and depths are in feet.

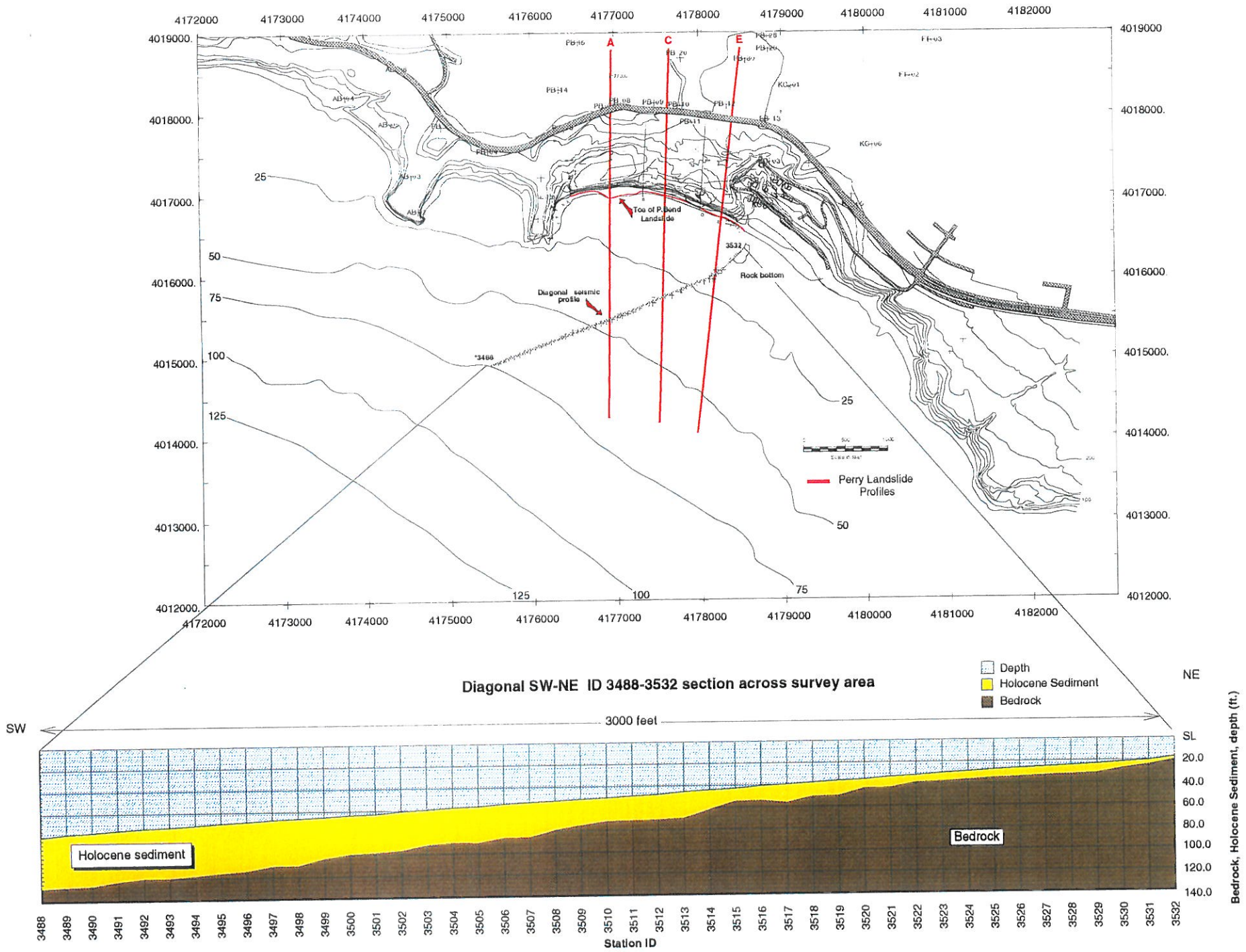


Figure 14. Offshore seismic profile *3488 to *3532 showing Holocene sediment cover over bedrock relative to the Portuguese Bend Landslide. Holocene sediments, contours and depth measure ments are in feet.

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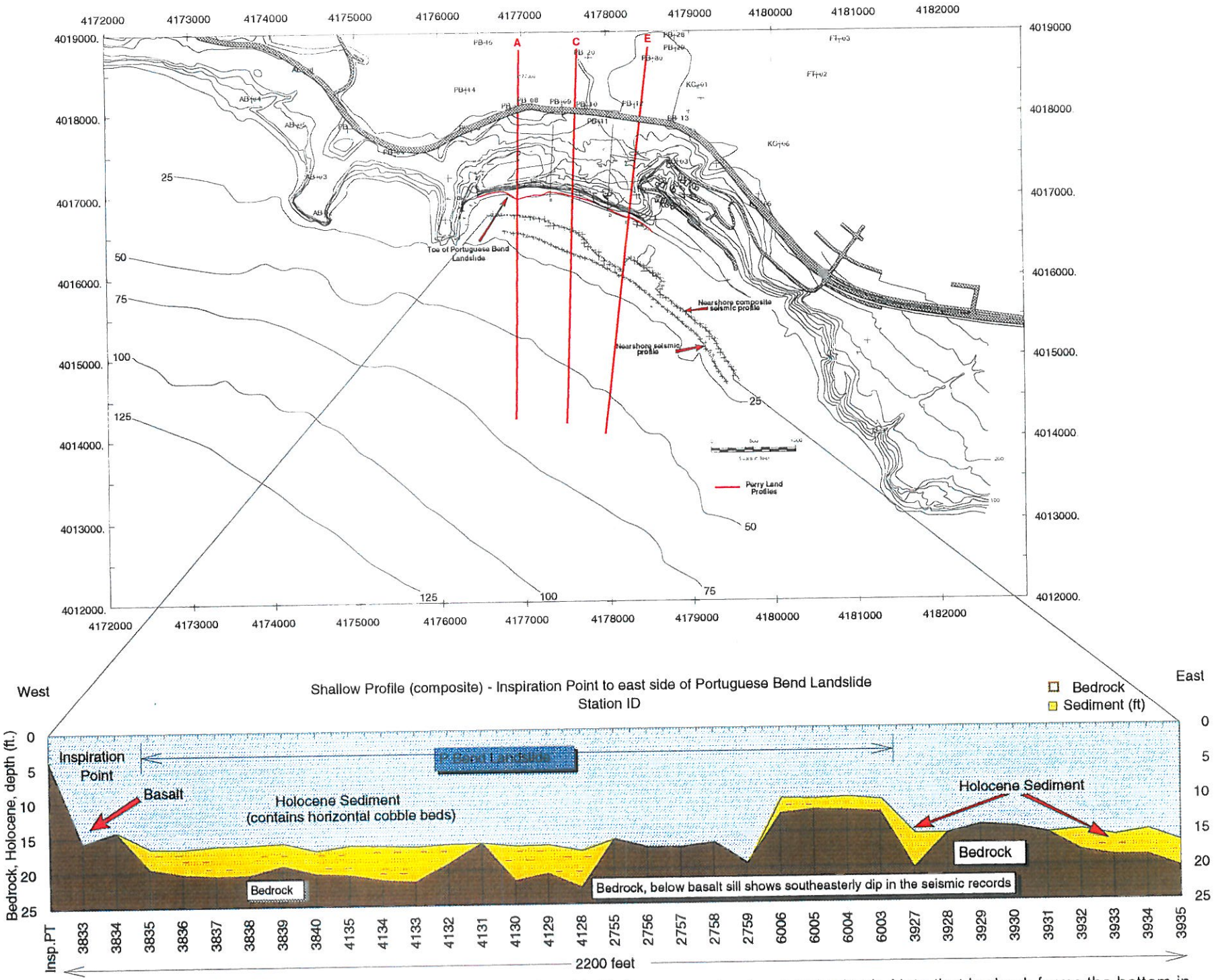


Figure 15. Composite profile of shallow traverses closest to shore showing thin Holocene overburden over bedrock. Note that bedrock forms the bottom in several areas, near Inspiration Point on the west, in the central area off the eastern side of the Landslide and off basalt and dolostone natural groins on shore.

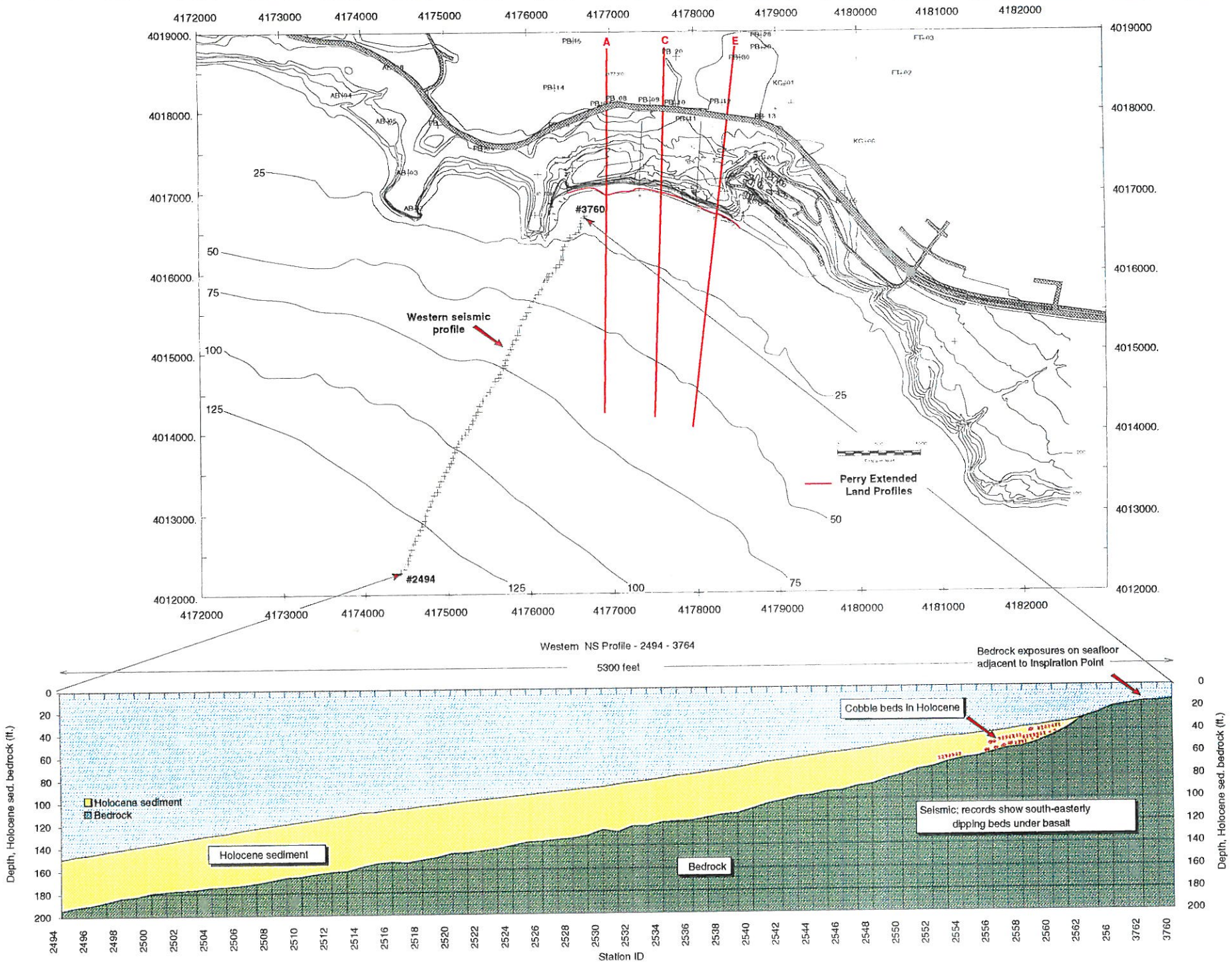


Figure 16. Western side of Portuguese Bend Landslide. Traverse runs north-south along the eastern margin of Inspiration Point. Cobbles and coarse sand are abundant near shore between stations 2562 and 2552 that would make vibrocoring in this area difficult. Sediment thickens seaward and the sediment bottom is featureless with little relief. Note: large vertical exaggeration (5.3 to 1).

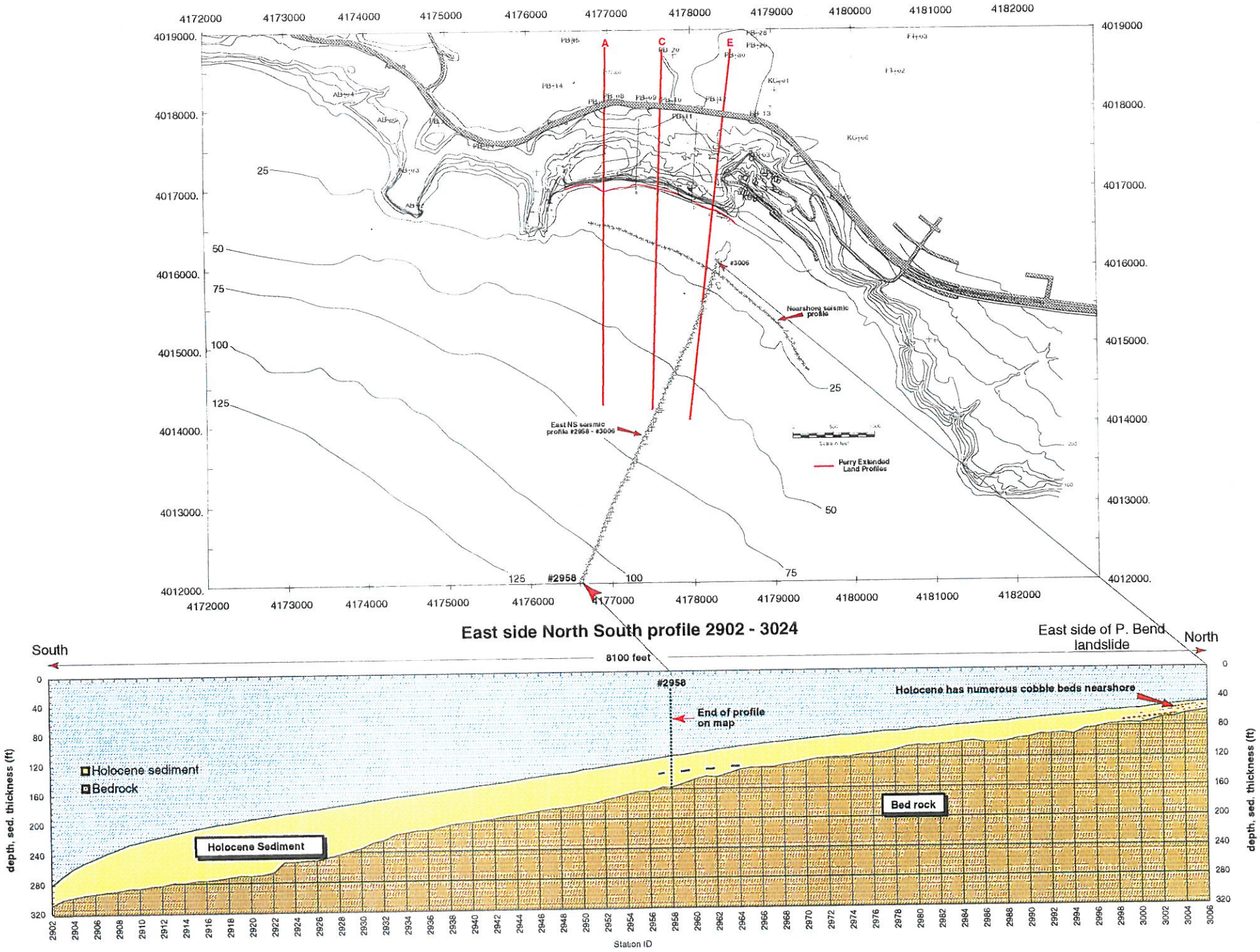


Figure 17. North-south profile from shelf break to the eastern side of the Portuguese Bend Landslide. Note that track on map does not go to the end of the profile. Vertical exaggeration is 5.2.

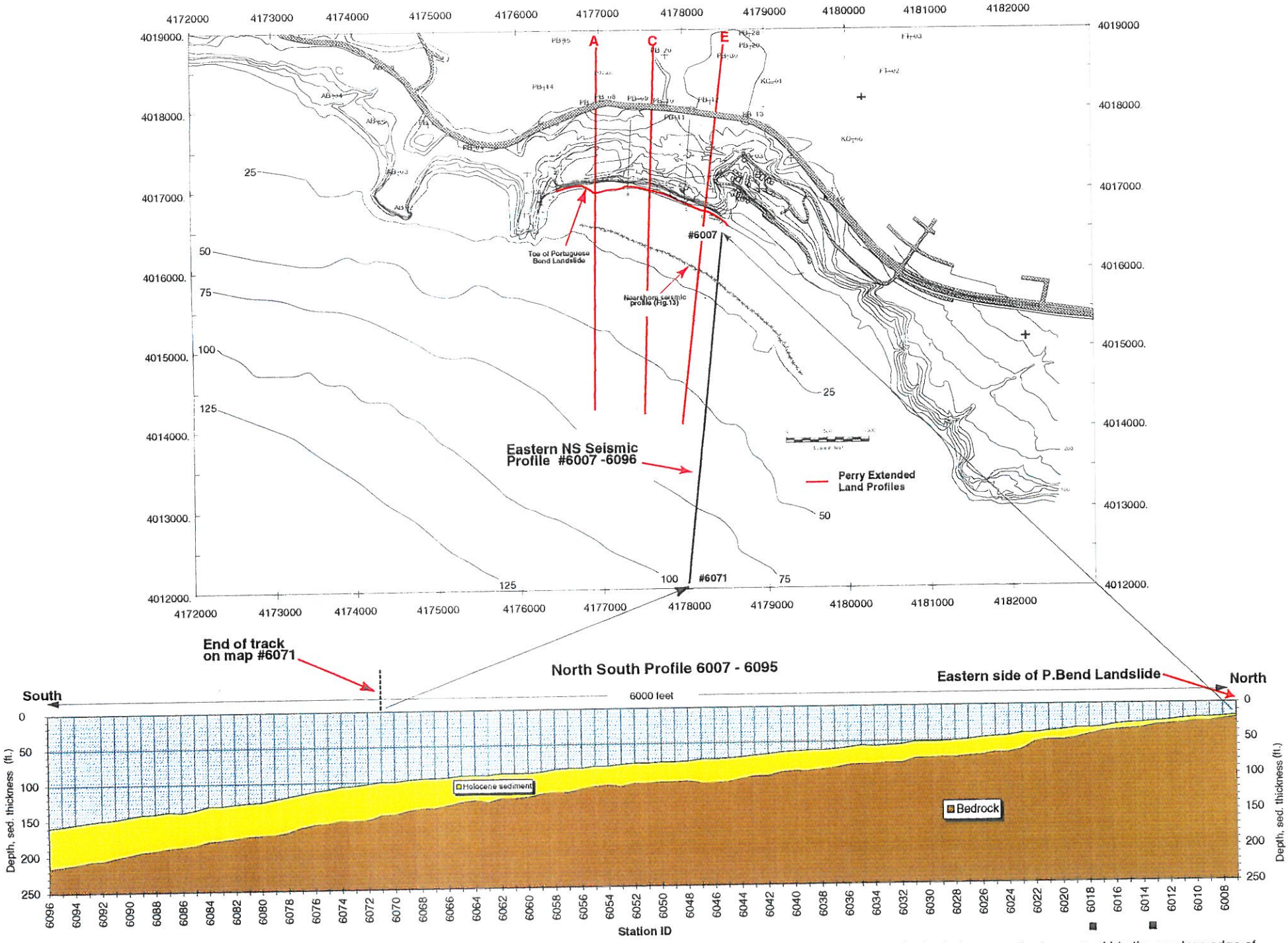


Figure 18. NS profile running south from the eastern edge of the Portuguese Bend Landslide. All of the traverse was over a Holocene covered bedrock, however the traverse skirts the western edge of a rocky bottom that forms the eastern edge of the survey area. Note that the profile extends beyond the boundary of the location map. Vertical exaggeration 3.6 to 1.

Profile Summary

All profiles, those presented and those seen on the original survey records show there is a thin cover of coarse sediment with cobble beds nearshore. This Holocene sedimentary body looses internal reflectors approximately 1,000 feet offshore in depths beyond 40 feet. Holocene sediments thicken seaward out to a depth of approximately 200 feet, where sediment transporting currents are no longer capable of carrying near shore derived sediments to the shelf's outer edge.

The major east-west fault that crosses the area can be seen on all north-south traverses. Although there is an indication of vertical displacement of bedding within bedrock at the fault, this is not reflected in the overlying Holocene cover. Undisturbed sediment with flat lying internal bedding overlying the disturbed areas in underlying bedrock, indicates that the fault has not been active since being covered by Holocene sediment, approximately 8,000 to 5,000 years ago. Prior to that period this was dry land with no marine sedimentation. Traverses made seaward of Portuguese Bend Landslide are similar to those made in the 1989 Abalone Cove survey using the same equipment. Therefore, it was possible to combine data and construct a map relating major landslides affecting the south shore of Palos Verdes Peninsula.

Comparative Studies

Abalone Cove Survey

Many of the reflective acoustic discontinuities found during our 1989 side-scan and seismic survey of Abalone Cove Survey are also seen in this Portuguese Bend survey records. Therefore it is useful to review previous findings, relating cored sediments to acoustic reflectors, because they can help in the interpretation of the records from Portuguese Bend where cores have not been taken. The findings from the Abalone Cove Survey also provide information on the feasibility of vibrocoring and whether any additional subbottom information could be obtained by vibrocoring in Portuguese Bend.

The Abalone Cove Survey was designed to determine if bottom topography or sedimentary features, seen in seismic records, indicated recent movement along landslide glide planes in bedrock or in the Holocene overburden covering bedrock in Abalone Cove. A thick blanket of Holocene marine sediments covers most of the bedrock of this area. Truncated bedrock bedding forms a gently seaward sloping rock surface that shows this region was subjected to nearshore erosion, prior to, or during the last rise of sea level. The sedimentary blanket seen in the seismic records must have been deposited since this flooding and must therefore be less than 3,000 years old, probably much younger. High resolution seismic records show that acoustic reflectors in the Holocene sediments are lenticular in shape and concentrated in zones that run parallel to the present shoreline. We

interpreted these to be old cobble beaches and berms deposited during still stands of sealevel as it flooded the Continental Shelf following the melting of the Pleistocene ice sheets. Similar lenses were seen in the seismic records made in Portuguese Bend Cove out to depths of 30 to 40 feet. Nearshore vibrocores showed that the seismic reflectors were cobble beds, probably laid down as lobes of prograding beach cobbles similar to those on the present shoreline. We were not successful in penetrating any of the cobble areas with multiple layers. The maximum penetration of the four inch diameter vibrocores in Abalone Cove was 4 feet. Cobbles and coarse pebbles encountered at the 4 foot depth prevented sampling at greater depths. We were unable to core material anywhere we found the pronounced acoustic reflective layers. It is important to point out that Portuguese Bend Cove has more numerous and thicker beds throughout the area seaward of the presently active landslide than Abalone Cove.

In April of 1989, linear ridges were seen on the side-scan sonar records directly seaward of the Abalone Cove Landslide. We were suspicious that they might be a seafloor expression of the onshore landslide. However, they were not found upon reinvestigation in October, 1989. It appears that the ridges seen in April were caused by the unique oceanographic and sedimentary processes active within Abalone Cove. Linear ridges of bottom sediment within the depth range of strong swell-induced bottom currents (less than 40 feet) proved to be lobes of coarse sediment that change form by both erosion and transportation by storm-swell generated bottom currents. Coarse beach sands are carried seaward by rip currents during storms forming a prograding lobe of nearshore sands. The linear ridges seen on the side-scan records are believed to be reflections from the seaward side of the elevated prograding wedge of sediment moving seaward from shallow water. The most likely source of this coarser sand is erosion of the onshore toe of the landslide within the surf zone during most of the year. During periods of high swell and during winter storms this sediment is mobilized and carried seaward by rip-currents forming broad lobes of sediment running roughly parallel to the present shoreline. The orientation of the ridges is parallel to the refraction patterns of swells entering Abalone Cove during storms. Coarse shoreline sediments and landslide debris carried seaward, thus prograde over the smoother and finer grained offshore sediments, forming lobes of sediment, the seaward edges of which form linear ridges. After storm periods, swell induced bottom currents weaken and bioturbation becomes the dominant sediment transportation mechanism. High energy bedforms, giant ripples and lobes of coarse sediment, spread out and loose the relief that was detected as linear ridges by the side-scan sonar.

The change in the nature of the linear ridges, found during the two phases of the Abalone Cove study do not support the contention that the linear ridges are sea floor

expressions of a projected zone of weakness within weathered basalt that has been encountered in onshore core holes. The seismic and core evidence indicate that the present active landslide terminates at the shoreline along the northeastern margin of Abalone Cove and does not extend offshore.

Bioturbation and continued low energy wave activity smooth out storm generated relief after sediment transport ceased and sedimentary boundaries became less distinct. Both side scan-sonar and diving observations showed that there is no surface expression of landslide activity seaward of the present shoreline exposure of the slide plane.

However, because of the inability to use boat supported side-scan and seismic instrumentation shoreward of the surf zone, along with the dense kelp beds over the nearshore rocky bottom, the seismic survey could not cover shallow areas with enough detail to positively conclude that there has not been ancient movement along sub-bottom acoustic discontinuities within the bedrock out to depths of 15 feet, the minimum safe depth to operate a boat in this area.

However, the lack of exposed cobbles ridges or any indication of exposed beds thrust to the seafloor from below is strong evidence that Holocene sediments have been stable since the flooding of the region during the Holocene rise of sea level. Undistorted acoustic reflections (that coring showed to be buried cobble beds) are strong evidence against offshore recent landslide movement for at least the past 3,000 years.

Divers found outcrops of basalt in the central part of Abalone Cove, where a set of linear ridges appears to trend into an abrupt break in bottom type. This would indicate that the western margin of the "ancient landslide", described in Ehlig (1987), is stable and rock outcrops are not displace Miocene sedimentary rock carried seaward by an old landslide slip plane. Although this boundary, has a similar trend and lines up with a suspected ancient landslide boundary and valley on land, (Robert Stone, et al., 1987), it does not appear to be active at this time and is probably a sediment filled channel formed during lowered sea level.

However, important questions remained after the survey. We could not determine from the data collected if past landslide movements extended offshore prior to Holocene deposition. We know this was a time when the larger ancient landslide covering much of the region shoreward of the Abalone Cove Slide was active. Most importantly we could not determine without offshore drilling, if planes of weakness within the bedrock of the region resulting from these ancient landslides could be reactivated and displace all proposed remedial mitigation efforts planned for the Abalone Cove area.

It was submitted to the Rancho Palos Verdes Abalone Cove Technical Panel to provide them with a more complete picture of the offshore geology of the region and the nature of

the overburden blanketing the ancient bedrock erosion surface. The primary goal of determining if the present day onshore landslide activity extends offshore, was achieved with a determination that there is no displacements of cobbles or sediment overburden that has accumulated over the past 3,000 years.

Because of the possibility of misinterpretation of the seismic data and the limited numbers of shallow cores we were able to take in the Holocene cobble rich sediment we feel it would be prudent to check the possibility of a deep weak zone with a high hydraulic pressure capable of reactivation of an ancient landslide be checked by drilling a test well at the shoreline just seaward of the active landslide. Instrumentation within this core hole could obtain data that would insure that the basalt shear zone observed farther inland is no longer active.

This review is included in this report because similar conditions appear to be present within in Portuguese Bend Cove and should be considered in the oceanographic, geological and geophysical parts of this feasibility study. More details are available in the Final Report submitted to the Public Works Department of the City of Rancho Palos Verdes (Dill, 1989.)

Santa Monica, Castellammare Mesa offshore survey

A similar side-scan and seismic study was conducted off Castellammare Mesa just north of Santa Monica, California. The objective of this study, like the Abalone Cove and Portuguese Bend survey, was to determine if landslides in that area extended offshore. Unlike the Abalone Cove and Portuguese Bend studies, we could show that the landslides extend offshore creating chaotic bedding and a seafloor with little to no Holocene cover. This unique bottom type continues seaward out to a major fault that forms a break in the sediment distribution patterns of the region (Dill and Slosson, 1992, Slosson and Dill, 1993). This study is referenced because it provides a comparison of an area where landslides extend offshore to an area off the Palos Verdes region where there is no apparent modern day offshore component to the active landslides onshore.

Densely populated bluffs overlooking Santa Monica Bay in the Castellammare area, are subjected to massive landslides resulting in highway damage and structural loss to the home owners of the region. Working under the premise that this instability was not man made, but was long term geological process, geological studies were conducted to determine if the present instability is related to both modern and ancient landslides that may have been active prior to the flooding of the continental margin by a rising sea level following the last ice age. Seismic profiles were used to construct: 1) an offshore bathymetric map of the region; 2) an isopach map of the thickness of overburden; 3)

profile charts of the thickness of two seismic lines showing Holocene sediments; and 5) a geological interpretation map based on the seismic stratigraphy of the region.

Concentrated off the Will Rogers Beach State Park seaward of an area known as Castle Rock, seismic traverse lines extended 2 miles offshore to a point where it became clear that the geology being recorded was not related to land stratigraphy. Traverses parallel to the shoreline were run between the juncture of Tuna Canyon on the west, to just east of the juncture of Sunset Boulevard and Pacific Coast Highway, a total distance of about 2.5 miles.

It became apparent early in the survey that the nearshore area north of a reported offshore fault exhibited a poorly defined and chaotic stratigraphy with little coherent structure. This type of acoustic record is characteristic of geological formations that have suffered extensive fault and/or landslide movement which brings about destruction of well defined primary depositional features. This lack of structure within bottom sediments extended seaward (south) almost to a projected east-west trending offshore fault identified as the "Malibu Coast Fault" on maps of the region, and show a line of gas and oil seeps along the fault to the west of our study area.

A preliminary reconnaissance of the onshore geology, prior to the survey, showed that the sedimentary rocks forming the cliffs and shoreline exposures of bedrock, are chaotic and highly disturbed by thrust fault and landslide movements, similar to those at Portuguese Bend.

In areas where our seismic traverses crossed the projected trend of the *Malibu Coast Fault* zone, both echo-sounder and seismic records show what appears to be bubble screens, both in the water column and within the sediment. This phenomena indicates that the geological structures of the region are leaking gas from fractured underlying petroliferous formations similar to areas reported by Greene and Kennedy (1986) on the *Malibu Coast Fault* further to the west and that this fault related release of gas extends into our area of study.

Our survey indicates that there may be two east-west trending offshore fault zones one crossing the sea floor along the 60 to 70 ft. contour and one along the outer limits of the survey in an area cut by a buried channel system. The outer fault zone has tilted terraces along cut and fill structures within the buried channel, indicating movement prior to the area being covered by Holocene sediments. What is striking, however, is the lack of topographic relief seaward of the present coastline which rises abruptly at the shoreline to a series of uplifted and tilted coastal terraces. Viewed from sea, there is a notable tilting of the two mesas, Parker and Castellammare, showing that this region has a long history of tectonic displacement. This is not surprising, noting its close proximity to the large thrust

faults that formed the Transverse Range of mountains just to the north. The lack of high relief offshore demonstrates the erosive power of transgressing sea level following the Ice Ages which was capable of planing off all pre-existing topographic features like those found on land, which certainly were formed during low stands of sea level during periods of continental glaciation.

The seafloor sediments seaward of Topanga Canyon and Sunset Boulevard junctures with Pacific Coast Highway almost out to the projected fault zones, are markedly different from other areas surveyed, in that there is no Holocene overburden. The major trend of sea floor bottom contours does not comply with the seaward boundary of this structureless Holocene sediment denuded bottom, indicating it is not acting like other areas of the sea floor. The seaward edge of this structureless area is marked by a small escarpment which has been filled in with Recent sediment. Seaward there is a wedge-shaped fill that thickens seaward .

A lack of fill over the area near Castle Rock indicates that the area is probably unstable and moving. Holocene fill can not build up because it is eroded away as it is thrust up into the area of swell-induced bottom erosion. Our interpretation is that areas not subjected to coastal landslide movement and tectonic uplift retain their Holocene fill resulting from the marine transgression, whereas the area off Castle Rock continued to rise and any marine Holocene sediment, if ever deposited, has been stripped away. We thus interpret this to indicate that the structureless area is not passive sea floor but has been and may still be part of an active offshore extension of the modern landslides that are common and well documented along the unstable cliffs and tectonically tilted mesas that form the Santa Monica coastline. Further, we suggest that the sea floor boundary with no acoustic structure is the outer edge of an offshore unstable region related to onshore landslide movement. If projected back under the coast the slip plane would be encountered at between 30 and 60 feet below present sealevel.

Both coring and gas samples would be valuable additions to providing a better understanding of this geologically interesting region of the California coast line.

The high resolution seismic evidence supports all contentions that the local landslide movements have a long history extending back beyond the colonization of the region by man. The instability of the sedimentary rocks and alluvium are related to: 1) the tectonic activity of the region; 2) changes in sea level following the past Ice Age; and 3) do not stop at the shoreline. The unstable physical nature and the geology of the region demand that all future use of the region, along with decisions of whether or not permit construction or recommend other uses of the land, be made with these unique coastal geological factors in mind.

Acknowledgments

Special thanks are extended to Dr. Perry Ehlig, City Geologist for Rancho Palos Verdes, who provided valuable advice and corrections to the final report along with historical records, reports, and land maps for our study. Charles Abbott and Don Wilson of Charles Abbott Associates, Inc. provided guidance throughout the study. Dr. Robert Walker of the Corps of Engineers provided suggestions and comments that greatly improved the final report. Neil and Kyle Marshall, and Karel Zabloudil provided logistical support both at sea and in the office from EcoSystems Management Inc. Their review of the material as it was being prepared for this report were invaluable. We also want to thank the secretaries at CAA for providing us with support when presenting the preliminary results of this report.

The public works crew and park ranger of Cabrillo Park were extremely helpful and provided a safe over night storage of our valuable equipment and boat during the survey.

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Minerals Management Service, Pacific. OCS Region,
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Camarillo , CA 93010

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Field Methods and System Description

Seismic Survey system

The survey was conducted from a 25 foot survey vessel specially equipped for shallow water seismic surveys (Fig.4). The boat was launched from the boat ramp at Marina del Rey approximately 8 miles south of the survey site. The survey system is specially designed to work in nearshore areas where larger vessels cannot safely obtain data. Two seismic systems were used in the survey to obtain the detail needed to identify anomalous bedding or sedimentary features related to offshore slumping, landslide displacement or fault activity: 1) a High-Resolution, Subbottom Profiler (HRSBP); and 2) a "Boomer."

This equipment package allows subbottom structures just below the sea floor surface to be examined in detail by high frequency acoustic energy and the deeper structures by lower frequency sound energy which does not give the detail but has the capability of deeper penetration. By operating both systems at the same time and recording returns on the same chart, we could compare in real time, both deeper structures from the "Boomer" with the structures in the overburden above bedrock. This system was used successfully in surveys off Palos Verdes Peninsula south of the study area (Dill, 1989; Dill et. al., 1990; and Dill and Slosson, 1993) and was used in this survey because it optimizes the ability to interpret all subbottom features that might be related to faulting and landslide displacements. Seismic traverses were made at a constant RPM that gave us and average speed of 4.5 knots.

Recording was on a dual channel Precision Graphics Recorder (PGR) thus permitting a direct correlation between the type of signals being received at different depths of penetration and resolution. Operating at 3.5 KHz the HRSBP system allowed detailed observation of sedimentary structures and continuity of beds within the overburden. In several areas the bedding of the underlying bedrock was also observed on the 3.5 KHz. system. Dual channel recording permitted us to compare, on the same record, the Holocene sediments internal structures defined by the 3.5 KHz soundings with structures seen in the underlying bedrock structures seen on the "Boomer" records. In several areas where overburden thicknesses exceeded the resolution of the 3.5 KHz system the lower frequency system permitted determination of depth to bedrock. The recorder sweep rate of 1/4 second provided a depth scale for the "Boomer" of 200 meters, with scale lines every 20 meters. The 3.5 KHz recorded every 1/8th second giving a full scale depth range of 100 meters with scale lines every 10 meters. Navigational fix marks were placed on the chart every 15 seconds and numbered to correspond with the fix locations provided by the MiniRanger

III™ and ECO-NAV computer. A simplified schematic diagram of the equipment used is given in Figure 6.

"High resolution subbottom profiler (HRSBP)." The HRSBP uses a 3.5 KHz "Lollypop" transceiver towed over the side of the survey vessel. Its output signal is triggered by an EcoSystems designed power and triggering instrument package. The HRSBP transducer both sends and receives acoustic signals and is operated at a frequency of 3.5 KHz with variable power from 1,000 to 10,000 watts. This provides sufficient power at these operational frequencies to theoretically penetrate and receive echoes to sediment depths of up to 100 meters. Reflected signals from the outgoing signal pulse, generated at the transceiver, not only create returns from acoustic discontinuities within the sediment overburden but also from bedding planes in the underlying bedrock. The lapsed time between signal generation and the return of these reflections from the subbottom are recorded on a dual channel Precision Graphics Recorder and can be used to determine sediment/rock thickness, acoustic reflectively (sediment type and rock hardness) and continuity of bedding along survey traverses. The system can resolve individual sedimentary bedding planes and internal structures due to changes in the nature of sediments, i.e. muds, sand and gravel, and sediment/rock interfaces, with a maximum resolution of about 0.2 meters.

"Boomer" The "Boomer" type of Acoustic Sub-bottom Profiler utilizes a broadband electromechanical acoustic source mounted on a towed sea-surface sled to produce a sharp high energy pulse fired every 1/8th second. Energy pulses from the transducer have a sound frequency range between 200 to 2,000 Hz. This system, operating with a 1,000 joule power package, gives penetration and resolution intermediate between the Sub-bottom Profiler and larger Sparker or Air-gun seismic systems used in deep penetration surveys for oil structures. The system gave sub-bottom penetrations to 50 meters with a resolution of about one meter. Filters were used to enhance the quality of recorded signals by narrowing the spectrum of the returned seismic signals to a range between 270 to 1,100 Hz. A towed hydrophone array was used to focus acoustic returns from the bedrock .

Sediment Velocity Corrections. The recording equipment used in this type of survey scans the width of the recording paper at a rate of one sweep either in 1/8th (125 milliseconds) or 1/4 of a second (250 mS). The time between outgoing and incoming acoustic signals can thus be related to the thickness of the water column, thickness of sediment or thickness of underlying rock units if the velocity of sound is known. The scale marks on the record tapes are set to record in meters of water depth assuming a sound velocity in seawater of 1450 m/sec. However, in order to account for variations in water sound velocity and salinity we use a bar check before and after each day's survey to

calibrate the instruments and take into account variations of sound velocity in the survey area. The bar check is a standard offshore survey calibration method. It is done by lowering a reflecting metal plate over the side beneath the transducer with a calibrated steel wire cable. Soundings recorded on the recorder tape at depths of 10, 20, 30 and 40 feet are used to measure the distance between the outgoing signal and the echo return to calibrate the system. This value is then used to determine water depth, and acoustic reflectors within the sediment and underlying bedrock.

The sound velocity within the sediment overburden and the underlying bedrock are higher than in the water column velocities, therefore, a velocity correction must be made for the decreased travel time to obtain corrected thicknesses. In this study we used the average values of sound velocity obtained for sediments and rock types off southern California by Moore (1969) and Hamilton (1971). The Moore and Hamilton values were obtained by using a diver operated probe that measured seawater velocity between two transducers at a fixed distance of one meter. The probe was then pushed into the sediment and allowed to come to equilibrium, and the velocity of sound then measured in the sediment between the transducers. Values taken in situ by probes were later checked using sediment cores taken at the underwater sites and retrieved for laboratory determinations. Additional measurements were made using sonabuoys to measure refraction velocities in the southern California region in both shallow and deep water. The average velocity for unconsolidated California shelf sediments is 1700 m/sec. Thus for our values we apply a velocity correction of thickness measured on the chart (t) x 1.17 = overburden thickness. For the underlying rock we used a correction based on an average of 2110 m/sec for the sound velocity in Neogene sedimentary rocks given in Moore (1969) and used by Fischer and Rudat (1987) in their report on the sediments and structure of the San Pedro and Santa Monica Shelf. By using the same values we will be able to compare values of depths reported in other offshore surveys and calculated rock thicknesses in areas to the east of this survey. Thicknesses of penetration were made by measuring the thickness of reflective beds that were continuous over several fix locations, using the first arrival of an echo from the subsurface rock/sediment interface to locate and define a bed for measuring and using (ts) x 1.45 = corrected rock thickness. The later value was also used to determine apparent dip by measuring the distance along the bottom between a fix where continuous beds were truncated by the sediment/rock erosion surface, and tracing them down dip over a given distance along the bottom determined by a subsequent fix on the traverse. The tangent of the distance across the bottom and the depth to the top of the bed followed down dip over this distance gives the apparent angle of dip for the acoustic reflector. It is assumed that the

acoustic discontinuities are related to bedrock surfaces and the dip of the beds. This is the standard procedure used to measure dip in high resolution seismic stratigraphy studies.

Motorola DGPS™. We used a modified Motorola "six-gun" differential Global Positioning System (DGPS) for navigation on this survey. This system used has a ±1 m. accuracy. The DGPS system signals have been degraded by the US Military so that signals from a single unit are not accurate within 100 meters. However, by putting a second unit on a benchmark and comparing the signals from an instrument that is not moving and is at a known location, the moving instrument can be calibrated to remove the Government "degradation" so as to get accuracies within one meter. The determination of position is accomplished by determining the range between satellites and a shore station and a DGPS located on the survey boat. As the vessel moves, its positions are automatically computed displayed on the monitor of a laptop computer. Navigational data is recorded on a magnetic diskette. The navigational computer was programmed to place event marks on the Precision Depth Recorder (PGR) at 15 second intervals and simultaneously record the time, date and sequential shot point numbers on the record. This same data was recorded on the floppy disk in the computer along with the DGPS navigational data. This data is also printed on a hard copy tape incorporated in the computer as a back-up. The print-out is also used to check data logged by the operator on the PGR recordings of the seismic instruments on the ship and a back-up hand written trip log kept by observers on the boat.

The offshore seismic tracks to be followed during the survey were pre-plotted and placed in the computer. The navigation system has a video screen that shows the position of the vessel relative to these pre-plotted lines. The boat operators keep the boat cursor on these lines during the traverses, changing course to keep the boat travelling on the pre-selected track lines to insure complete coverage of the area. Following the survey the actual position of the vessel is plotted on a track chart generated by a shore-based computer plotter. These plotted station locations are then used to provide accurate positions for sedimentary structures and features measured by the interpreter geologist from the seismic records. All data is then placed in a spreadsheet for analysis and plotting using navigational software and desk top computers.

Shore stations were chosen using the topographic map of the area provided by Dr. Perry Ehlig and CAA. The shore station bench mark was located so as to obtain maximum coverage without line-of-sight obstructions.

All plots for this study were originally made at a scale of 1" = 200 feet. Shore line features are based on two land surveys, 1) a 1984 map from CAA, and 2) a 1988 map by Horizon Surveys provided with geological modifications by Dr. Perry Ehlig representing CAA.

Plots of the survey lines were constructed using Surfer (v 4.0) PC software and a Hewlett Packard 7576 plotter. The navigational data along with measurements of depth and overburden thickness were placed as a text file in an Excel software spread sheet that could be read using Surface III™, v 2.5.1 , a mapping and plotting software for the Macintosh developed by the Kansas Geological Survey. Using Surface III™ plots as a base for map construction, Adobe Illustrator 5.5 (a EPS graphics program) and Canvas 3.5.3 were used to construct the final maps and charts in this report. Seismic records and data sheets obtained on this survey have been turned over to CAA for distribution.