Final Report

Abalone Cove Offshore Survey, Palos Verdes, California

Submitted February, 1990
to
Public Works Department
Rancho Palos Verdes

by
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Phase I and II Project Summary.

This report covers a two phase study of Abalone Cove, located on the southern shoreline of Palos Verdes Peninsula, California (Figure 1). The survey was designed to use seismic, side-scan sonar, diving, vibrocoring and background geological information to determine if elements of a presently active landslide on shore extends offshore. During Phase I (April, 1989) which was conducted to determine the general nature of the sea floor and the subbottom sediments a number of anomalous linear ridges were found in the northeastern section of Abalone Cove. These required further study to determine if they could possibly be related to recent sea floor instability. The Phase II (October, 1989) follow on survey determined the nature of these ridges using diving observations and measurments, coring and detailed side-scan sonar coverage of the specific areas where ridges had been found. This second survey showed that the April ridges had been modified and were not well developed in October, probably having been modified by several storms that had swept through the area since the first survey. Diving observations controlled by precise electronic navigation and side-scan sonar coverage preciçely relocated the ridge systems found in Phase I to within ± 2 meters. The bottom in April ridge locations turned out to be the contact between a bottom with finer grained sediment with little surface relief and a coarse arkosic sand which had large ripple marks. The contact appears to be the boundary of a sediment wedge derived from near shore sediments that prograded seaward over a thick overburden that blankets the bedrock of the cove. Our conclusions are that giant ripple marks and the seaward facing lobes of coarse sediment forming the seaward side of the prograding front, probably created the acoustic reflections seen in April. This front appears to be decaying because of bioturbation and the smoothing of sedimentary features by swell induced bottom currents.

Six vibrocores were taken in the area of the April Ridges (Figure 2 and Appendix II). Core # 2 taken near the sediment boundary contained near its bottom a large chunk (3 inches in diameter) of semi-consolidated muddy quartz sand that had well developed shear structures. However, it was confined to the bottom of the core near a cobble rich layer and appears to have been an isolated block which we fortuitously cored. This material was not found in other cores and it is concluded from the examination of all cores that this block was astypical and not an indicator of sheared sediment formed in responce to landslide induced stresses.

The penetration of 5 of the 6 Vibrocore cores taken in the area was stopped by either cobble beds within the sedimentary overburden or bedrock. Maximum penetration in the area of April ridge development was less than 4 feet due to cobbles. These cobble beds showed up as strong horizontal reflectors in the high resolution seismic profiles and probably represent ancient shore line features deposited during post glacial rise of sea level across the shelf. It is important to point out that he seismic records show that these cobble beds are not distorted nor have they been thrust

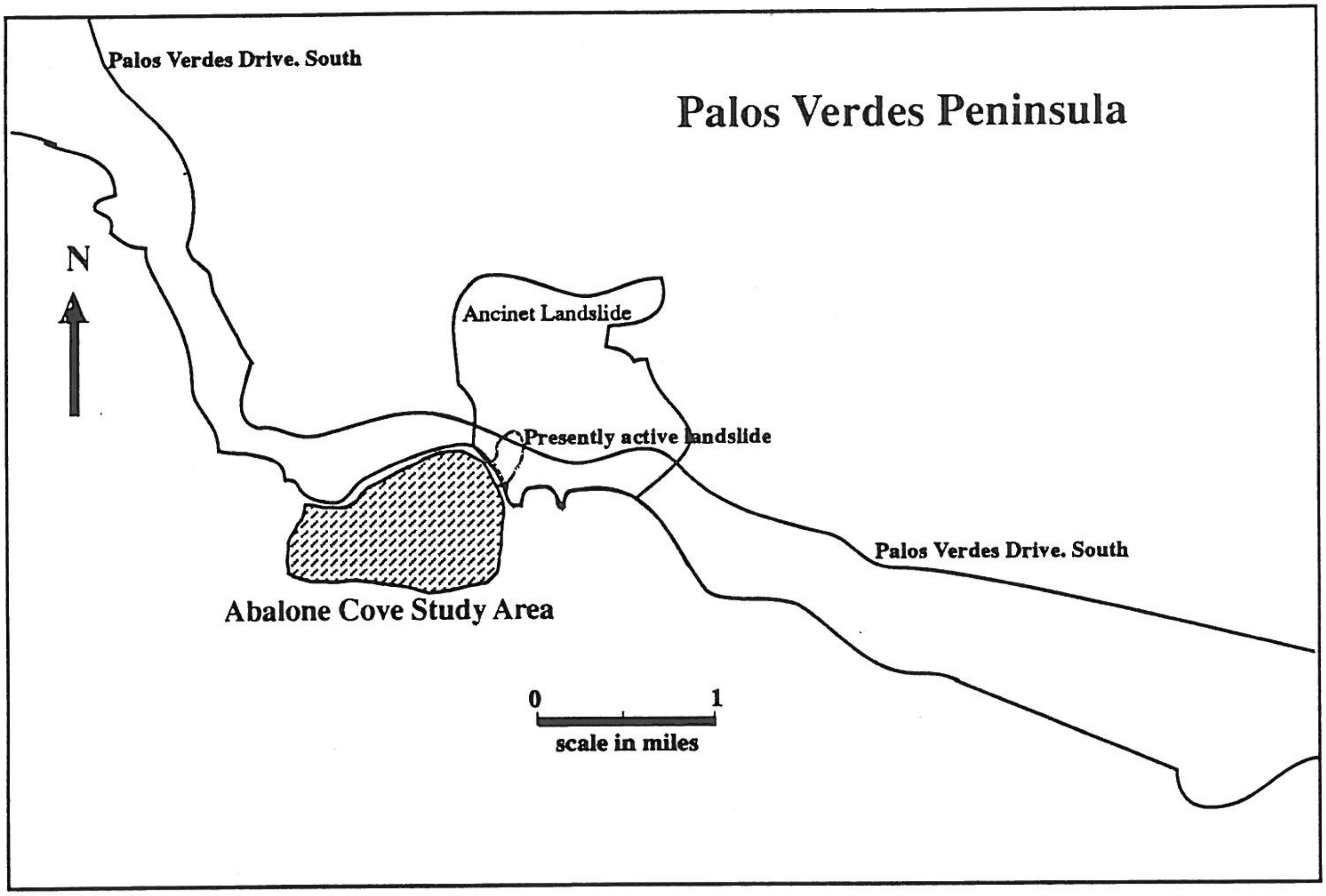

Figure 1. Abalone Cove survey area (stippled) located approximately four miles west of the city of San Pedro on the southern side of Palos Verdes Peninsula, California. Also shown are the approximate boundaries of the "ancient landslide" and the presently active landslide area that prompted this study. Map is modified from Conrad and Ehlig (1987).

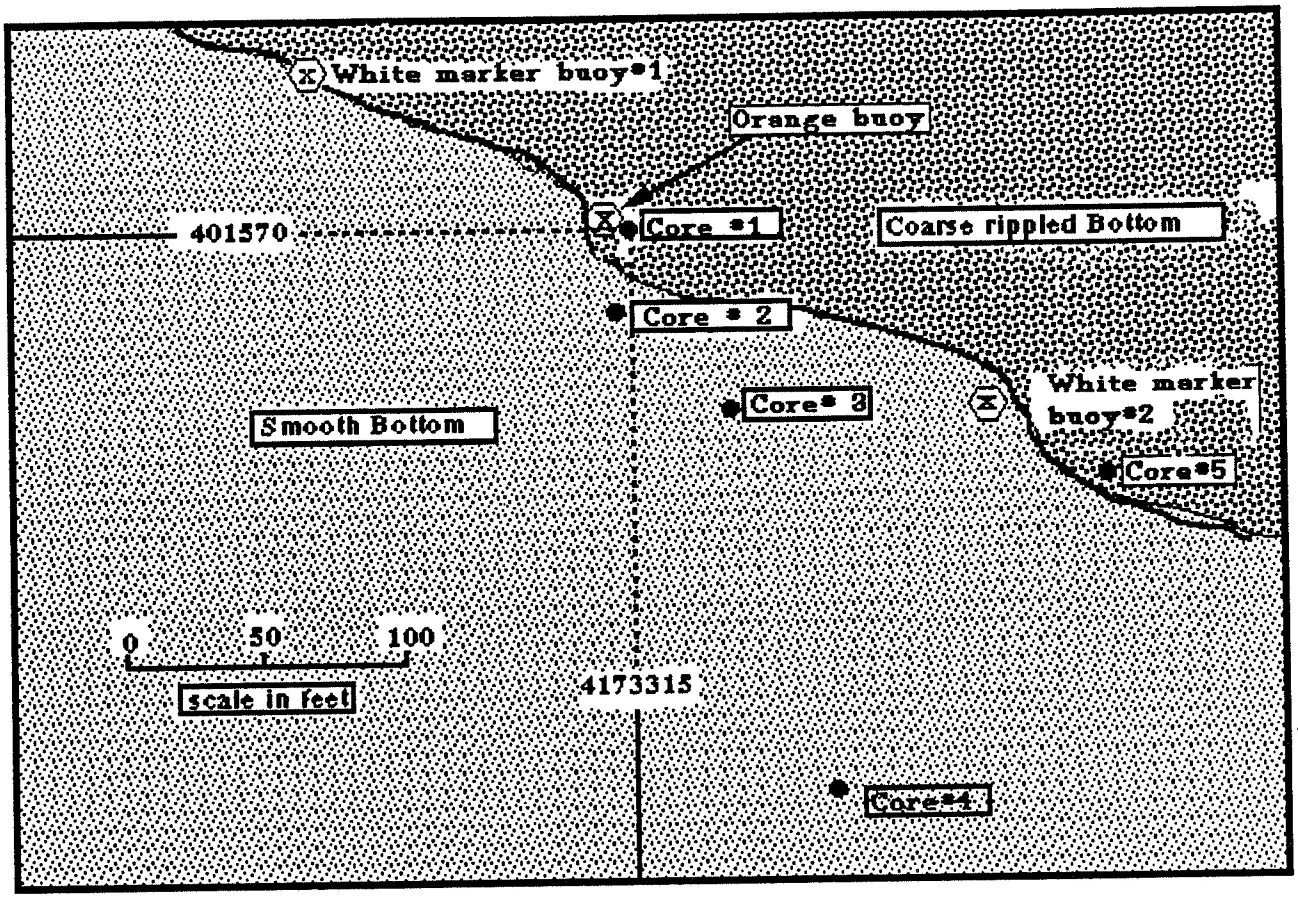

Figure 2. Location of vibrocvores relative to the coarse/fine grained sand boundary (see Figure 7 for location in Abalone Cove). Easting and Northing Map Coordinants are drawn to vibrocore #1 location with dotted lines from solid lines on figure boundary. Coordinants are in feet northsouth and eastwest.

up as ridges anlong landslide glide planes. The data from this survey fully supports the contention that at the present time the sea floor within Abalone Cove is stable and not affected by onshore landslide activity.

The bedrock defending the eastern side of Abalone cove does not appear to be mobilized or contorted and has therefore been stable since sea level crossed this area approximately 5,000 years ago. The rock outcrops seaward of the small point west of the lifeguard stand are basalt intrusions similar in nature to the rock defending Portuguese Point. This strongly indicates that the area does not represent a seaward displacement of recent Monterey shale by modern landslide activity. Further, after confirming the basaltic nature of the outcrops and a review of the seismic records it can be concluded that these basaltic outcrops are anchoring the western side of Abalone Cove as well as Portuguese Point.

Recommendations

The present coverage of seismic and side-scan sonar is adequate for assessment of offshore movements related to onshore landslides. Therefore, no additional geophysical offshore survey coverage is recommended. The dives made during Phase II indicated that a sediment boundary caused linear features seen during Phase I and Phase II. However, the limited visibility in the inner part of the traverses and the one day of diving allotted to this part of the survey did not permit a complete examination of this boundary. It would be advisable to investigate this contact further using local diving scientists familiar with working in the area and with local boat support. California State University at Long Beach has a biological program to track and census large electric rays living in Abalone Cove. During their diving observations they could be extremely useful in helping to define the sediment boundary when visibility permits. The person to contact is Dr. Richard Bray Department of Biology, California State University, Long Beach if the Panel of Experts feel additional information is needed concerning the nature of the bottom in Abalone Cove.

The sheared chunk of sediment in core #2 is probably an isolated occurrence and it is not recommended that C_{14} dates of shells within the cored sediment be attempted even though that was one of the objectives of coring in Phase II. However, because of the limited control provided by this reconnaissance survey and the small number of cores it would be advisable to drill a land based control core hole near the present shore line to see if the sheared zone found earlier in basalts underlying the presently active landslide extends seaward of the present landslide toe.

Background

This report presents the results of a two phase offshore seismic, side-scan sonar, vibrocoring and diving survey off Abalone Cove, Palos Verdes, California (Figure 1). The project was developed under the guidance of the Rancho Palos Verdes' Abalone Cove Panel of Experts with a major goal to provide this group with offshore information to assess whether there are any anomalous features on the sea floor and in the subsurface sediments and bedrock that could be related to onshore landslide activity. The main approach was to use high-resolution seismic profiles and side-scan sonar to determine if there is any displacement of bedrock, or topographic anomalies that might indicate deep seated zones of weakness seaward of the toe of present active landslide (Ehlig, 1982 ; Ehlig, 1987 ; Slossen, 1987). The major objectives of both surveys were formulated following field investigations with Mr. Jon Taylor, Associate Engineer for the Rancho Palos Verdes Public Works Department and Dr. James Slossen, of Slossen and Associates and at a meeting on February 23, 1989 with the Rancho Palos Verdes Abalone Cove Panel of Experts. The surveys were designed to determine if there were any indicators of an offshore continuation of a zone of weathered basalt observed in cores taken onshore into Abalone Cove that could have acted as a slip plane for past or future slump movements (Conrad and Ehlig, 1987). Seismic equipment was chosen that would provide high resolution profiles of sediment thickness, acoustic discontinuities at bedrock sediment interfaces, and resolve topographic irregularities that might represent boundaries of ancient or recent landslide movement. A separate side-scan sonar survey of the Abalone Cove sea floor was conducted to detail and locate any micro-topographic features that could be related to offshore movements or displacements along landslide boundaries.

The initial phase of the survey started on April 11, 1989 and concluded on April 14, 1989. A total of 21 side-scan-sonar swaths and 25 sub-bottom high resolution traverses were made in the area. Survey track lines were controlled by a Motorola Mini-Ranger III electronic navigation system. This system has a location accuracy of ± 2 meters. Geological supervision and field work was under the direction of Dill Geomarine Consultants using Ecosystems Management Associates, Inc. as a subcontractor to provide at sea support of both personnel and a vessel equipped with side-scan sonar, seismic and navigational instrumentation.

The second phase, based on data obtained on the April Phase I survey was conducted between October 3 and 7, 1989. It consisted of; 1) resurveying an area where linear features were observed during the April survey with side-scan sonar; 2) taking sediment cores with a Rossfelder Corporation PC-4 vibrocore; and 3) diving to observe and sample bottom types and sediment boundary conditions in the inner portion of Abalone Cove where linear ridges were discovered in April. A video tape of bottom conditions was also taken by divers being towed over areas where ridges had been seen on side-scan swaths in April.

The seismic profiles were laid out in a grid that provided a coverage that would show displacement or anomalous thicknesses of sediment overburden over bedrock. If found these features would indicate recent movement or the occurrence of faults and zones of weakness in the bedrock underlying Abalone Cove. Also to be determined was the continuity of the wave resistant basaltic sills and dikes that are protecting the headlands of Portuguese Point at the east end of the Cove. We also wanted to determine of similar basalts were defending several smaller points that extend into the cove along the shoreward perimeter to the west of Portuguese Point (Conrad and Ehlig, 1987). The precise navigation and depth information permitted the construction of a detailed bathymetric map of the cove. Overburden thickness measured from the seismic profiles were used to construct a sediment isopach map. This map when superimposed on the map allowed the comparison of sediment thicknesses to surface topography and the ability to relate this information to other geological features and oceanographic conditions that have affected sedimentation in the area. The seismic profiles also showed structures and faults in the bedrock beneath the overburden that could be related to pre-Holocene periods.

Oceanographic conditions

The complex set of wave and swell patterns reaching the Abalone Cove area on the southern side of Palos Verdes Peninsula are generated by storms in the North Pacific and in Antarctica. These wave and swell patterns are refracted around Point Conception to the north and the offshore islands to the south. The prevailing winter storm swells from the northwest are refracted around the western side of Palos Verdes Peninsula and reinforced or attenuated by swell patterns in the form of long period swells from the southern hemisphere. Thus, the survey area is subjected to a highly complex and variable set of swells and local wind derived waves that induce bottom and long shore currents of varying magnitude at different times of the year. These currents are capable of moving sediment both onto and off the beach. The narrow shoreline with high cliffs and coarse cobble beaches attest to the strength of these processes and their periodic erosive nature (especially during storms). Strong rip currents are generated within the cove by storms generate plunging breakers that pile up water within the cove and from the refraction of swells around the points. These rip currents cut away any coarse sands and finer material carried to the beach by stream discharge and cliff retreat. The sediment eroded from the shore and cliffs is eventually deposited offshore seaward of wave and swell activity. The thick overburden within the cove is evidence that these erosional process followed by redeposition offshore has been active over the past 2 to 3 thousand years, a time when sea level reached its present elevation after a sharp rise during the late Holocene (Shepard and Dill, 1964, Shepard, 1973, Fisher, et al. 1987a and 1987b).

Two distinct water masses were observed in Abalone Cove. Nearshore there is usually a highly turbid area that has a seaward boundary just south of the kelp forests that colonize rocky and coarse cobble/sand bottoms. This water mass is obviously deriving much of its suspended turbidity from the erosion of shoreline deposits and runnoff carried to the beach during winter storms. Soil and crushed rock debris also carried to the shore zone by landslides is being continually eroded and contributes coarse grained sediment to the beaches and fine grained sediment to this turbid water mass. Waves refracted around points create a shoreward flow and back wash off rocky headlands provides a source of organic materal to a protective pocket that keeps this water mass confined within the northeastern corner of Abalone Cove. Swells and breaking waves create turbulence that keeps fine grained sediment and organics in suspension maintaining the distinct nature of this turbid body of water. Winter waves also break off the lush organic growth covering the rocky areas, break it down and create organic debris that is swept both onto the beach and spreads seaward to be buried in sediment settling from suspension seaward of bottom wave activity.

Because of this configuration, the nearshore waters within the Cove are usually turbid both from organic material and sediment kept in suspension by the shore break of plunging waves and strong swell induced bottom currents. During these surveys and based on discussions and observations of local inhabitants it is concluded that the water visibility in the inner area is usually less than one to three feet except during the rare periods when swells are not actively entering the Cove and stirring up the bottom. During these quiet periods the waters can clear as the suspended material settles forming a turbid thin flocculated gelatinous layer on the bottom. Phase II diving operations were fortunately conducted during one of these quiet periods thus permitting video taping of diver traverses over areas usually to turbid to photograph.

A second water mass lies within the outer part of the Cove beyond the major kelp beds. This water is California Coastal water and is in itself a highly complex mixture of water moving along the coast and upwelling from the deep basins offshore. This offshore water has a horizontal visibility between 10 to 20 feet except near the bottom where there is often a turbid layer caused by muddy waters churned up near shore spreading seaward.

Occasionally water from far offshore is driven by favorable winds to the Southern California shoreline and the entire coast is bathed in clear warm water that is usually found only in areas around the offshore islands like Catalina. It is during these periods that bottom observations and photographs should be made to assess the offshore conditions within Abalone Cove. Unfortunately these conditions can not be predicted and therefore can only be taken advantage of by local divers with equipment that is readily available within a days notice. We were lucky on the Phase II period to have one day of good diving weather that permitted video coverage of diver traverses.

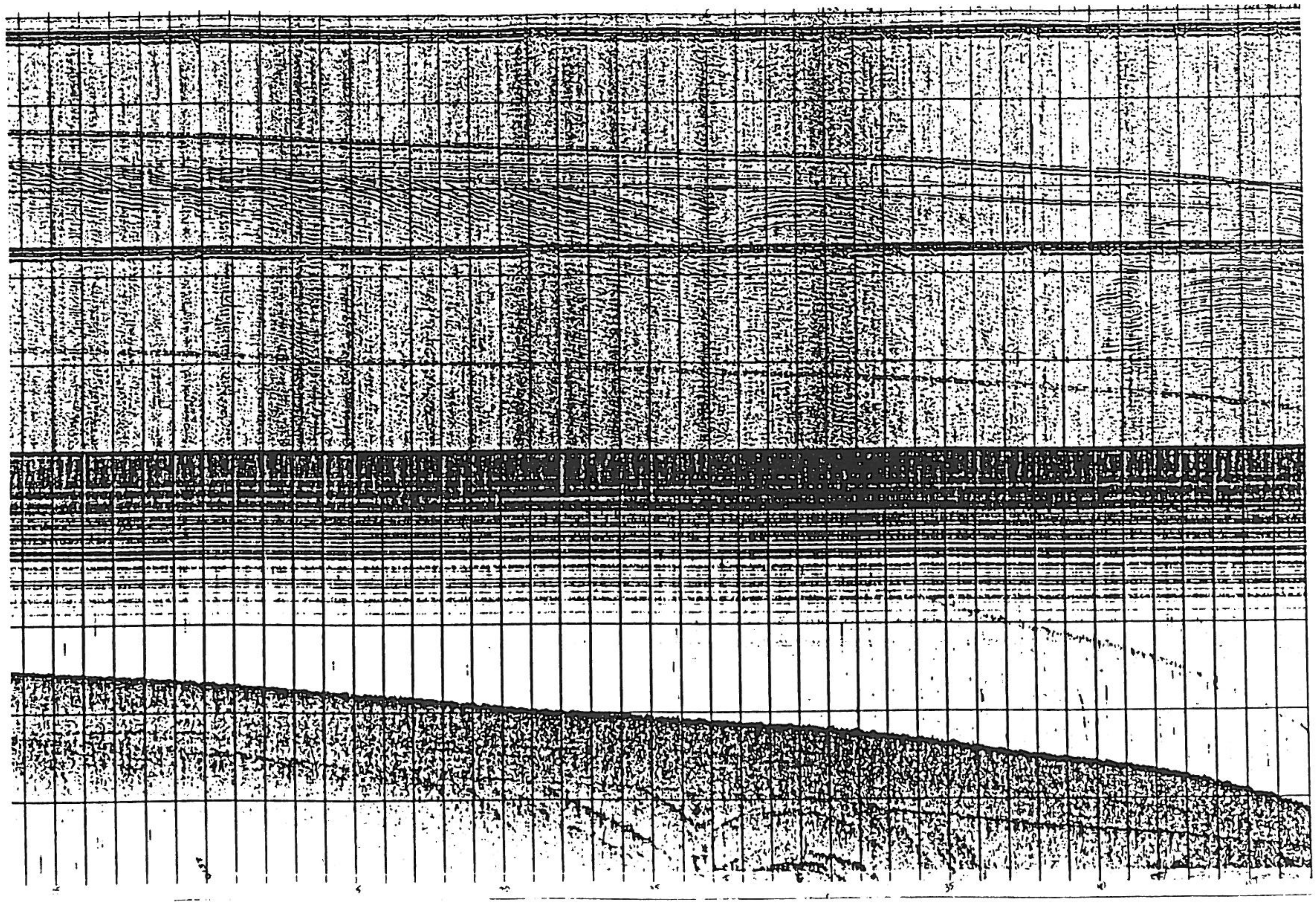

Figure 3. Record of a profile of both Boomer (top) and 3.5 kHz (bottom) seismic systems showing the bedrock structures and internal reflectors in the overburden. This section is at the shelf break seaward of Portuguese Point. Depth intervals 40 m for boomer, 20 m for 3.5kHz.

Tidal variation within Abalone Cove is up to 7 feet during spring tides. Consequently tide level data was used to correct depths recorded in both the seismic and echo sounder traverses. All values have been reduced to the Mean Lower Low Water datum so that they can be compared even though taken at different tidal stages. Tide tables based on gauges at Los Angeles Harbor were used for this conversion.

Coastal currents during the survey period were weak. Their direction and magnitude can be correlated to tidal stages, first flowing east and then west along the coast. A weak surface water current was experienced when wind velocities exceeded 15 knots. Wind chop was minimal except during the last day of the coring operations when surface winds exceeded 25 knots and caused termination of operations because of dragging the ships anchor in the sandy sediments of the cove.

Survey Results

Seismic Profiles. Seventeen, northeast-southwest seismic lines were run roughly perpendicular to the shoreline, starting as close to shore as possible. The starting points for the inner parts of these traverses were controlled by dense kelp beds growing on nearshore rock outcrops. We could not tow seismic recording hydrophones through these beds without tearing away large fronds. These contain gas filled bladders that attenuate seismic signals when they foul the transducers of the equipment. Traverses were run seaward to a depth of about 90 meters (300 ft.). At this depth it was evident from the seismic profiles that we were in a distinctly different geologic province and beyond areas of where geologic features could be related to shoreline and onshore landslide movement. Both the "Boomer" and 3.5 KHz traces show bedrock structures that indicate past tectonic movement, but there is little or no evidence that this movement has continued after the Holocene sediment buildup. Overburden sediments are either featureless or contain coarse grained reflectors that are flat lying and not distorted in areas where bedrock has been contorted (Figure 3). The sediment overlying tectonically contorted bedrock in this outer part of the survey gradually thickened seaward and contained undisturbed internal bedding. There were no obvious anomalies within the sedimentary overburden or topographic breaks in bedrock surfaces at this outer part of the Shelf that could be attributed to recent slumping or landslide movement.

The outer areas of the survey showed a roughly linear zone of highly reflective beds within the overburden and an anomalous roughness in the bedrock surface just beneath these layers. This linear feature runs approximately parallel to the present shoreline (Figure 4). It could be interpreted as either an old shoreline or possibly a cobble filled channel cut in bedrock. The feature is found between present sea floor depths of 120 to 130 feet, in an area where the overburden thickness is between 50 to 70 feet thick. This places the feature between 170 to 200 feet below present sea level

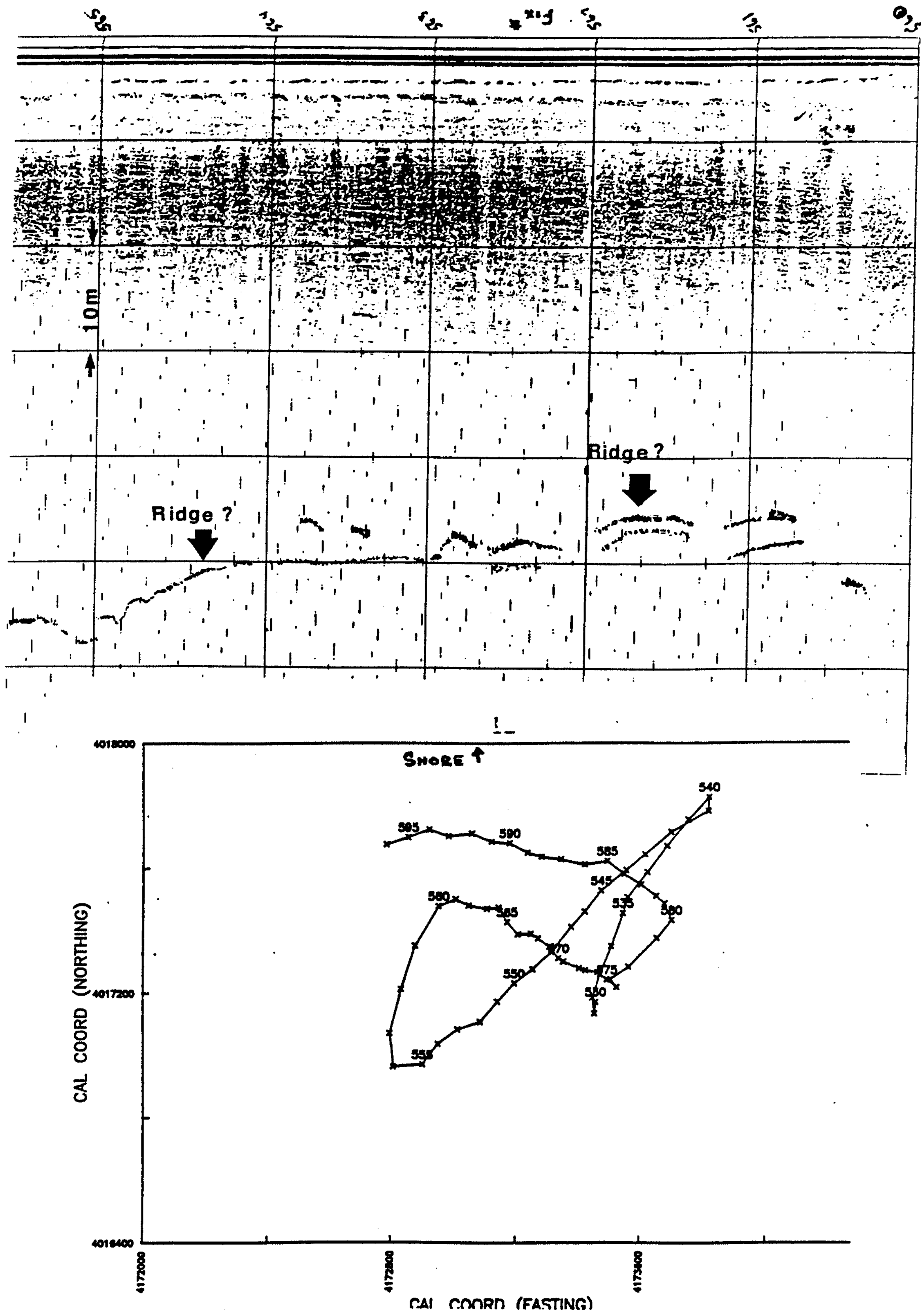

Figure 4. Linear reflector on October side-scan record (Dark arrows) between 55 and 60 meters from the survey ship. Lower part of figure is of the track with Fix numbers and Cal Coordinates in feet. Boat was running approximately parallel to the shore line off the Lifeguard station. At Fix #566 diver tow crosses this same line and observed that the feature was the boundary between coarse ripple-marked sand and a finer smooth muddy sand bottom.

and would indicate it formed during early Holocene times (see Appendix IV for additional plots of sediment thickness and bedrock topography).

The lack of any reflective topographic relief on the side-scan sonar records across this outer region indicates that the sediment in this depth of water is fine grained and has accumulated slowly as an undisturbed deposit following the Holocene rise of sea level over the outer Continental Shelf break. Using the generally accepted sea level curve for southern California (Emery, 1960; Emery, 1967; Shepard, 1966 ; and Shepard, 1973) this would indicate that the strand line crossed this outer part of the survey area about 12,000 years before present (yBP). The seismic records indicate that since that time reflecting beds within the sedimentary overburden blanketing this outer part of Abalone Cove has not been displaced nor been affected by movements related to coastal landslides on Palos Verdes Peninsula .

Ten east-west seismic lines were run to provide a cross-check coverage of the seventeen northeast-southwest lines and to permit the construction of a three dimensional isopach model of sediment thickness over bedrock. The lines were approximately 150 meters (500 ft.) apart with some deviation to insure crossing areas where projections seaward from land geology suggests possible offshore related movements, i.e. faults or erosional channels. . Two diagonal lines were also run to permit a cross check of computer plotted depths along all the lines and to provide tie lines that would allow the comparison of depths at crossover points. This method allowed us to check the accuracy of the navigational system and our computer generated tidal corrections which reduced all soundings to Mean Lower Low Water. All crossover points agreed within one tenth of a meter indicating the system and the corrected plots were well within the requirements of the survey.

Overburden thickness was distinct and measurable on all of the traverses where it covered bedrock. However, in areas of dense kelp beds or where large boulders, cobbles or bedrock of probable Miocene age cropped out on the sea floor, the thicknesses were not as well defined due to acoustic interference and the marginal ability of subbottom profiling systems to discriminate the thin cover of sediment that is less than one meter thick. However, there is in general a relatively thick blanket of sediment over much of the area that indicates high rates of sedimentation.

At the base of the cliff formed by Portuguese Point on the eastern side of Abalone Cove, the basalts along the shore abruptly penetrates through a relatively thick cover of overburden (greater than 10 m) without shallow lateral extensions into the bay. There is one small stack approximately half way out on the point that could be an outlier of this main body, but it too is surrounded by a thick overburden. The basalt outcrops therefore must have been a wave resistant bodies, formed prior to the deposition of the thick overburden that has buried their bases. The seismic profiles show that there are several areas in the inner parts of the Cove with topographic highs surrounded by bedrock without apparent bedding. These could be basalt dikes extending up through the overlying sedimentary rock beds or outcropping sills in tilted bedrock. The well developed bedding within most of the bedrock including that surrounding the basalt highs, strongly suggests sedimentary material similar to that forming the Monterey Formation silicious shales (Conrad and Ehlig, 1987) seen in the cliffs of the region underlies most of the cove.

Phase I. Side-Scan Sonar Traverses;

One day was spent surveying the area using side-scan sonar with a 500 kHz. transceiver. A total of 15 north-south lines and 12 east-west lines were made concentrating our efforts in the inner portions of Abalone Cove in depths less than 130 ft. The outer part of the area was found to be a flat featureless plain with little relief or patterns of sedimentation that warranted extensive survey effort. The Side-Scan Sonar swaths were designed to provide an overlapping grid so that bottom features would be seen at a different acoustical aspect on several crossings. We concentrated lines in the area seaward of the active landslide at the northeastern shore of the Cove. Survey boundaries encompassed all of Abalone Cove between Portuguese Point on the east and westward to the eastern boundary of the old Marineland Park. The inner most part of Abalone Cove received limited coverage because dense kelp beds prevented the towing of the transducer "fish" along traverse lines. However we were able to "see" in under the kelp as we traversed parallel to the shoreline seaward of the kelp beds. Each swath was able to cover about 300 ft. (100 m) of bottom on each side of the boat. The seaward limit of the survey was determined after making several passes over a flat featureless bottom. This assessment of the nature of the sediments was later confirmed by the seismic records which showed a thick blanket of sediment overlying bedrock in the outer parts of Abalone Cove.

One experimental high resolution traverse was made running parallel to the shoreline just seaward of the rock/sediment interface in depths of about 40 feet. This run used a faster sweep rate that detailed the bottom in a swath that was 40 meters wide on each side of the vessel and much less could be seen than on the longer range reconnaissance 100 meter swaths used for the rest of the survey. This traverse showed in detail the nature of the sediment surface and the sediment/rock interface along with an estimation of rock outcrop relief. The size of the survey area and a limited amount of survey time available for this type of detailed coverage made it uneconomic to use for reconnaissance which requires first the finding of features and then detailing them once recognized. However, the higher resolution at a narrower swath coverage afforded by this application was extremely useful in Phase II which required the delineation of a number of sedimentary features found using the reconnaissance mode.

Phase II. Side-Scan Sonar Traverses

Following the recommendations made by the Advisory Panel after Phase I, one day was spent resurveying the area where linear ridges were observed during the April survey using side-scan sonar with a 500 kHz. transceiver. A total of 26 northeast-southwest lines and 12 east-west lines were made concentrating the effort in the inner portion of the Abalone Cove in depths of less than 60 feet. This area is off the present day landslide just seaward of the lifeguard station (Figure 5). We also relocated an area of rock outcrops observed in Phase I so that they could be inspected by divers to determine if the rock outcrops were Monterey shale or basalt.

Geological Interpretation

Side-Scan Sonar.

Linear ridges. The most significant discovery of the April side-scan survey was a series of northwest-southwest trending ridges or linear bottom irregularities approximately 1200 feet seaward of the toe of the active landslide on shore (Figure 6). The acoustic shadows from these features were recorded on five (5) traverses *"A" Fix* # 260 to *"A" Fix* # 274; *"A" Fix*# 461 to *"A" Fix* # 465; *"A" Fix* # 583 to *"A" Fix* # 606; *"A" Fix* # 812 to *"A" Fix* # 818 and *"A" Fix* #875 to *"A" Fix* # 880 (Figure 7)1. Another smaller linear ridge was seen just seaward of the change in the trend of the shoreline west of the lifeguard station within Abalone Cove. The feature is seen on traverses *"A" Fix* # 115 to *"A" Fix* # 121; *"A" Fix* # 493 to *"A" Fix* # 497 and *"A" Fix* #493 to *"A" Fix* # 497. These feature if projected shoreward would intersect the trend of a major valley forming the western margin of an "ancient inactive landslide" described by Ehlig (1982; 1987). The nature of the side-scan reflections, although not quantitative, give an indication of indication of their height and which side of the ridge is facing the transducer. The darker returns are from surfaces of reflecting bodies of topographic relief. Light areas are acoustic shadows from areas of no return behind these reflecting bodies. The shape of light areas indicates the amount of acoustic shading and gives an indication of the height and extent of the ridges. Using this criteria the estimated height of the April linear ridges were less than 2 feet (50 cm), however their length exceeded the swath width of individual traverses and had to be measured on several side-scan traverses to determine their extent. Seismic records showed that the linear sea floor ridges occurred at the surface of thick accumulations of overburden in an area that is surrounded by a relatively featureless bottom (based on acoustic returns from the side-scan traces). The features occurred in pairs forming two parallel ridges that were between 50 to 100 feet (15 to 33 m) apart. However, near the basalt outcrops forming the eastern part of Abalone Cove at the base of Portuguese Point they were only 10 to 20 feet (3.3 to 6.6 m) apart having a more northerly trend than the features in the central part of the Cove. If the features seen on successive crossing are all related, the April ridges had a total width of about 1200 feet (364 m). The double set of ridges seaward of the

O Fix # n **= October Fix number located on maps in Appendix IV.**

1*"A" Fix #n* = April Phase I Survey fix numbers which are located in Chart in Appendix IV.

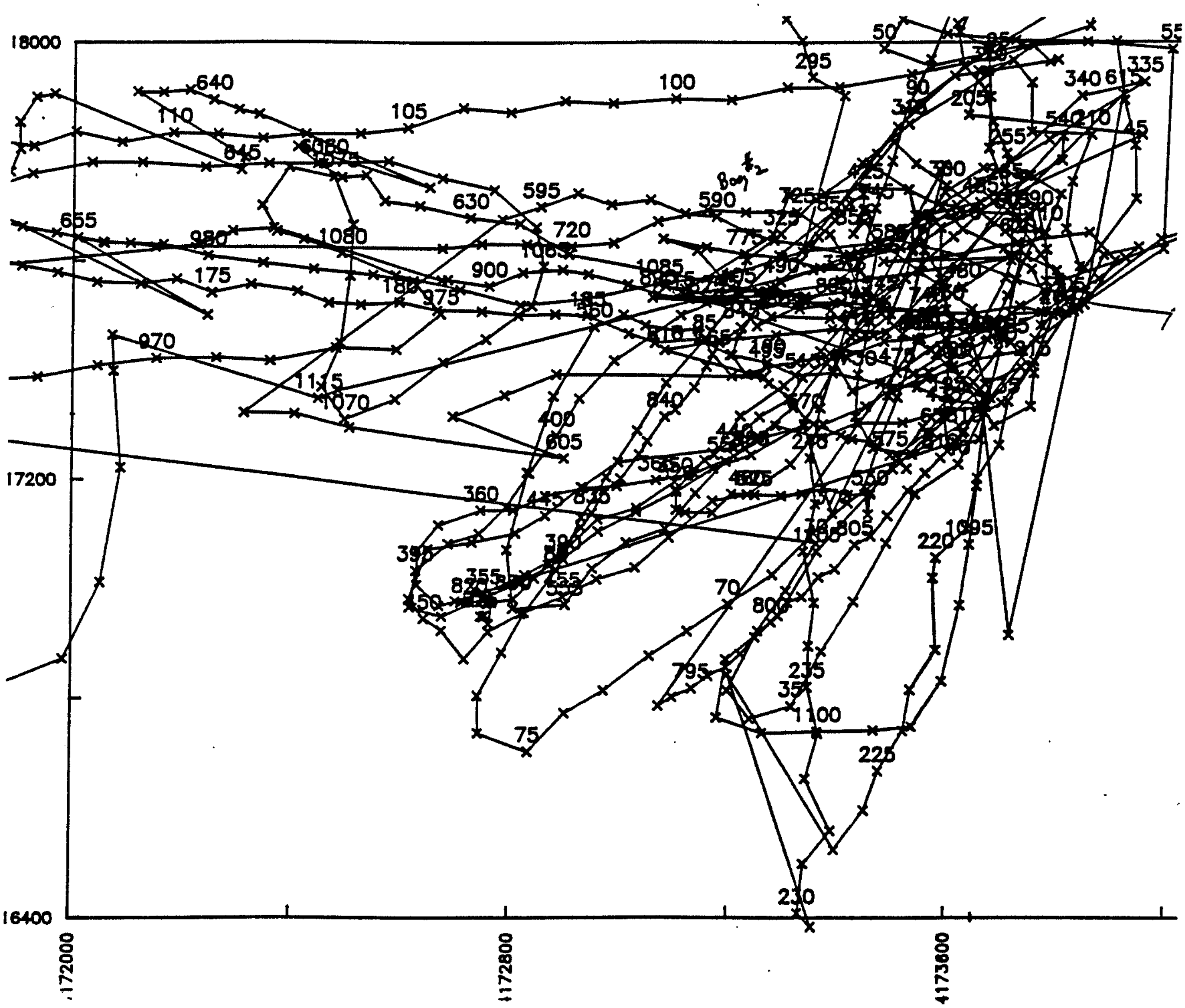

Figure 5. Overlapping track lines for the October side-scan sonar swaths showing coverage. Individual lines were broken out and plotted separately in numerical order using fix locations and then used to check for locations of linear ridges seen in the April survey. California northing and easting coordinates are given in the figure margins and are in feet. Copies of the original grids are in Appendix IV.

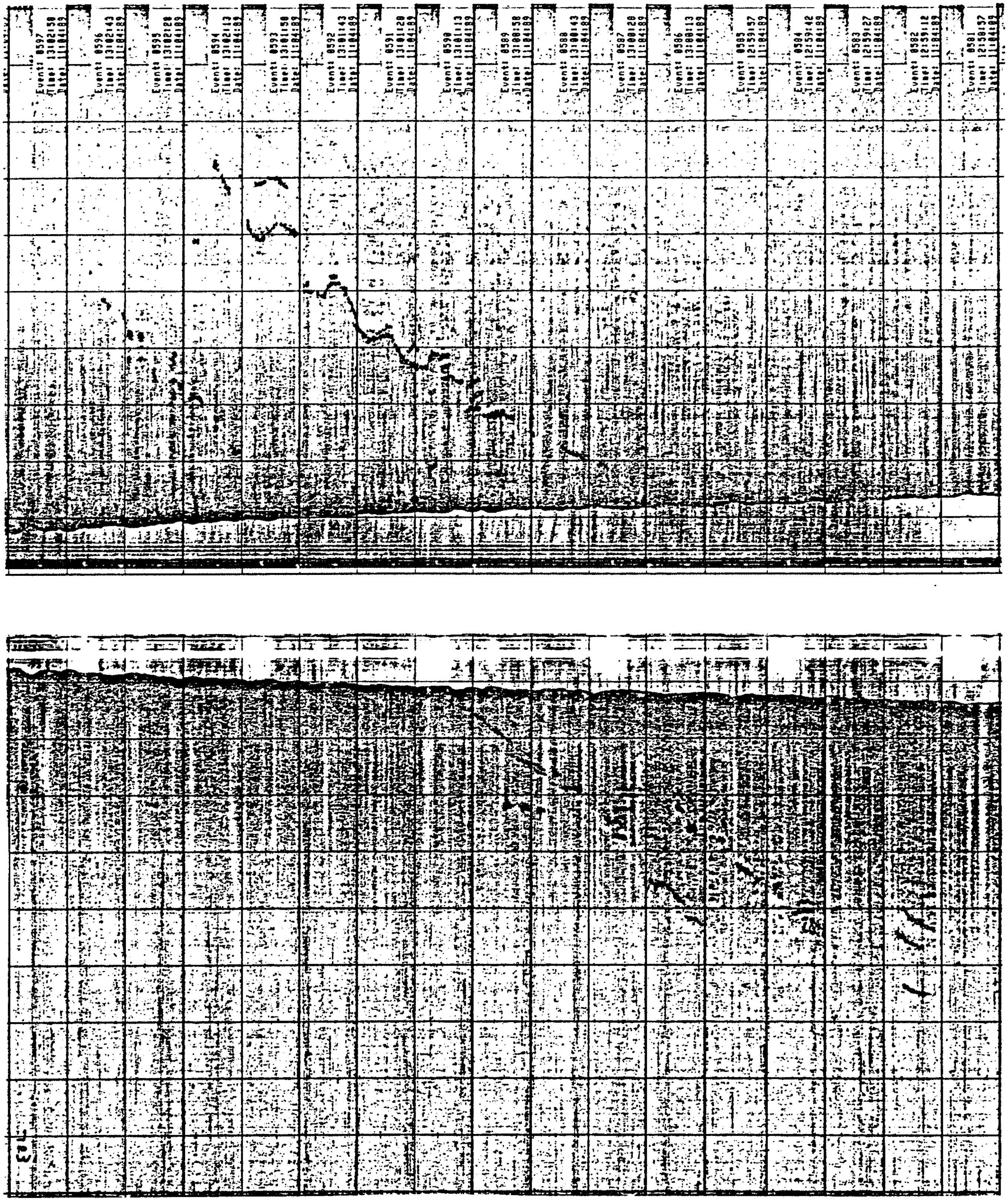

Figure 6. Side-scan sonar record of the April 1989 linear ridges. Event numbers correspond to electronic fix numbers on charts in Appendix IV. Horizontal grids are 10 meters apart, the vessel was traveling at an approximate speed of 4 knots. Note how the nature of the reflections changes as the aspect of the reflecting body changes as the vessel crosses the ridges. Figure have been touched-up to bring out features that are more distinct in the original records.

shoreline toe of the present onshore landslide formed a feature similar in size to onshore landslide units (Ehlig, 1982; 1987), which have a head to toe length of approximately 1400 feet (420 m) and a width of about 1200 ft. (364 m).

The linear features are all within sedimentary overburden and have more than 40 feet (12 m) of sediment thickness beneath them. However, the overburden thickness where the features are found is slightly less thick than that a short distance further offshore and appears to be related to a perceptive but not marked increase in the roughness of the surface of the underlying bedrock erosion surface. There is clear seismic evidence that the bedrock is not cropping out on the sea floor causing these features. The reflections and the linearity of these features are markedly different from any other area of the survey. The occurrence of these ridges when presented to the Advisory panel following the Phase I review, resulted in a recommendation that additional information was needed on the nature of these features because of the possibility that they could be indicators of recent movement within the overburden covering bedrock. The dip of the beds seen in seismic profilesi indicated that this movement could be along a seaward extension of landslide slip planes located within a basaltic layer cored on land, below the major slip plane of the landslide active at the shoreline, approximately 1200 feet (364 m) to the north. Because of this concern the Phase II survey was planned for October, 1989.

A higher resolution side-scan traverse was run parallel to shore using a swath width of 165 feet (50 meters) instead of 270 feet (100 m) to better delineate the nature of the nearshore bedrock outcrops and boulder beds (traverse between *"A" Fix* # 1310 to *"A" Fix* # 1375). Although there are areas where there appears to be breaks in rock type and bedding continuity, there is no clear evidence of faulting or bedrock displacement on this traverse. Unfortunately, the nearshore area, where one can project the linear ridges across this traverse, is covered by sediment. However, the unusually straight rock/sediment boundary seen on the high resolution side-scan traces (Figure 8) is seaward of the western boundary of the ancient landslide identified by Ehlig (1987) and Slossen and Havens (1987) on land. This linear rock/sediment boundary also seen on air photos has a trend that is similar to the trend of the linear ridge further seaward, indicating a possible relationship between these features. This possibility relationship was checked on dives made in Phase II described later in this report and found to be coincidental .

Bedforms. Another interesting feature is the apparent coarse grained sediment zone lying between depths of 50 to 80 feet (15 to 24 m). The side-scan images from this surface indicate a rough bottom with large linear ripple marks. The size of the ripples also indicates a much coarser sediment at this depth than in other areas of the survey (larger ripple wave lengths indicate a coarser grain size than small ripples). A similar band of coarse sediment and giant ripples has been observed by Dill on many diving traverses in others areas of southern California and is attributed to relict coarse grained arkosic beach or dune deposits laid down during a still stand of sea level between 6,000 to 8,000 yBP (Emery, 1967; Fischer, et al. 1987). This would correspond in time to the last flooding of the region during the Holocene transgression (Shepard, 1966). The brown colored sediment found in the cores looks similar to these sediments. However, the marine shells within the sediments cored in Phase II are clearly marine and not of eolian origin which would indicate that the sediment was deposited under water in the marine environment and not as a dune.

Phase II. Side-scan sonar Survey

Traverse locations and map. The uncertainty of the origin and extent of the linear features observed during Phase I required a more detailed investigation of their nature. The area was therefore reinvestigated in October, 1989 using a 500 kHz side-scan sonar, diving and coring by a vibrocores. High resolution results were achieved by conducting a dense grid of side-scan sonar swaths across the area where ridges had been found in the April survey. Each pass had a total width of about 165 ft. (50 meters) (Figure 5 and see Appendix IV). The navigational fixes locating the different traverses by side-scan sonar were numbered sequentially2 and controlled by a Mini Ranger III navigation system (see Appendix IV). Because many of the traverses crossed and are superimposed on each other it was necessary to plot only a part of the survey as a series of overlay maps so as not to confuse station locations. A second semi-transparent overlay containing data from the Phase I ridge locations, diver traverse and core locations was constructed at the same scale. This overlay was then placed over each side-scan map and to compare the features seen on the side-scan record with Phase I data, diver observations and core information. For instance using this system we could see that the line containing *O fix #* 55 to*O fix #* 75 crosses the April double ridge system at *O fix #* 67.5 and *O fix #* 68 respectively and runs parallels to the diver traverse #3 between *O fix #* 64 to *O fix #* 72. The side-scan sonar during the October survey could then be used to see if the ridges were still observable and compare the older data with observations made by the diver on his tow over the bottom.

The well developed ridges seen in the earlier survey were not found, only low indistinct linear features indicating bottom conditions had changed. It is important to note that there was a period of extremely severe storms that generated large swells and high surf conditions between Phase I and Phase II surveys (Ehlig, personal communication, 1989). These long-period, high energy 3swells undoubtedly reached the bottom and set up strong oscillatory currents capable of moving sea floor sediment in the depths that the ridges were seen on Phase I. Dives confirmed these

O Fix # n = October Fix number located on maps in Appendix IV.

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2 ***O Fix #n*** = October fix number located on maps of Phase II in Appendix IV.

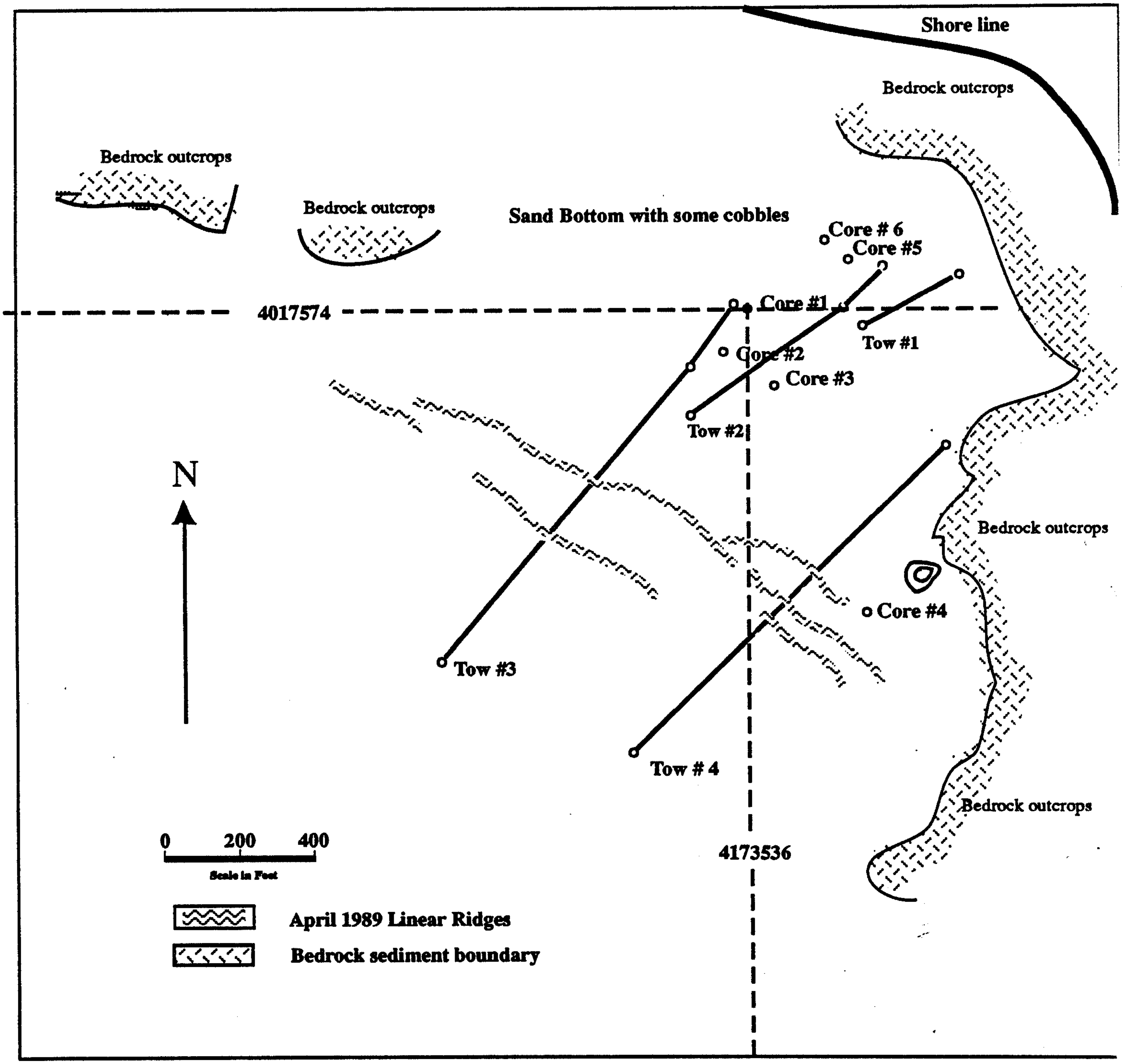

Figure 7. Diver tow traverses with location of vibrocores and the April linear ridges relative to the positio of bottom features. California Coordinates give position of core #1 a position located by divers at th contact between smooth and rippled bottom and the probable site of a April prograding sediment wedg from shallow water. Scale is in feet.

changes and possible bottom sediment transportation. Such comparisons require the precise navigational system used in both Surveys

Ridges. The distinct ridges seen during the April survey were not encountered during Phase II crossings of the area. Instead the bottom showed a series of lobes and a multi-crested pattern that looked like a field of giant ripple marks. There were persistent ridge like features which, as will be discussed later, turned out to be changes in sediment type and micro relief. The closest related feature to the April ridges was seen on the October swath between *O fix* #560 to *O fix* #575 that runs parallel to the shoreline. A linear reflection parallels this line that is at the same location as the ridge seen in April and is approximately 130 to 150 feet seaward of the October traverse. This ridge is seen as a weak reflector at the outer limit of the side-scan swath. It has a total length of over 400 feet. However, other side-scan sonar lines that crossed this same October ridge system at slightly different angles did not show a reflection ridge system in areas where it was observed in April. This would indicate that in some areas and at some aspects the reflections from this October feature become undetectable using the side-scan sonar. For instance the line *O fix* #230 to *O fix* #248 that runs toward shore crossed perpendicular to the April double ridge system with no indication of a reflecting ridge system at the crossing points at *O fix* #237 and *O fix* #238. *O fix* #239 should have intersected the April ridge but showed no indication of reflectors only a smooth non reflective bottom along the entire sonar swath. Between *O fix* #340 and *O fix* #356 the traverse cuts diagonally across the zone of ridges seen in April with no indication of their presence in October where the swaths cross the older ridge location at the crossing points at *O fix* #349, *O fix* #350, and *O fix* #352.

The lack of distinct ridges seen in April in October strongly suggests that the bottom has changed, a condition that was later verified by dives at the former ridge sites. These observations showed that the bottom is a coarse, low relief sediment with a ripple marked surface. The ripples were not actively forming in responce to the weak swell induced bottom currents. There is strong evidence from the diving traverses, described in more detail later, that this lack of relief is due to the flattening of giant ripples by swell induced bottom currents and bioturbation (the activity of burrowing and plowing organisms).

Sediment features. The sonar records show areas of giant ripple marks in the inner shoal parts of Abalone Cove. Because of their size and orientation parallel to shore, they are assumed to be related to a zone of coarse sediment. Swell induced oscillatory bottom surge in shallow waster form giant ripples in coarse sediment. The ripples seen on the side-scan records and the weak reflecting ridge in an area where strong returns from linear ridges in April turned out to be a boundary between a bottom with finer grained sediment with little surface relief and a coarse arkosic sand which had large ripple marks. It appears that this sedimentary boundary was more distinct during the April period than October causing it to appear as a distinct linear ridge in the Phase I survey. It is not uncommon for such sedimentary prograding bodies to have several lobes of sediment over riding each other and having a linear pattern. The double nature of the April ridges could have been one of these double lobes..Other areas of the California Shelf where these coarse/fine grained sediment boundaries have been observed (Mission Beach, off San Diego) have marked change in bottom roughness at different times of the year. This phenomenon is controlled by storms which build giant ripples and then during calmer periods when there is little to not swell activity the ripples decay becoming subdued and even obliterated by bioturbation (Dill, 1958).

Rock outcrops. Isolated rock outcrops which show up as dark areas with distinct shadows on the side-scan records were observed throughout the inner part of the cove. The eastern margin below Portuguese Point is a basaltic sill which extends out into the Cove to the west only a short distance before being covered with a thick overburden layer. There are several partially buried basaltic (?) stacks just east of the main drop off that are surrounded with coarse sediment and cobbles. The small points of land that protrude out into the cove to the west of Portuguese Point all appear to have a rock defended sea floor seaward of their location. Several large rock free areas were encountered in the near shore part of Abalone Cove just west of the Lifeguard station which are probably sediment filled channels cut into the old bedrock erosional surface. These probably formed when sea level was below its present stand. The rock on either side of these old channels is well bedded and shows up as linear ridges capped by kelp reflectors on the side-scan sonar. In general the kelp beds reflect a rocky bottom with either basalt or Monterey (?) formation outcrops. There are some kelp beds which are attached to large boulders which appear to be eroded remnants left from the erosion of a retreating shoreline. Several of these large boulders can be seen in and just seaward of the surf zone to the east of the lifeguard station.

Bottom Diving Observations

Tows and linear ridges. Although the side-scan survey of Phase II conducted during October, 1989 did show some poorly developed linear ridges, they did show extensive areas of giant ripple marks with crests running parallel to shore in the areas where ridges had been observed in April, 1989. Using the side-scan and the Mini Ranger III navigation system to relocate positions we made a series of diver towed traverses that crossed the areas where linear features were found in April and in the area where the weak reflector was seen during the pre-dive survey on Phase II. On these traverses the diver descended to the bottom seaward of the replotted positions of the April ridges and was then towed along the bottom toward shore (Figure 7). In areas beyond the kelp beds, diver horizontal visibility at the beginning of the dive was approximately 20 feet (very good for this area). However, visibility dropped to almost zero once the diver reached a depth of 20 feet due to a dense turbid water mass stirred up by the swell induced currents in the shallow nearshore waters. In all instances this layer was shallower than the depths where April ridges or the ones seen on Phase II were found so that all traverses crossed the pre-plotted position before visibility limited observations. When the diver noted a change in bottom type he would signal the surface vessel via the tow line to stop and relocate over his bubbles. A navigational fix was taken, a buoy dropped to locate the site and the traverse continued. When the diver could no longer see the bottom the traverse was terminated and the location plotted. Upon surfacing the diver described his dive profile for the record and explained the conditions warranting a fix. The side-scan sonar was run during the diver towed traverses. In this way the diver was able to relate features seen on the bottom with those giving echoes on the side-scan sonar record. Samples of bottom surface sediments were taken on diving traverses to give a generalized pattern of sediment types along their length.

The outer parts of the diver traverses reveled a bottom that was highly reworked by organisms and pocked with numerous small holes made by burrowing organisms (worms, fish and shrimp). The sediment also had large numbers of semi-buried kelp and sea grass fronds. These semi-buried plants verified the recent occurrence of strong bottom currents capable of tearing growing plants from their moorings and transporting this material and fine grained sediment into deeper water. The sediment surface in the outer areas of the traverses was covered with a thin flocculated mat of organic material that was easily stirred up when contacted by the diver. Several large depressions were observed that were probably caused by rays feeding on buried organisms (evidence of bioturbation). These observations are important because they confirm the high rate of bioturbation seen in cores taken in this area. The side-scan records in these areas were smooth and featureless even though there was some micro-relief observed both by the divers and recorded in the video tapes made during the traverse.

The diving team specifically looked for any indication of hard rock outcrops or areas of compressed sediment forming resistant sea floor ridges like those seen in other areas of offshore fault exposures. None were observed on the dives made during this survey. It is important to note that both traverses #3 and #4 crossed all of the April ridge systems with out any indication of a marked change in bottom relief. Side-scan sonar swath between *O Fix* #77 and *O Fix* #93 runs parallel to dive traverse #4. On this traverse the diver carried a video camera and continuously recorded the bottom features over the entire dive. There were no indications of a ridge system at *O Fix* #82 and *O Fix* #83.5 the locations of the April ridge system. Side-scan sonar swath line between *O Fix* #170 and *O Fix* #196 crosses the diver traverse at *O Fix* #189 which is 60 feet from the location of the first contact with coarse sand encountered during the dive at diver location #9. The side-scan sonar shows a linear feature at 66 ft. (20 m) at this location giving a positive correlation between the location of a April ridge system and a change in sediment type from medium to coarse sand and a smooth bottom to one with ripple marks observed by the diver in October. This transition was also recorded on the diver video recordings. It is important to emphasize that the only feature that correlated with the ridges seen on the side-scan sonar being run during the dive was a change in grain size and the beginning of giant ripple marks in the coarser sediments.

The diving observations therefore strongly indicate that the linear ridges seen in April were probably a sediment boundary feature and not a sea floor surface manifestation of movement due to offshore land-sliding. This observation and conclusion is also supported by seismic records which show a thick layer of sediment underlying the April linear ridges. If movement had been translated through this sediment overburden there should have been some indication of this in the form of a compressed ridge of semi-consolidated sediment. No ridge of this type was observed. Further the seismic records showed that within the sediment overburden there were numerous hard horizontal reflective layers that are probably from cobble and pebble beds. These cobble and shell beds were encountered in the vibrocores to be described later in this report. The diver observations confirmed that these coarser cobble, pebble and shell beds had not been thrust to the surface along landslide glide planes to to form an anomalous sea floor deposit or cause linear ridges like those seen in April. The use of divers to observe the bottom in areas of side-scan sonar surveys thus have been critical in providing ground truth necessary for interpreting side-scan sonar images and reaching the conclusions of this report.

Description of basalt outcrops. During the April Phase I survey a large, anomalous submerged rock outcrop was found seaward of the projection of the western boundary of the "ancient landslide" and deeper than the outer kelp boundary seen elsewhere in the Cove. One of the recommendations from the Phase I report was to further investigate this outcrop because it could be an indicator of recent sea floor movement along a former plane of landslide weakness.

The rock outcrop, is located just offshore of the zig-zag stairway down the shoreline cliffs off the western boundary of the ancient Abalone Cove Landslide zone described by Ehlig (1987). It is somewhat linear and lines up with a seaward projection of a fault seen in air photos of the rock outcrops on the shore line. It was important to determine if this outcrop is basalt or sedimentary rock. If the former, it could be an eroded remnant of an intrusion. However, if it was sedimentary, it could represent movement that has displaced the Miocene shale seaward and could be of a relatively recent origin. The seafloor near the outcrop did not show coverage by a thick sedimentary blanket like other areas of Abalone Cove. Another interpretation could be that the

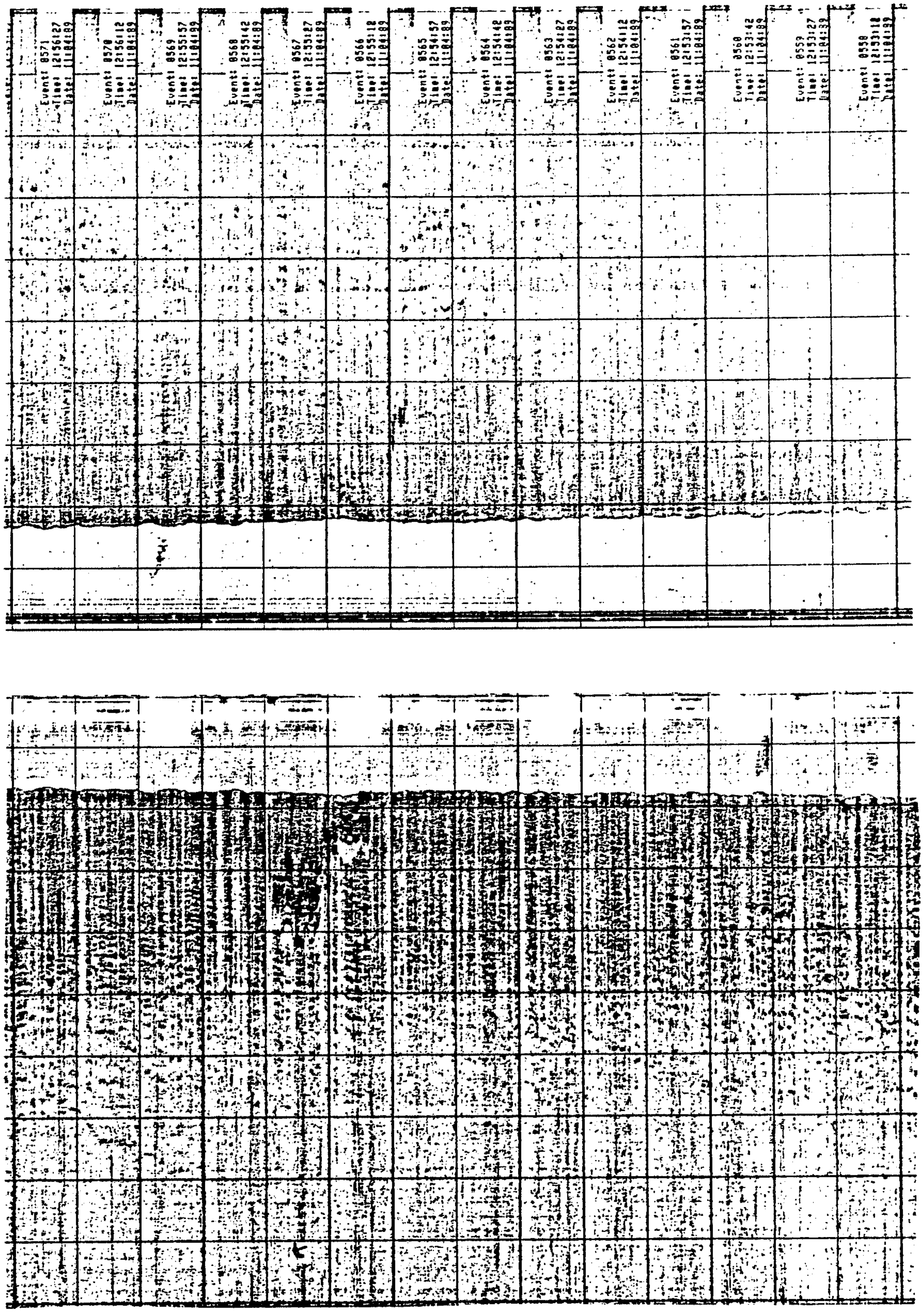

Figure 8. Side-scan of isolated basaltic ridge found in April and observed by divers and videotaped during the October Phase II survey. Side-scan chart intervals are 10 meters apart. Note the irregularities on the bottom towards the top of the figure these are from giant ripple marks forming in a coarse sand sediment.

topographic high is swept clean by swell induced bottom currents in the relatively shallow nearshore waters. In either instance following the Phase I survey, this outcrop represented a factor that could be related to the western boundary of an ancient landslide and could represent a zone of weakness along which further movement could take place.

The Phase II dives showed that this large rock area was a highly resistant basaltic ridge. It was covered by a lush community of plants and sessile organisms typical of rocky habitats. Large gorgonian corals, anemones, rock boring molluscs and a diverse population of kelp and sea grasses were common. Surrounding the rock outcrop was a thin layer of fine grained muddy sediment (probably less than several feet thick). Relief of the ridge at the point of the dives was about 10 feet. The divers estimated that the area of rock bottom was about 5000 square feet. Rock samples showed that the ridge was composed of unweathered basalt, with numerous veins of white quartz, similar to the basalt defending Portuguese Point to the east. No sedimentary rock was observed. This would indicate that the small point shoreward of this resistant outcrop owes its origin to the protection given it from wave action and is a rock defended promontory similar to Portuguese Point. Prior to being flooded by rising sea level this outcrop would have formed an offshore stack of resistant rock that refracted waves away from this part of the coast and resulting in the formation of the small point. However, when the stack became submerged, approximately 4,000 years ago, wave action could reach the present shore line and start eroding away the cliff areas but not as fast as unprotected areas of the beach to the east and west. This topographic relationship indicates that the basaltic sill or dike forming this submerged stack has been in its present location for a considerable period of time. It therefore does not represent displaced Miocene shale like that seen on shore and it is unlikely that there has been recent seaward displacement of shore material along the western side of the "ancient landslide" identified by Ehlig (1987).

The identification of this rock outcrop as basalt also provides ground truth information for better interpreting seismic records which showed a region of poor internal reflective material in this part of Abalone Cove. Using this diver obtained data the seismic profiles indicate that the basalt extends only a short distance seaward and then becomes sandwiched between well bedded sedimentary rock. This would indicate that the basalt forming the ridge is an intrusive sill within the Monterey formation, similar to the sill defending Portuguese Point.

Vibrocores

Six vibrocores were attempted following the side-scan survey and diver observations. All cores were taken in the vicinity of the April ridges with the primary objective to obtain evidence of the time of formation of the ridges (C_{14} dates of shells etc.) and the sediment type to determine if there had been offshore landslide movement and if so, when. The exact sites (Figure 7) were buoyed at the locations where the side-scan and diver observations showed the sediment boundary between coarse sand with ripples and relatively smoother medium sand. The first four cores (#1 through #4 in Figure 7) all penetrated several feet into the sediment and retrieved good samples. Core #5 must have also hit a hard resistant bed after less than 12 inches of penetration because it only retained cobbles in the core nose and a small amount of sand that was lost at the core was brought aboard the core vessel. Core #6 came back aboard with a badly bent core nose indicating it had encountered near surface bedrock or a cobble bed and did not retrieve sediment. Both of these short cores were away from the area of ridges and near rock/sediment boundaries.The successful cores provided samples of the substrate and contained shell material that can be dated using C14 dating methods and used to determine rates of sedimentation if there was an indication of any landslide activity in the areas of the linear ridges. Logs and descriptions of the four (4) successful cores are presented graphically in Appendix II and in general as follows:

Core#1. This core was located in 33 feet of water (Figure 7), 10 feet south of an orange buoy placed at the boundary between rippled coarse and a smoother medium sand bottom at an area where linear ridges were observed in the April survey. The core penetrated to a depth of 36 inches where it was stopped by a gravel layer that contained some pebbles. The larger pebbles were up to one inch in diameter. The upper 27 inches was a uniform brown arkosic angular medium to fine sand. Round elongate burrows, indicated by a darker coloration, extended down to the 27 inch penetration level and then stopped as the core became much darker probably indicating a zone of reduced material. These was no apparent change in grain size nor was there a smell of hydrogen sulfide at this contact. The main cause of color change appeared to be an increase in organic reduction and a slight increase in darker colored mica grains and heavy minerals.

Core #2. This core was located 75 feet south of the orange buoy (Figure 7) in 32 feet of water. It penetrated 44 inches into the bottom and was stopped by a layer of rounded black chert cobbles and broken shells within a coarse sand matrix. A semi-consolidated, sheared, argillaceous sand layer approximately 4 inches thick was cored just above the cobble layer. This sheared sediment was conspicuous because of it is markedly difference from the other material found throughout the core. However, closer examination of the rest of the core showed that it probably is an erratic block of material deposited above the cobble zone. It is important to stress that this is the only material of this type found in any of the cores. It is noteworthy, because it is the type of material one finds in shear zones caused by offshore faults that reach the surface. However, its isolated occurrence and the known thick sequence of overburden below this location shown in the seismic profiles crossing the area argue strongly against it being a near surface indicator of recent landslide activity at this location. Also there was no indication of this type of material at the seafloor surface when this site was examined and buoyed for coring by diving.

Core #3. This core was located 150 feet south of the orange buoy in 32 feet of water. Penetration was stopped at a depth of 44 inches by a cobble layer in a poorly sorted coarse sand and broken shell matrix. The upper 11 inches consisted of a brown coarse arkosic sand. At a penetration depth of 11 inches, burrows became common that had a dark grey to black color. These features are attributed to a high concentration of organic material. This layer persisted to a depth of 25 inches where a higher abundance of shell in a arkosic sand started. At 34 inches there was a distinct layer of small half inch long *turitella* shells. Below this shell layer the sediment gradually coarsened with occasional distinct harder more consolidated broken shell rich muddy layers. At a penetration depth of 42 inches the core encountered a pebble and cobble layer with abundant broken shells some of which were broken bits of abalone shell. Semi-rounded cobbles of chert up to one inch in diameter of Miocene (?) age were also present and probably responsible for stopping further penetration by the core. Seismic profiles show strong reflectors within the overburden in this area which the cores confirmed as being cobble layers.

Core #4. This core was located 450 feet southeast of the orange buoy on a magnetic bearing of 345^{o} in a water depth of 55 feet. The core penetrated 48 inches into the sediment. The upper portion of the core had a high water content and was loosely compacted. Some of the upper layer was lost (approximately 5 inches) when the core was opened. This material was collected in a Zip-lock bag and retained for microscope study. It had a greenish brown color and a high concentration of mica and flocculated organic material that gave it a soupy consistency. Below this soupy part of the core was a 2 inch thick layer of consolidated angular arkosic sand with a greenish brown color. At a depth of seven (7) inches there was an abrupt break in sediment type with the beginning of a shell layer containing large turitella shells up to one inch long and about 0.75 inches in diameter. This shell had been drilled by a predator and was definitely of marine origin. Abundant shell hash was also present in the sandy matrix. The layer contained abundant organic material but did not have a hydrogen sulfide smell. At ten (10) inches the shell layer ended and the core contained a 13 inch section of dark greenish brown fine grained angular quartz rich sand. Grains are of a uniform size with some broken shell fragments throughout the section. Shell layers were encountered at 38 and 42 inches that contained small turitella shells. One large pebble of igneous rock (maximum dimentions of two inches) was encountered at 26.5 inches that was well rounded indicating erosion in a stream or beach environment.

Cores #5 and #6. These cores all encountered either bedrock or a hard resistant layer in less then 12 inches of penetration and the only material retrieved was in the blades of the core catcher. Core #5 had about 12 inches of coarse brown arkosic sand above the catcher but it was lost when brought aboard the ship. The sands appeared to be similar to those recovered in the upper layers of cores #1 and #2. Core #6 did not recover a sample just a badly dented core nose and a bent core barrel indicating a very hard substrate was encountered. This core was at the western boundary of the Cove near basalt outcrops at the base of Portuguese Point.

Coring had to be terminated following core #6 because of 45 mph strong winds and increasing swells. The anchors were unable to hold the core boat on station and the movement prevented successful coring.

One of the objectives of the coring program was to obtain material for C_{14} dating. We obtained enough shell material (35 grams) in two cores. However, due to not finding conclusive evidence to relate the linear ridges found in April to possible offshore landslide movements, obtaining dates from this material was postponed until guidance is obtained from the Panel of Experts as to whither or not they need this information in their onshore stabilization efforts.

In general the sediments found in the cores were what one would expect from a shore line deposit off a tectonically active beach or coastal dune system. The marked reddish brown color and the arkosic nature of the sand is similar to that found in the Pleistocene dune sequence lining Santa Monica Bay to the northwest and zone of relict sediment forming offshore all along the California coast. This deposit has been described by Emery (1960) and Shepard (1973) and is attributed to an relic shoreline dune deposit that was reworked and modified in the surf zone as the transgressive Holocene seas flooded the Continental Shelf. The high organic content is probably related to the present day high production of plant and animal debris in near shore rock areas. This material is transportation seaward by bottom currents and then reworked into the sediments by bioturbation and burial when storm induced currents rework bottom sediments. The composition of the core surfaces are in agreement with observations made and samples taken on diver traverses and seen on the video records. The stopping of penetration by cores encountering cobble layers at the depths of 3 to 4 feet is consistent with the depths reflective layers appear on near shore seismic traverses.

The shell layers found above the pebble and cobble beds are similar to back berm lagoonal sediments along this part of the California coast. The cobble beds and the arkosic sands are not similar to the preset day beaches indicating a different environmental setting existed at the time of their deposition to the one existing today. The extremely angular nature of the grains indicates that they have not had a long resident time in a surf or beach environment before deposition.

Conclusions from Phase II Survey

The primary objective of this Phase II study were to determine the nature of linear ridges found during the April survey of Abalone Cove. These ridges were known to be in areas, underlain by a thick sequence of sedimentary overburden. The major concern was that they were orientated roughly parallel to the toe and had dimentions similar to the active landslide on land. The Phase II survey was designed to determine if these ridges were related to recent movement along landslide glide planes in bedrock or in the overburden covering it in Abalone Cove or to some other phenomenon non-related to the shore landslide activity. The thick overburden sediments underlying these linear features found in the April 1989 survey have accumulated as overburden since this area was flooded by rising Holocene sea level and must be less than 5000 years old, probably much younger. This sedimentary bottom lies within the depth range of strong swell-induced bottom currents and thus is subjected to erosion from these currents. The area also receives sediment from the beach area by seaward transportation of material by rip currents during storms. The change in the nature of the linear ridges, found during this two phase study do not support the contention that the linear ridges are sea floor expressions of a zone of weakness within weathered basalt that has been encountered in onshore core holes. The seismic and core evidence indicate that the present landslide terminates at the shoreline along the northeastern margin of Abalone Cove and do not extend offshore.

It appears that the ridges seen in April were caused by the unique oceanographic and sedimentary nature of Abalone Cove. The ridges are believed to be reflections from the seaward side of an elevated prograding wedge of sediment moving seaward from a shallow water. The most likely source of this coarser sand is probably sediment deposited 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. This material over rides the smoother and finer grained sediments found seaward of the lobes forming a linear ridge at the contact boundary. After storm periods the relief shoreward of this boundary becomes subdued and spread out by decreasing swell induced bottom currents and bioturbation. The orientation of the ridges is parallel to the refraction patterns of swells entering Abalone Cove during storms. This type of sediment transportation and the orientation of the ridges could have resulted from the oceanographic processes prior to the April survey. Bioturbation and continued wave activity then smoothed out the relief after sediment transport ceased and the boundaries became less distinct and like those seen in the October dives.

Unfortunately, the seismic survey did not cover the ridge area in enough detail to positively conclude that there has not been ancient movement along sub-bottom acoustic discontinuities or that there has been in the past some surface manifestations of such a movement. However, enough information does exist to state that it is highly probable that the linear ridges seen on the April Phase I survey were the seaward margin of a prograding sedimentary wedge of sediment and not likely the surface manifestation of recent sea floor movement. The lack of shallowly buried cobble beds or any indication of this material on the sea floor surface or in animal burrows and depressions certainly indicate no recent movements caused the April linear ridges. However, it would be prudent to further check this possibility by drilling a test well at the shoreline just seaward of the active landslide to insure that the basalt shear zone is no longer active.

Dives made in the central part of Abalone Cove, where a set of linear ridges appears to trend into an abrupt break in bottom type, found outcrops of basalt. This would indicate that the western margin of the "ancient landslide" described in Ehlig (1987) is stable and not displaced Miocene sedimentary rock along 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.

The survey presented in this report was by nature one of reconnaissance and conducted with limited prior knowledge of the offshore area of Abalone Cove. It is 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 amount of data obtained during this first offshore survey of the Abalone Cove region has been extensive and time has not allowed it to be fully evaluated. However, the basic objectives of the survey have been met and this report contains all of the information that is considered to be pertinent to the original objectives of the study. The reporti is submitted to the Panel of Experts for their consideration in the planning of future remedial actions to stabilize onshore landslides . It is our intention to continue working on the data to analyze the information derived from the survey over the next 6 months. It is planed that when this geological information, not all of which will be directly related to the objectives of the survey, is analyzed and the conclusions from it become more definite that a final scientific paper written and ready for publication in 1990. An abstracts covering the work have been submitted and accepted for presentation before the Annual Meeting of the Society of Sedimentary Geologists in June of 1990. The paper will be coauthored by Robert F. Dill, David MacEachren, and Dr. James Slossen the chairman of the Abalone Cove Panel of Experts.

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Appendices I - IV

Appendix I

Field Methods and System Description

Seismic Survey system

Two seismic systems were used in the survey to obtain the detail needed to identify anomalous bedding or sedimentary features related to offshore slumping 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 rapidly attenuated high frequency acoustic energy. Deeper structures are examined 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 the eroded bedrock. This system optimizes the ability to interpret all subbottom features that might be related to faulting and slump displacements. Abalone Cove proved to be acoustically quite favorable for this type of equipment and the system obtained detailed acoustic records throughout the survey area of both the sediment overburden and the structure of the underlying bed rock.

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 corresponding underlying structure of the Miocene bedrock and locate areas of faulting from the "Boomer" with overlying Holocene sediments. 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 40 meters. The 3.5 KHz recorded every 1/8th second giving a full scale depth range of 100 meters with scale lines every 20 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.

The combination of seismic and side-scan sonar acoustic instrumentation provided information on bottom features both laterally and within the sediment and rock below the sea floor. The side-scan sonar provides an acoustic picture of the bottom as a 100 meter swath on both sides of the survey boat. This system proved to be extremely important in finding linear ridges and defining the sediment distribution pattern within Abalone Cove that could be related to the geological history of the region. Unfortunately the side-scan sonar could not be operated at the same time as the seismic due to acoustic interference between systems. Therefore two separate survey had to be made of the area. However the use of the precision navigation allowed overlays of the surveys to be made at equal scales and a direct comparison of data from both systems. A simplified schematic diagram of the equipment used is given in Figure 9.

High Resolution Subbottom Profiler (HRSBP). The HRSBP uses a 3.5 KHz "Lollypop" transceiver towed over the side of the ship. 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 1000 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 creates 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 O.2 meters.

"Boomer". The "Boomer" type of acoustic sub-bottom Profiler utilizes a broadband electromechanical acoustic source to produce a sharp high energy pulse fired every 1/8th second from a surface towed sled. Energy pulses from the sled-towed transducer have a sound frequency range between 200 to 2000 Hz. This system, operating with a 1000 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 145 meters in the Abalone Cove area 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 1100 Hz. A towed hydrophone array was used to focus and 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 or 1/4 of a second. 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. The sound velocity within the sediment overburden and the underlying bedrock are higher than in the water column therefor a thickness 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 seawater velocity of 1450 m/sec was used to calibrate values taken in situ by probes and later on in cores retrieved for laboratory determinations. The average velocity for unconsolidated shelf sediments is 1700 m/sec. Thus for our values we apply a 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 Shelf. By using the same values were 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 again by measuring the distance along the bottom between a fix where continuous beds that 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 therefor give the dip of the beds. This is the standard procedure used in high resolution seismic stratigraphy studies.

Side-Scan Sonar. This system, utilizes a side looking towed transducer/receiver, to send and receive acoustical pulses at 500 KHz to the area on both sides of the survey boat. It's narrow beamed receiving transducer is configured to receive only echoes returning directly abeam of the towed transceiver. A continuous record of echoes from geological features such as bedrock and sedimentary bedforms is recorded on a strip chart. When this information, controlled by precise navigation, is plotted on a regional map it provides an acoustic picture of the bottom that extends on both sides of the survey vessel. This system is analogous to a radar except it uses acoustic energy and echoes to depict locations and relative positions of objects on the sea floor. Acoustic shadows behind the objects returning echoes, give an indication of their height above the sea floor. The system digitizes the returned signals, records the slant ranges of objects from the position of the boat. In this survey we used a 500 KHz transducer that provided a swath of acoustic coverage of about 100 meters (330ft.) on each side of the vessel. The swath length depended on water depth, depth of the transducer and power of the transceiver. The distance between traverse lines were adjusted so as to get complete coverage of critical areas indicated by land geology where faults and slump zones might extend seaward into Abalone Cove. We also ran one high resolution line using a sweep distance of 40 m on each side of the vessel which proved to be highly effective in determining the details of rock bottom and sedimentary features. Unfortunately the limited area of coverage by this system does not permit the surveying of large areas in a short period of time. It is much more efficient to use the longer swath paths for reconnaissance survey like this one.

MiniRanger III. The MiniRanger III navigation system is a microwave, "radar-type" positioning system with a range (line of sight) of 40 km and an accuracy of ±2 m. The determination of position is accomplished by determining the range between the mother station located on the survey boat and land based stations. As the vessel moves, its positions are automatically computed by intercepts of distance arcs from two shore stations located at Bench Mark locations on land. Range data, expressed in meters (m) is continually displayed on the front panel of the Mini-Ranger III console. This information gives the survey crew a visual check of distance from the shore slave stations. The range data is also recorded on both a magnetic diskette and a hard copy tape read-out from the ECO-NAV computer aboard the survey vessel. The navigational computer was programmed to place event marks on the PGR recorders at 15 second intervals and simultaneously record, in real time, the range-range distance to shore stations, time, date, and sequential shot point numbers on an internal magnetic disk. 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 and side-scan instruments on the ship and a back-up hand written trip log kept by observers on the boat.

The offshore seismic and side-scan sonar 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 (Chart I). These are then used to provide accurate positions for overlays of data from the side-scan and seismic tracks. All data from both the side-scan and sonar tracks reflect the navigational control and were used to plot the three dimensional data.

Shore stations were chosen using the topographic map of the area provided by the Rancho Palos Verdes Public Works Department. Shore station bench marks were located so as to obtain maximum coverage without line-of-sight obstructions. Two stations were used, one located at bench mark SPH-H8A on the western side of Portuguese Point at an elevation of 137.51 ft. and the other located near Station G-7 (± 6 ft.) at the southern rim of the jumping grounds of the Portuguese Bend Riding Club off Narcissa Drive at an elevation of 420 feet. Both stations

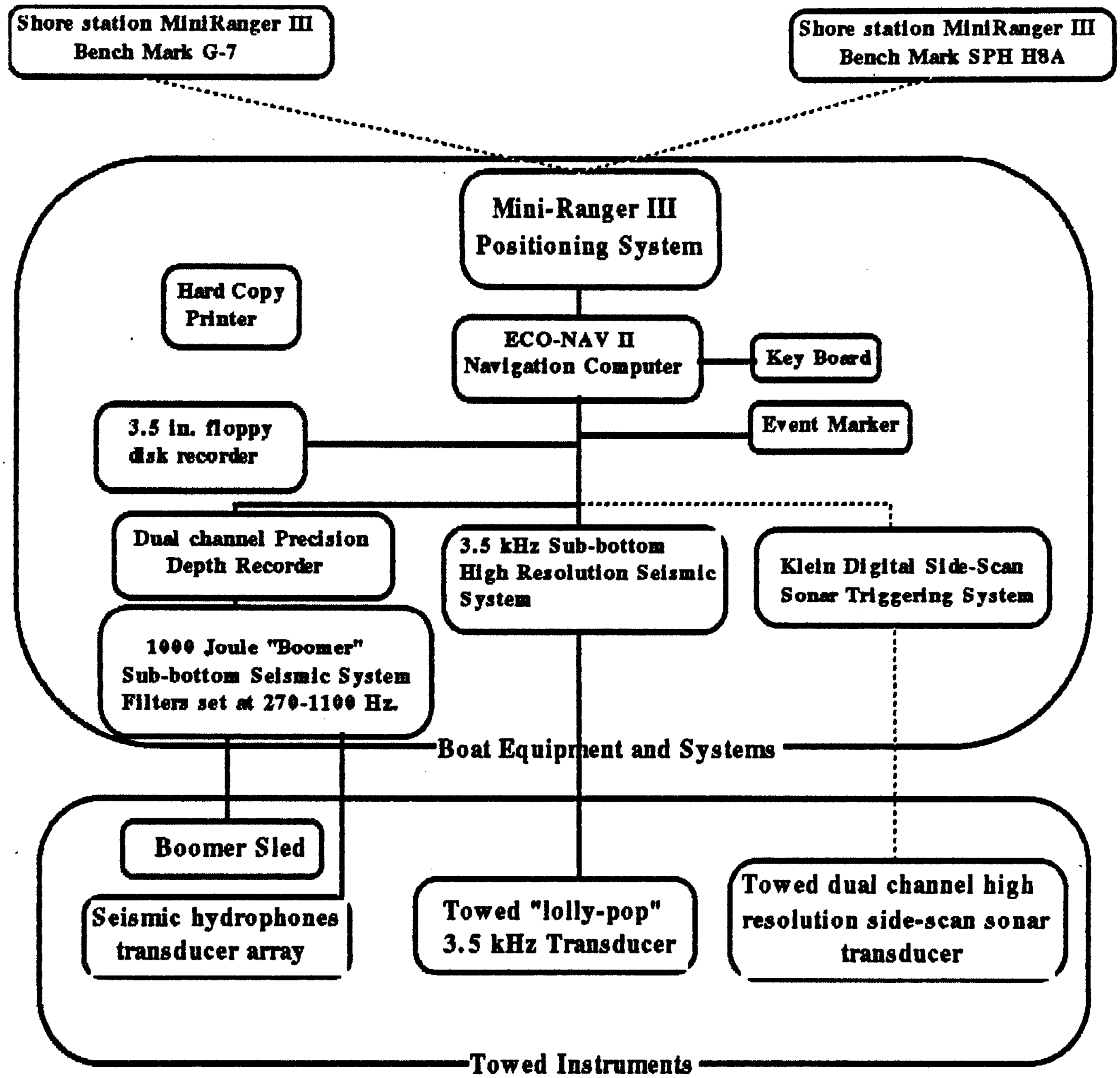

Figure 9. Schematic drawing of the system used in the Abalone Cove Survey. All equipment was providedc by EcoSystems Management.

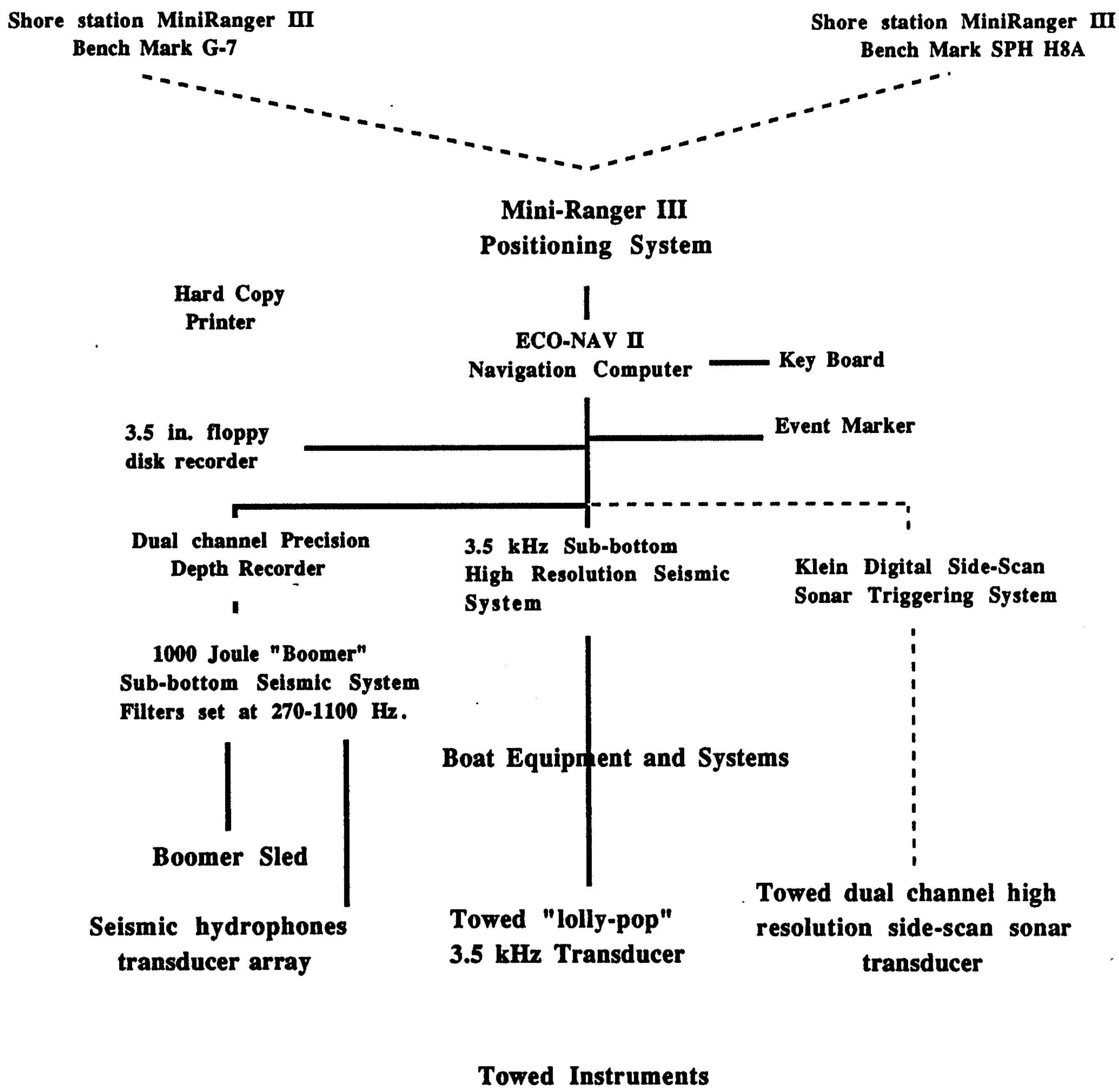

Figure 9. Schematic drawing of the system used in the Abalone Cove Survey. All equipment was providedc by EcoSystems Management.

overlooked the survey area and provided accurate locations throughout the field work period. The exact surveyed location of station G-7's bench marker was not known because the original monument had been knocked over by a bull bulldozer after its original placement. However our inspection of the sight indicated that it had not been greatly displaced and could be used because its apparent movement was within the accuracy of the Mini-Ranger navigation system (± 6 ft.) and the type of seismic data being obtained from the ship. A PVC pipe imbedded in a concrete block was placed in the ground at this Mini-Ranger shore station so that the sight can be reoccupied if needed in the future. All plots for this study were originally made at a scale of 1" = 200 feet. Shore line features are based on maps provided by the Public Works Department of Rancho Palos Verdes which were at the same scale. Fixes from the MineRanger III are numbered consecutively from Fix #0 to Fix #3430 the end of the survey. Survey Lines were numbered relative to their starting position to the coordinates of the survey chart.

Vibrocore. A Rossfelder Corp. P-4 medium frequency vibrocore was used to take 6 cores during Phase II of the survey. This instrument has a four (4) horsepower of power generator that vibrates at a frequencies up to 3600 rpm (60Hz) and provides a centrifugal force of between 6000-7000 lbs to the core nose. The Vibrocore is designed for coring unconsolidated sediments in the marine environment, taking sediment samples with a 4 inch diameter aluminum core tube. It has its own winch and power supply. The instrument is relatively light in weight and can be deployed from small vessels equipped with an "A-frame" capable of supporting pull-out loads. We initially used a 20 foot barrel but found that this was not necessary because cobble beds prevented penetration in the area being investigated to depths of less than 10 feet.

The sight for coring had been pre-selected during the side-scan surveys and bottom observations in areas where linear ridges had been observed during the April Phase I survey. We concentrated in areas where we had observed sediment boundaries that gave a linear return on the side-scan records. Buoys had been placed at desired locations for coring during the previous days survey. The tending vessel would then anchor so that the stern of the boat was at the buoy using a two anchor system to prevent movement during coring. After the core was retrieved it was stored in an upright position allowing any water to drain from the cored sediment. Excess core tube above the point of maximum penetration was then cut off and the core capped at both ends. Material from the top of the core and in the core catcher were then examined in the field, placed in sample bags and logged for content.

Upon returning to shore, the cores were opened using a pair of electric shears, retaining the core in the barrel. A visual inspection and description of the core was then logged using a hand lens. The cores were then closed and are in storage at the Dill GeoMarine Consultants warehouse.

Survey Boat. The offshore part of the survey was conducted from a 22 ft. inboard/outboard boat equipped with table space for supporting seismic recorders, shipboard navigational instrumentation, a davit for the over-the-side towed transceivers and seismic transducer array, and radio links with shore stations. A team of four operators recorded field logs of the operations, tended towed equipment and marked the recorder tapes with information from the navigational computer and seismic instruments. Two portable Honda generators provided electrical power to run instrumentation. The boat was launched and recovered from the Cabrillo Beach Park boat ramp each day and kept during the night in the Park Ranger's vehicle compound at the Park.

Appendix II
Core descriptions and logs

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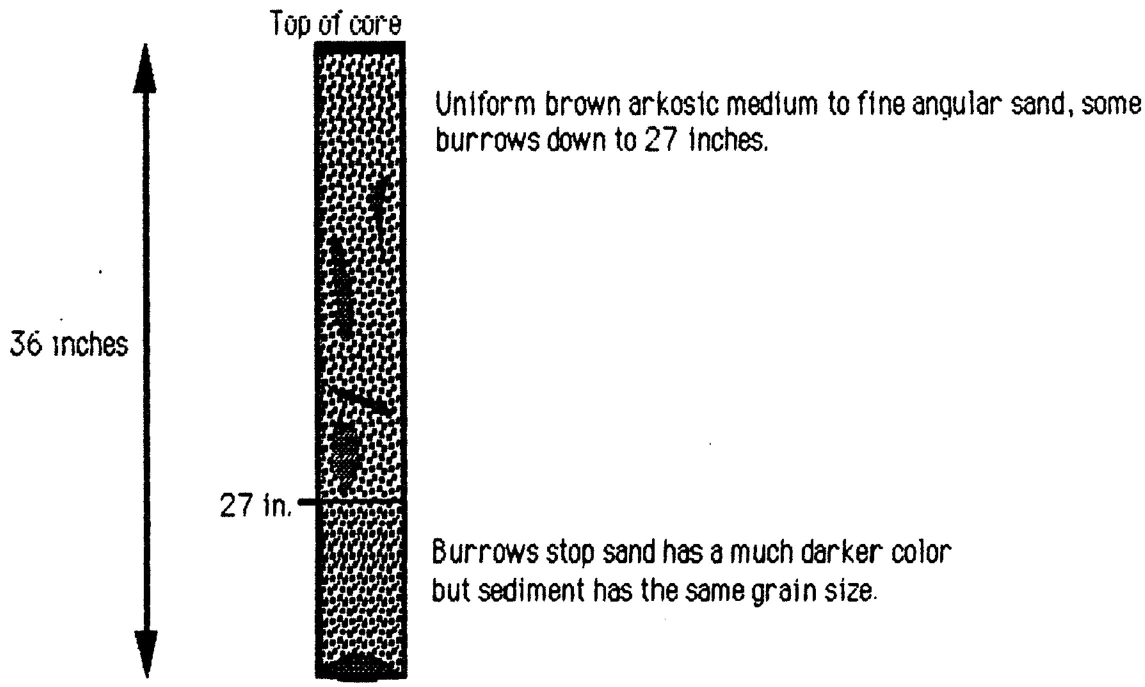
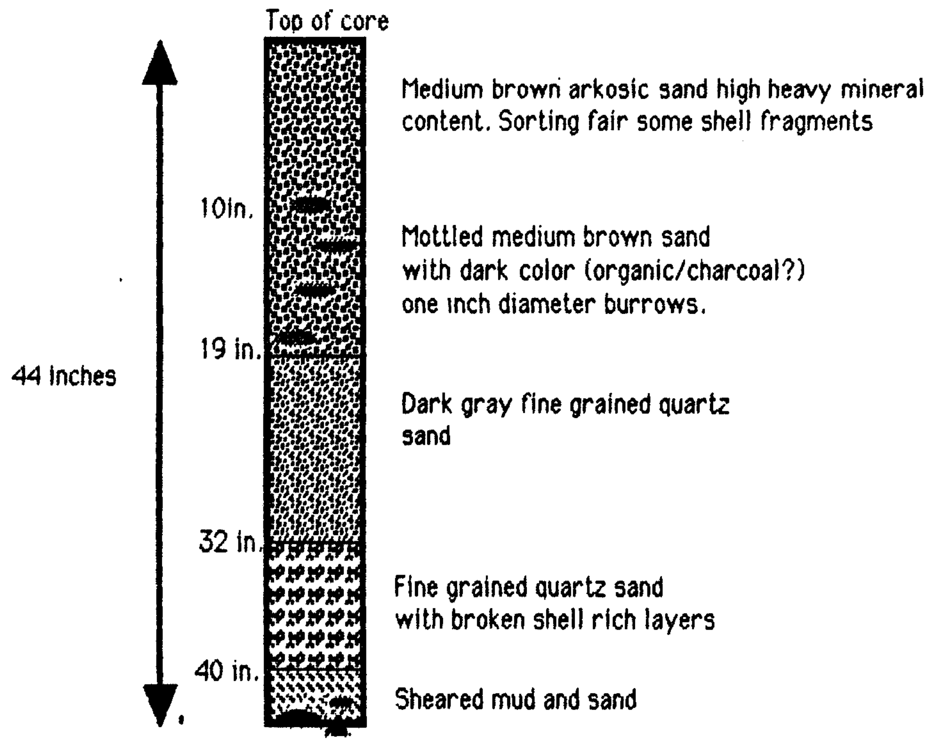
Core descriptions and logs

Core #1



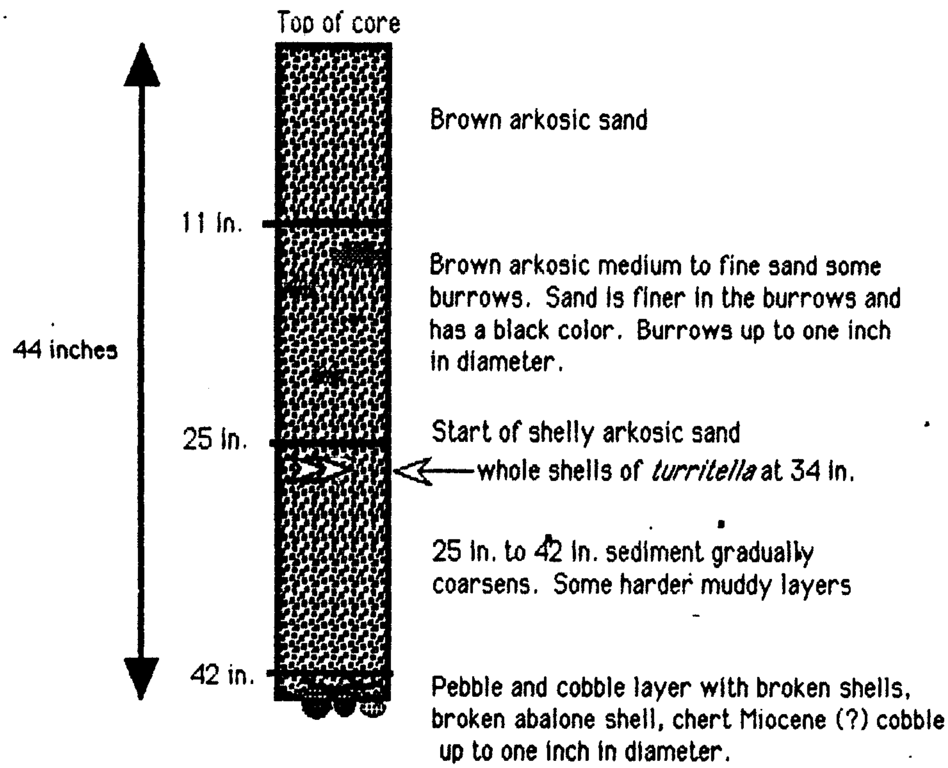
Vibrocore No. 1. Depth 33 feet. Located 10 feet south of orange buoy (see Figure 2). Core penetrated slowly and was stopped by a gravel layer that was in the core catcher. Sediment at the bottom of the core had a darker color due to reduced organic material and dark mica flakes. No smell. Core barrel bent at sea floor interface changed to a shorter 12 ft. barrel for next cores.

Core#2



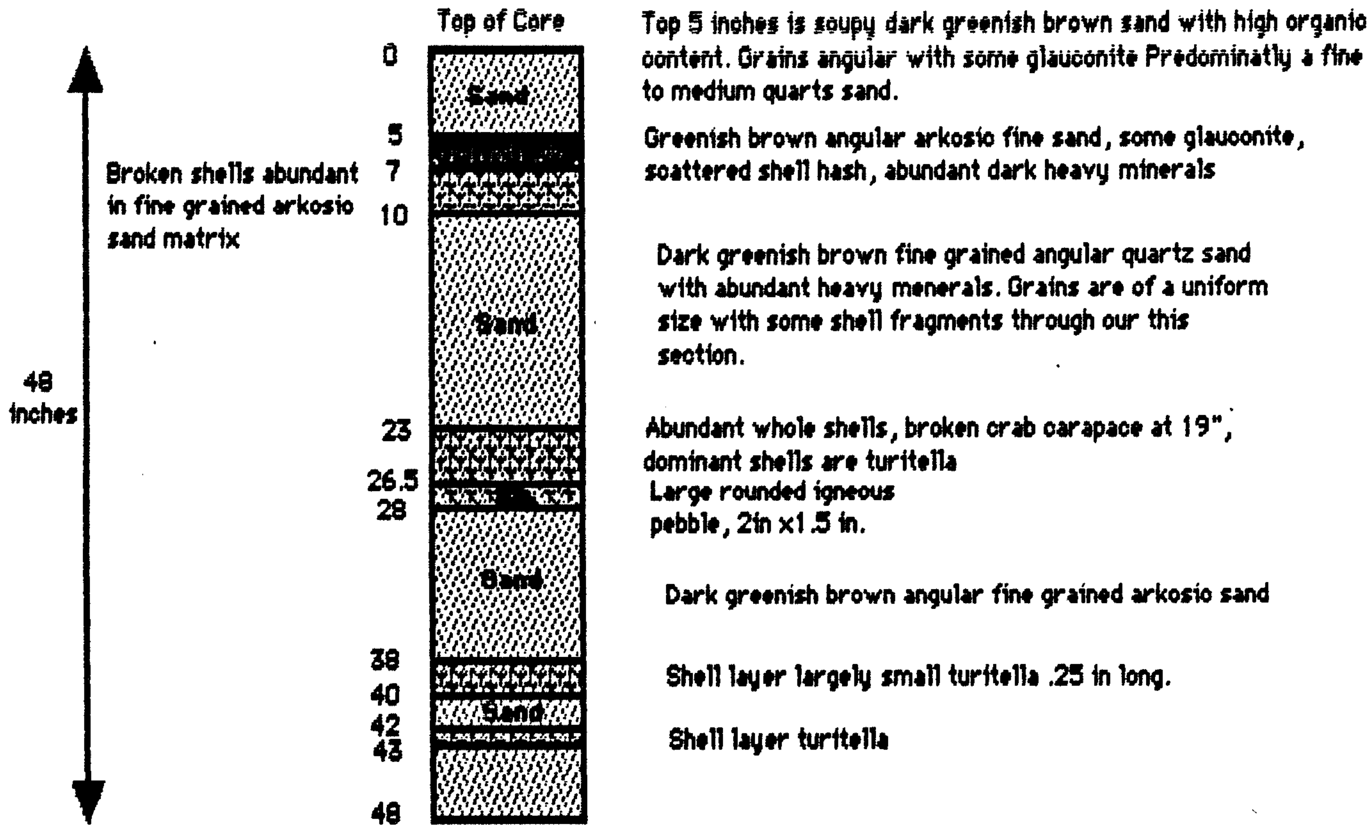
Vibrocore No. 2, depth 32 feet. Located 75 feet south of orange buoy (Figure 1). Core penetration stopped by a rounded cobble layer composed of black chert, broken shells and mixed in with the cobbles and pebbles in a sandy matrix. A sheared, muddy-sandstone layer approximately 4 inches thick was above the cobble layer. The sheared area was thin and did not extend up into the upper part of the core, could be an erradic.

Core #3



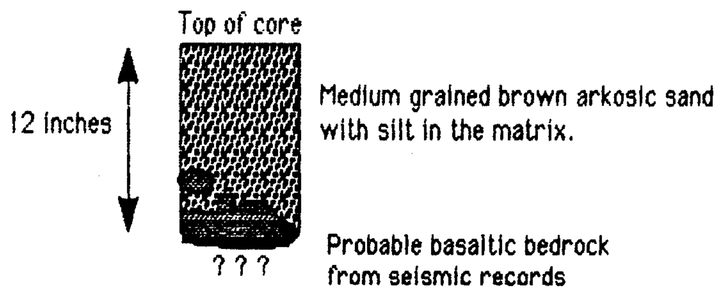
Vibrocore No. 3, depth 32 feet. Located 150 feet south of orange buoy (Figure 1). Core penetration stopped by a cobble laver with a shell and pebble matrix. Core tube bent at the seafloor upon pull out.

Core #4



Vibrocore No.4. Located 450 feet southeast of orange buoy on a magnetic bearing of 345 degrees. Upper five (5) inches highly bioturbated and has a soupy consistancy. The sediment is a dark greenish brown arkosic quartz rich sand. Grains are angular. Shell layers are made up of turitella shells some up to 1 inch long, but the majority less than 1/4 inches long. One large rounded pebble of igneous rock at a depth of 26.5 inches indicated beach erosion.

Core #5



Vibrocore No. 5, depth 35 feet. Located 250 feet southeast of orange buoy (Figure 1). Core barrel self destructed on bedrock at a depth of less than 12 inches. Brown arkosic sand trapped by core catcher flowed from core upon retrieval but was collected for analysis in a zip-lock bag. Seismic profiles in this area show a strong reflector below a thin cover of sediment.

Appendix III

Abstract submitted for presentation of an oral presentation at the Annual Meeting Society of Sedimentary Geologists June 3-6, 1990, San Francisco, CA.

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Title
A new approach; using high resolution seismic and side-scan sonar traverse , diving and coring, provides answers to coastal stability and possible offshore extensions of landslides into Abalone Cove, Palos Verdes Peninsula, California,

Abstract
The configuration and stability of the present coast line near Abalone Cove, on the south side of Palos Verdes Peninsula, California is related to the geology, oceanographic conditions, and recent and ancient landslide activity. Offshore seismic, side-scan sonar, diving, and coring surveys, standard tools for offshore construction, oil exploration and hazards studies, were used in a new way utilizing a desk top computer to relate marine geology to the stability of a coastal region and shoreline configuration. This paper details the systems used, present findings relative to potential landslide movements, coastal erosion and discuss how conclusions were reached to determine whether or not onshore land failures extend offshore.
Precise navigation permitted correlation of data needed to define the offshore geology and sea floor sediment patterns. A Mackintosh II™ desk top computer and commercially available software (WingZ™ and McGridzo™) provided the analytical tools for constructing base charts and overlays of topography, isopachs of sediment thickness and sediment distribution patterns to relate this geology with an extensive engineering and geological study of the coastal zone forming Abalone Cove, an area of active landslides. Vibrocoring provided ground truth sediment data for the high resolution seismic traverses. Seismic records reveled; 1) a thick layer of Holocene sediment covering an eroded bedrock plane truncating bedded sediments of the Monterey Formation which has a Miocene age.; 2) evidence of ancient shoreline features, rising sea level, basalt stacks and sills; and 3) several well defined faults and tectonic structures within the bedrock. However the data does not conclusively support the possibility of present day land movements extending into Abalone Cove.

Abstract submitted for presentation for a poster presentation at the
Annual Meeting of the Society of Sedimentary Geologists
June 3-6, 1990, San Francisco, CA.

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Title
Seismic, side-scan survey, diving and coring data analyzed by a Macintosh II™ computer and inexpensive software, provide answers to a possible offshore extension of landslides at Palos Verdes Peninsula, Calif.

Abstract
A Macintosh II™ computer, utilizing commercially available software, was used to analyze and depict the topography, construct an isopach sediment thickness map, plot core positions and locate the geology of an offshore area facing an active landslide on the southern side of side of Palos Verdes Peninsula, California. Profile data from side scan sonar, 3.5 KHz and Boomer sub-bottom, high-resolution seismic, diving, echo sounder traverses and cores--all controlled with a mini Ranger II navigation system-- were placed in MacGridzo™ and WingZ™ software programs. The computer plotted data from seven sources was used to construct maps with overlays for evaluating the possibility of a shoreside-landslide extending offshore.
The poster session describes the offshore survey system, demonstrates the development of the computer data base, its placement into the MacGridzo™ gridding program and transfer of gridded navigational locations to the WingZ™ data base and graphics program. Data will be manipulated to show how sea floor features are enhanced and how isopach data was used to interpret the possibility of landslide displacement and Holocene sea level rise. The software permits rapid assessment of data using computerized overlays and a simple and inexpensive means of constructing and evaluating information in map form and the preparation of final written reports. This system could be useful in many other areas where seismic profiles, precision navigational locations, soundings, diver observations and cores provide a great volume of information that must be compared on regional plots for the development of field maps for geological evaluation and reports.

Appendix IV (located in back packet)

Track Charts
Phase I
Phase II
Diver Tows and Core Locations
Depth Contour Chart of Abalone Cove
Isopach of sediment thickness (MacGridzo and WingZ