THE SEDIMENTS IN THE HEAD OF CARMEL SUBMARINE CANYON

by

Steven Russell Wallin

UNITED STATES
NAVAL POSTGRADUATE SCHOOL

THESIS

THE SEDIMENTS IN THE HEAD OF
CARMEL SUBMARINE CANYON

by

Steven Russell Wallin

December 1968

THE SEDIMENTS IN THE HEAD OF CARMEL SUBMARINE CANYON

by

Steven Russell Wallin
Lieutenant, United States Navy
B. S., U S. Naval Academy, 1962

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
December 1968

ABSTRACT

Carmel Submarine Canyon is cut into the Santa Lucia granodiorite formation and is the only canyon on the California coast which is cut in granitic rock. The innermost head of the canyon exhibits a wide, bowl-shaped appearance, not unlike a glacial cirque.

Granodiorite outcrops on the submarine terrace on the north and south sides of the canyon and in the north canyon wall. Much of the terrace and upper canyon sides are covered by coarse sand while the interior of the canyon head is covered with fine sand.

The canyon is actively transporting sediment to deeper water at the present time. The chief source of sediments is coarse sand which is littorally transported from the mouth of Carmel River. This sand enters the canyon by way of three "rivers of sand" which extend over the canyon rim and down the slopes. Additional transport of sediment within the canyon head may be the result of slumps and slides lubricated by decomposition of vegetable matter incorporated in the sediments.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

LIST OF ILLUSTRATIONS

ACKNOWLEDGMENTS

The author wishes to express his appreciation for the assistance and advice given by Professor Warren C. Thompson, under whose direction this study was carried out. Photographic supplies and minor diving equipment were provided through the Office of Naval Research Foundation Grant to the Naval Postgraduate School.

The author is especially grateful to Lt. C. A. Moritz, who, while working on a related study, was an able diving partner and an always caustic critic.

The consummate knowledge and diving assistance of Cdr. Donald Ferrin, USN, who participated in a number of dives, was helpful in conducting the surveys of this study.

Additional diving assistance was provided by Lt. Richard Lennox, USN, Lt. Bruce Googins, USN, Capt. William Bond, USMC, and Sergeant Tom Maudlin of the Pacific Grove Police Department.

The beach off of which this study was made is under the jurisdiction of the State of California, and thanks are expressed to Mr. Charles Mehlert and Mr. Donald Rich of the California Department of Natural Resources, Division of Beaches and Parks, Monterey, for their cooperation in this study.

INTRODUCTION

OBJECTIVE

The objective of this investigation was to determine the general nature and the sources of the sediments in the head of Carmel Submarine Canyon (Figure 1). In addition, some feeling for the modes of sediment transport in the vicinity of the canyon head was desired. Field work in support of this study was started in mid-December 1967 and concluded in November 1968. This thesis presents the results of this field work and conjecture as to the sedimentary processes occurring in the canyon head.

BACKGROUND

References in the literature to diver-observed studies of the heads of submarine canyons are notable for their scarcity. Noteworthy among these are the studies conducted by Dill (1964), Chamberlain (1964), and Shepard (1948). To date no such comprehensive study has been conducted in Carmel Submarine Canyon.

Carmel Submarine Canyon is unique among California submarine canyons in that it is the only canyon the head of which is cut in granitic rock. The canyon also has a wide, basin-shaped head, not unlike a glacial cirque. This is in contrast to the deeply incised and narrow heads found in Scripps, La Jolla, and other California canyons that are cut in sedimentary rock.

FIELD WORK

Equipment. Equipment used in this study consisted of standard scuba equipment, an underwater camera, a 13-foot Boston Whaler boat, and transits to provide positions for offshore sample collection and charting. Special equipment constructed for the field work consisted of 7-foot calibrated stakes for installation on the sea floor and an underwater navigation board. In order to drive the stakes into the bottom, it was necessary to devise an underwater hammer. The latter equipment is depicted in Figure 4.

The navigation board was designed to aid in navigation and note-taking underwater. This consisted of a 1/8 x 12 x 15 inch sheet of plexiglas on which were mounted a magnetic compass and an oil-filled depth gauge. A 90-degree arc was etched on the board so that when the bottom edge of the navigation board was placed on the sea floor, a plumb bob gave the angle of inclination.

Underwater photography was accomplished using an f3.5 Rollieflex camera mounted in a Rollie-Marin underwater housing. Nearly all of the underwater photographs were taken by Lt. C. A. Moritz.

Sediment samplers employed in the study were a small snapper, a Phleger corer, and a small coffee jar. All of the equipment used, with the exception of the scuba equipment, was made available by the Naval Postgraduate School.

Positioning. Positioning by surveyor's transit located on shore was the method of navigation most used throughout the study. Because of difficulties caused by the movement of the small boat, sextant-angle navigation was resorted to only when sample positions could not be seen from the transits.

Two transit sites located at the ends of a measured baseline were established (Figure 5). The transit men were alerted by walkie-talkie when the sampling device was in the water. Samples and transit angles were assigned identical numbers as they were taken. Depending upon the angular relationship between the boat and the two transit sites, fixes with accuracies of 1 to 10 feet are estimated.

Data and Sample Collection. A total of 19 stakes were placed around the head of the canyon along the 100-foot depth contour (Figure 5). The purpose of the stakes was to monitor any slumps or gravity creep that might take place and to serve as navigational landmarks for the divers. Every fifth stake was fitted with a styrofoam buoy and 105 feet of light line (Figure 4). The buoyed stakes were placed as Stakes 1, 6, 11, and 16 in the line of 19. After emplacement on the bottom by a diver, the buoy was released to float to the surface. Immediately upon surfacing, the buoy's position was fixed by transit angles from the shore. The buoyed stakes served to fix the position of the entire array. Two sets of measurements were made at the stakes of the sand level and bottom slope, and are reported in Table I.

The primary sediment sampling device employed in the collection of offshore samples was a light-weight snapper. The snapper was handled manually on a 300-foot length of 1/4-inch polypropylene line. It was found that once wet, the polypropylene line lost its tendancy to kink and could be effectively tended without the use of a winch or reel by simply laying it in the bottom of the boat after each cast.

Use of the snapper produced two mechanical problems. The first of these was its non-uniform descent. From the boat the sampler could be seen angling away in an unpredictable direction on each cast. Since the target for all transit angles was the boat, this abnormal behavior may have resulted in fix errors of up to 30 feet.

The other problem arose in areas where the sediment grain size was coarser than 1 to 2 millimeters. Closure of the snapper was always incomplete in these areas due to coarse sand grains jamming the hinge. As many as 15 successive attempts were made in coarse sand areas without success. The poor sample return was not a matter of activation of the sampler because in every case the device was tripped. In addition, difficulties were sometimes encountered when a large grain of sand would hold the lips of the cup open and the fines would be lost in recovery of the sampler.

Bottom samples were also gathered by diving. Site-to-site transportation for the diver was provided by running the boat in reverse and towing the diver from the bow. Speeds were kept well below 5 knots to prevent injury. The sample container used was a small glass coffee jar. Care was required to ensure that the cap was removed prior to descending because increasing water pressure soon made removal of the cap impossible. Upon arrival on the bottom, the diver made a sight evaluation of its overall character and selected an area which seemed to be representative. The coffee jar was then filled with a sample and returned to the surface.

Six attempts were made to core the bottom in the canyon head, all of which were unsuccessful (Figure 15). Each attempt yielded a small amount of mud smeared on the upper end of the core tube. In every instance, the core cutter was recovered undamaged. It appeared from this evidence that the bottom was a layer of mud overlying a thicker layer of relatively clean sand.

Sample Representativeness. Considerable attention was given to the problem of representativeness of the samples collected. This problem is particularly acute in this area because of the patchy distribution of the bottom sediment types. Diver observations made possible a comparison of samples gathered by the snapper with a visual examination of the bottom where the samples were collected. Examples encountered that illustrate the limitations of surface sampling without accompanying diver observations will be presented.

While on a general reconnaissance dive on the north side of the embayment which contains the canyon head, a small open area of fine sand was found among the rocks which characterize the bottom locally. Nearly in the center of the sand patch was a clear imprint left by the snapper. This sample location was believed to be the same as that where Sample 12 was taken (Figure 15), and gives the erroneous impression that the bottom in this area is all sand and no rock.

An example of inadvertent bias that is possible in the textural data can be seen by comparison of the sediment parameters calculated for Samples 22 (median 1.94 phi) and 23 (median 1.94 phi), which are snapper samples, and those calculated for Samples 47 (median -.36 phi) and 48 (median -.75 phi), which were diver-gathered samples. Figure 15 shows the location of these samples to be in close proximity to one another, but the textural parameters show the samples to be very dissimilar. Again the snapper samples do not portray the true character of the bottom because diver observations in this area showed the bottom to be covered with very large, nearly symmetrical, wave-induced ripple marks in which gravel and pebbles occur in the troughs and medium to fine sand on the crests. Since the wave lengths of the ripple marks were 6 snapper-cup diameters or more, samples representative of the bottom could not be gathered in this manner.

Representative diver sampling of the ripple marks also proved to be a problem. In an attempt to get a sampling of all textures, the diver made collections in this area by sweeping the coffee jar from trough to crest on the ripple mark. This had the effect of combining all of the grain sizes present into one sample. This is undesirable because it tends to produce a somewhat arbitrary bimodal distribution, but it gives a rough value for the general texture of the bottom.

Sampling for the grain-size distribution in a ripple mark environment such as this is difficult when the objective is to present a large-scale picture of the textural distribution. Because of the repetitive grain-size distribution that is essentially identical from one ripple to another, and the fact that ripple mark crest lengths are usually in excess of 100 feet, a grain-size contour chart with sufficient detail to accurately represent the texture of the bottom would appear as a series of parallel lines.

DESCRIPTION OF THE AREA

LAND TOPOGRAPHY

The coastline surrounding the head of Carmel Submarine Canyon is one of meagre beaches entrapped by bold outcrops of granodiorite (Figure 2). The northern terminus of the Santa Lucia Range provides a mountainous background behind the beach. Immediately inshore of the canyon head there is a curving coarse sand beach, and behind it, at the foot of the mountain mass, is a miniature alluvial plain that has been laid down by the meanderings of San Jose Creek.

Clearly visible on the surrounding hillsides are the remnants of at least two ancient marine terraces (Figure 3). The uppermost of these lies at an elevation of about 200 feet and appears to be part of the larger marine terrace which can be seen at various places along the full length of the Santa Lucia Range. The lower terrace, at an elevation of about 40 feet, encircles the coast around the embayment which contains the canyon head. A bathymetric survey of the canyon head by Keithley (1968) (see pocket on rear cover) indicates the existence of still another terrace of marine origin underwater in the canyon head.

SAND DEPOSITS

Two rivers enter the ocean in the immediate area (Figure 2). At the north end of the study area the Carmel River debauches into the Pacific and in some years carries a considerable sediment load. Although the river flows only intermittently in the winter, it makes the primary contribution to the sand budget of the area. San Jose Creek, which has a very steep gradient, is also an intermittent stream. However, its contribution to the sand budget of the area is secondary.

A pertinent observation regarding the mineralogical composition of the sands introduced by these rivers emerges from study of the rocks outcropping in their watersheds (Geological Map of California, Santa Cruz Sheet, 1958). In the upper reaches of the Carmel River drainage basin, there is a sizeable area of metamorphic rock. Weathering of this rock and its eventual transport by the river brings it to the beach in the study area. The watershed of San Jose Creek contains granodiorite and shale but no metamorphic rocks. Use of this fact was made in a gross qualitative analysis of the beach sands which is presented later.

Beaches in the area consist of Carmel River Beach on the north, Monastery Beach on the south, and three meagre beaches between (Figure 2). This chain of beaches is interrupted by outcroppings of granodiorite.

GEOLOGICAL SETTING

Rock types outcropping on the coast around the head of Carmel Submarine Canyon are shown in Figure 3. The dominant rock type is the Santa Lucia granodiorite, a small pluton of Cretaceous age. Santa Lucia granodiorite underlies much of the local area and is the rock into which the head of the submarine canyon is cut. All underwater rock outcrops noted by divers were of this rock type. The general trend of the dominant faulting and jointing in this formation is north northwest-south southeast. Not too surprisingly, the general trend of the submarine canyon also has the same orientation.

Overlying the Santa Lucia Formation and in faulted contact with it are coarse sandstones and conglomerates of the Carmelo Formation, of Paleocene age. This formation outcrops over part of Point Lobos and comes in contact with the ocean at Whaler's Cove and at the locations shown in Figure 3. The conglomerate is composed of cobbles set in a medium sand groundmass. The cobbles are composed predominantly of rhyolite and dacite porphyry with a respectable percentage of quartzite.

Other rock types in the area are the Monterey and Chamisal Formations (Bowen, 1965). The Monterey Formation is a siliceous marine shale of middle Miocene age which outcrops over a large area inland from the coast. The formation does not meet the ocean in the study area but is a major sediment source in the watersheds of Carmel River and San Jose Creek.

The Chamisal Formation, also of middle Miocene age, is a poorly consolidated cobble conglomerate and sandstone mixture of marine origin. What may be an outcrop of this formation occurs in a small area on the north end of Monastery Beach and is indicated in Figure 3 as being of "uncertain age."

There are four faults of significance which run into or through the area (Geologic Map of California, Santa Cruz Sheet, 1958). The two largest of these are the Sur and Palo Colorado Faults, which Martin (1963) states provide structural control for the outer, north northwest-tending portion of the canyon.

Running parallel to Carmel Valley on its south side is a fault known as the Carmel Valley Fault (Martin, 1963, in personal communication with O. L. Bowen). Although not well documented, the existence of this fault is evidenced by differences in foraminiferal ecology and seismic properties on either side. Extension of this fault seaward brings it coincident with the general trend of the landward end of the submarine canyon. Martin (1963) speculated that the fault constitutes a zone of weakness along which erosion of the submarine canyon has taken place.

In the land canyon cut by San Jose Creek there is a small fault called the Blue Rock Fault which has been traced to within 3 miles of the ocean (Geologic Map of California, Santa Cruz Sheet, 1958). Owing to the linear trend of San Jose Creek along the fault line, it is probable that the fault extends the full length of the land canyon and into the water at Monastery Beach to form a zone of weakness which lead to the genesis of the canyon head.

CANYON HEAD TOPOGRAPHY AND BOTTOM MATERIALS

SUBMARINE TOPOGRAPHY

The submarine canyon is cut into a terrace whose characteristic depth is about 30 feet (Figure 7). The zone between the shoreline and the general terrace level is very steep along the rock shoreline areas, and more gentle off the beaches.

The canyon rim occurs in depths from about 40 to 60 feet and appears as a well-defined change in slope, even in the sandy areas of the canyon head.

The head of the submarine canyon off Monastery Beach is bowl-shaped and bears a resemblance to a glacial cirque. The north wall of the canyon adjacent to the canyon head is an extensive rock exposure with percipitous slopes. Immediately north of this, the canyon wall is a steeply sloping sand surface with inclinations between 30 and 35 degrees. The south side of the canyon is also sand covered and has about the same slope.

On the south side of the canyon head there are several large rock outcrops (Figure 7). The largest of these outcrops, which trends northwest on the south side of the embayment, serves as a groin and appears to influence sand transport locally.

The bottom of the canyon is a gently sloping sandy trough to the deepest depths penetrated, and there is no well-defined canyon axis.

Minor features of submarine topography will be considered in the next section.

DISTRIBUTION OF ROCK AND SEDIMENTS

Rock. The only rock type that was observed outcropping underwater was the Santa Lucia granodiorite. This rock occurs on the south terrace adjacent to the shoreline of Point Lobos. It also covers much of the north terrace and north wall of the canyon head. It protrudes through the sand cover in a few places on the south side of the canyon head (Figure 7). The rock outcrops are definitely a part of the overall sediment picture in their control of the sand distribution and as a minor sand source.

Coarse Sand. The category "coarse sand" is a general one and for the purpose of this discussion is defined as sediment with a mean diameter coarser than 1 phi (1/2 millimeter). As shown in Figure 7, coarse sand is the most widespread bottom type in the study area, and is the only extensive bottom type found on the terrace. It extends over the canyon rim and down the slopes of the canyon in three places.

A minor sedimentary feature which is characteristic of the coarse sand area is ripple marks (Figure 8). The ripples are large with extremely long crests. Ripple lengths and heights varied from observation to observation but were always smaller in deeper water. The characteristics of the ripples are described later.

Another feature that was observed in the coarse sand area was a layer of indurated silty clay (Figures 11 and 12). The silty clay was found exposed in the troughs of the coarse sand ripple marks in the area shown in Figure 7 and was found as broken pieces in some places. The silty clay contained biogenous material whose concentration varied (Figures 11 and 12). This feature was exposed by vigorous oscillatory water motion associated with storm waves. The south edge of the area shown in Figure 7 was not explored and the extent of the feature may be much greater.

Fine Sand. For the purpose of this presentation fine sand is defined as sediment having a grain size between 1 and 4 phi units (1/2 to 1/16 millimeter). Fine sand occurs only on the slope of the canyon and is the predominant sediment type there. It occurs at the foot of the north wall of the canyon head and between the two areas of coarse sand on either side of the head (Figure 7). Most of the fine sand bottom is a haven for multitudes of tube worms (Figure 10). These organisms have the effect of stabilizing the slope, and their protruding tubes intercept vegetable debris which drifts downslope.

Sediment Mat. An unusual sedimentary feature of limited extent that was observed is a sediment mat, which consists of a diverse mixture of fine sand and intertwined kelp. The sediment mat is permanent and can be found in the old slump scar around Stake 13 (Figure 5). However, the dimensions of the mat are determined to a high degree by the availability of the constituents, and may at times cover a large part of the slope in the canyon head (Table I).

SEDIMENT SAMPLES

The locations of all sediment samples collected are presented in Figure 15. A list of the standard statistical parameters calculated for these samples is contained in Appendix I. Those stations for which parameters are missing are presented in Appendix II. Reasons for missing statistical parameters were nonrecovery of a sample, insufficient amount of sample to process, or something other than sediment contained in the sample.

As indicated earlier, sample representativeness was a problem in this study. Bottom topography and sampling methods were the chief reasons for the problem. Five of the samples exhibited bimodal or trimodal distributions. Since the statistical parameters presented in Appendix I do not adequately show this peculiarity, cumulative plots of the grain-size distributions are presented in Appendix IV.

Sample 37 is noteworthy for its coarseness. This sample was gathered by diving and is considered to be representative of the bottom in the area where it was taken.

Another interesting sample is Sample 19, which was found to have a large percentage of biogenous material and some very angular pebbles. This sample was examined for its biogenous component by Professor E. C. Haderlie of the Naval Postgraduate School, who established that the plants found in the sample are reeds and bull-rushes. This would appear to be an anomalous finding; however, the silty clay found in the coarse sand area next to the northern outcrop of granodiorite (Figure 12) also contains a large amount of matted vegetable matter which was determined by Haderlie to be of land origin, but its exact type was not discernible.

The bottom types shown in Figure 7 were compiled mainly from diver observations (Figure 6) and not from the statistical parameters. For this reason the indication of bottom types terminates in general at a depth of 120 feet. As shown by snapper samples and the unsuccessful coring attempts, the bottom in deeper water is characterized by a layer of mud overlying a thicker layer of relatively clean sand.

SEDIMENT DYNAMICS

SEDIMENT SOURCES TO THE CANYON HEAD

Carmel Submarine Canyon is at the present time transporting sediment to deeper water. Sediments being moved are mainly in the sand sizes. To appreciate the mechanics of this transport it is necessary to know the sand sources.

Littoral Drift. Littoral drift is the chief means by which sediment is being transported into the canyon head. However, this fact was recognized too late in the study to permit field measurements designed to gauge this transport. In the absence of data, some qualitative observations have been made for presentation here.

Wave Evidence. National Marine Consultants (1960) presented a compilation of statistical wave data for the California coast. The data show that 40% of all deep-water wave energy in the vicinity of Carmel Bay comes from the northwest. In addition, 90% of all deep-water wave energy in the area emanates from the sector between west and north-northwest.

Wave refraction diagrams for Carmel Bay prepared in a course on coastal oceanography at the Naval Postgraduate School were used to bring deep-water waves in to the shore. The direction-period combinations used for these diagrams are as follows: NW, 17 seconds; WNW, 15 seconds; WNW, 17 seconds; W, 11 seconds; W, 13 seconds; and W, 17 seconds. The periods of waves prevailing in this area are usually between 9 and 11 seconds, so the periods chosen in the exercise were long. The directions, however, were representative.

It was found that waves incident from a northwest to west direction generally create breaker angles conducive to littoral drift directed from the mouth of Carmel River southward toward the canyon head. Littoral transport along the shoreline on the north side of Point Lobos for all deep-water wave directions is also directed toward the canyon head according to the breaker angles there. These conclusions can only be considered to be generally true because the bathymetry of Carmel Bay and the offshore bottom is very complex.

Mr. Donald Rich, Superintendent of Point Lobos State Park, made available surf observations which were made by park rangers at Carmel River Beach from August 1967 to April 1968. One of the measurements recorded was the littoral current. For this determination, a packet of dye was thrown into the surf from the same point at the center of the beach on each observation. The progress along the beach of the center of the dye patch was then observed and recorded. The results are presented in Table II. Many of these observations show no drift at all but of those that do, there is a definite preference for a net southward movement toward Monastery Beach. Currents as fast as 1. 7 feet per second were recorded.

Several areas of granitic rock outcrop on the shoreline between Carmel River Beach and Monastery Beach which force any littoral drift to move seaward around them. Study of aerial photographs taken of this area revealed a narrow strip of open water between the shoreline and the inshore edge of the kelp beds. While walking along the rocky shore in these areas, scrutiny of the shallow rock tables just offshore from the outcrops revealed them to be covered by a veneer of clean sand.

On still another field trip to this area, vigorous wave action was observed to maintain the above mentioned sand veneer in a state of almost constant suspension. A current of fluctuating velocity was observed running southward along the meagre beaches and rock outcrops between Carmel River Beach and Monastery Beach. This current was rapid in the surf zone but could not be distinguished immediately to seaward.

Sand Chutes. Further evidence of the general transport of beach sand southward toward Carmel Submarine Canyon occurs in the form of sand chutes cut in the rock terrace along the north wall of the canyon head. The sand chutes are in general branched troughs varying in width from 2 or 3 inches to as much as 10 feet and oriented approximately parallel to the shoreline. Routes of the sand chutes could be traced for long distances through the outcrop and all chutes emptied onto the coarse sand bottom to the south. The chutes are generally well rounded and follow the jointing of the rock. Most chutes were observed to be filled with clean sand which in most cases was devoid of sand-dwelling organisms. Similar sand chutes were found in the rock bottom on the south terrace, but these are oriented perpendicular to the shoreline suggesting that erosion is due to wave-induced oscillation of the coarse sands on the bottom.

Beach Cusps. Another mechanism of sand transport is beach cusps and their associated rip currents. Beach cusps are a characteristic feature of both Carmel River Beach and Monastery Beach. They are nearly always present but are most noticeable during periods of high waves. At the onset of high waves the cusps in the area have been observed to deepen and develop rip currents emanating from their troughs. The rips are produced when water from a receding wave flows down either slope of a cusp and concentrates its volume in the trough.

These rips often achieve sufficient speed to break through the surf zone. This usually happens when successive breaker heights are decreasing in a wave train. When a rip breaks through the surf it carries with it sand that may be permanently lost from the beach. These rips are especially powerful off Monastery Beach. It is possible that the rip currents associated with beach cusps may function to transport sand which is surplus to the maintenance of dynamic beach equilibrium into deeper water.

Mineral Evidence. A gross analysis of the mineral composition of the sand samples was made, and was restricted to the beach samples. It was found that the major fraction in the sand grains is composed of quartz and feldspar, apparently largely plagioclase; these are considered to be derived from weathering and erosion of granodiorite. The beach sands also contain a sizeable amount of quartzite, and small amounts of garnet and opaque minerals in the fine sizes. Study of geologic maps of the area shows the only significant source of quartzite to be in the watershed of the Carmel River. However, minor amounts may be derived by disintegration of cobbles contained in the limited exposures of the Carmelo Formation on the shoreline of Point Lobos (Figure 3).

Vegetable Debris. A major contributor to the sediment in the area is vegetable debris. Accumulation occurs mainly in the fine sand and sediment mat areas indicated in Figure 7. The debris is made up almost completely of broken kelp. Vegetation is dislodged from its moorings at various places in the area and is carried by prevailing wind and wave action into the cul-de-sac around the head of the canyon. There the debris is broken up in the surf and is either tossed up on the beach or sinks to become part of the organic sediment mat or the organic "boas."

The latter are masses of intertwined kelp which are roughly circular in cross-section and very long, often exceeding 100 feet. These boas lie row upon row near the beach in the troughs of the large ripple marks described earlier. The passage of waves overhead causes the kelp boas to roll with the period of the swell through about half of their circumference in either direction. This oscillation can be observed to scour sand grains out of the ripple trough and into the ripples on either side.

The kelp boas appear to be a unique feature in that reference to such a feature could not be found in the literature. The name boa was selected because of their resemblance to a ladys' feather boa. It is believed that eventually the boas migrate seaward and become part of the intertwined kelp in the sediment mat which was described earlier. The remains of what may have been a boa is shown lodged against one of the reference stakes in Figure 13.

In addition to providing material for the organic sediment mat and the boas, individual pieces of vegetable debris have been observed moving down the slopes of the canyon head. At times, large concentrations of kelp also move down the slopes into the canyon head as evidenced by the large bundle which had fouled Stake 8 on the November 2 survey dive (Table I). Due to the large amount of vegetable debris found within the canyon head, it is probable that movement of the debris serves as an erosional agent on the sands over which it travels.

Local Shoreline Erosion. An apparently minor source of sediment to the canyon head is the erosion of the local shoreline. Most of the shoreline in this area is composed of granodiorite which appears to be comparatively resistant to erosion by waves. Erosion of the Carmelo conglomerate formation is actively providing sediment to the area, as can be seen by the beach composed of this material lying at the foot of the seacliff in which it outcrops. However, the conglomerate outcrops have been eroded back so far that communication with the sand budget of the inner canyon head appears remote (Figure 3).

Submarine Erosion. An apparently still less significant sediment source is the submarine erosion of rocks in the vicinity. Erosion takes place in three ways, each usually taking advantage of the inroads made by the other two. One of these means is the chemical weathering of the granodiorite as evidenced by the friability of dessicated samples of rock which underwater were very hard and difficult to remove. Another erosional agent is mechanical abrasion by the almost constant movement of sand in the bottoms of sand chutes and wherever sand moves around the base of rocks. Following a period of heavy wave action, barnacles to a height of about 6 inches above the bottom were observed to have been broken off and exhibited a sand-blasted appearance as a result of sand abrasion.

The third submarine erosional agent is that produced by encrusting marine organisms which, when broken off, commonly take part of the rock surface with them. Encrusting forms common to this area are mostly kelp (mainly *Macrocystis pyrifera*), sponges, bryozoans, barnacles and a small amount of surf grass. The hold-fasts of kelp are particularly effective in pulling pieces of rock from the bottom whenever the plants are torn loose.

Human Litter. There is still another sediment source worthy of note, and that is human litter (Figure 14). Any diver familiar with the canyon head can describe the sizeable quantities of beer cans, wine bottles, and derelict skin diving gear to be found on the bottom. This accumulation does not contribute significantly to the sediment budget, but it does provide a tracer by which movement of bottom materials from the beach to deeper water can be inferred.

SEDIMENT MOVEMENT AROUND THE CANYON HEAD

Slides, Sandfalls, and Gravity Creep. One slide or slump scar was observed during diving operations. This is located around Stake 13 and extends from the canyon rim at about 40 feet to below a depth of 100 feet, and has an average width of about 100 feet (Figure 5). Judging from the roundness of its edges, it appears that the scar is relatively old. It is presently serving as a reservoir for a large accumulation of broken kelp which forms the sediment mat described earlier (Figure 7). Although not observed, it is believed that slumping, lubricated by the decay products of entrained vegetable debris, is the mechanism by which most sediment deposited in the canyon head is transported to deeper water.

No sandfall was observed during the study; however, the occurrence of sandfalls was reported to have been observed by Cdr Donald Ferrin, USN, on several occasions over the past 10 years. The location of the sandfalls is placed in about 200 feet of water near the northwest end of the rock outcrop that forms the north wall of the canyon head (Figure 7). Cdr. Ferrin has observed a group of three sandfalls which run intermittently depending upon the sea conditions and the gradient of the bottom above them. The sandfalls are reported to be largely dormant during the summer and fall, with activity increasing coincident with the flow of the Carmel River through the berm in January and February.

Evidence of sediment creep under gravity as a mechanism of sediment movement within the canyon head was sought through notation of any apparent downslope movement or sand level changes on the reference stakes. No such downslope movement was observed. This does not mean that gravity creep is discounted as a sediment transport mechanism, only that none was observed during the study.

Sand Rivers. Another evidence of sediment movement observed while diving was the "rivers of sand" which represent broad pathways for downslope sand movement at three locations around the canyon head (Figure 7). Common characteristics of the sand rivers is their coarse sand and absence of biological habitation. The northern-most of the sand rivers trends southwest from the meagre beach just north of Monastery Beach. Samples 37 through 41 were all taken from this sand river (Figure 15). Samples and diver observations show the sediment texture to be very coarse, about the same as that of the beach sands. It is believed that this river of sand is a result of seaward diversion of littoral drift by the rock outcrop at the south end of that beach. It is assumed that this feature fed the sandfalls reported by Ferrin.

Another coarse sand river descends from the terrace along the rocks on the north wall of the canyon head (Figure 7). This feature is relatively narrow and was noted only where it crossed the line of stakes (Table I). It is believed that the location of this sand river is dependent on reduced wave action in the lee of the projecting rock and forms a natural repository for any littorally drifted sand which has managed to make the passage through the rocky sand chutes of the outcrop. In addition, it is believed that this is one of the avenues by which surplus sand, resulting from dynamic readjustments of the beach profile, is removed from the area.

A third sand river is located on either side of the rock groin on the south side of the canyon head (Figure 7). Evidence of this feature is provided by Samples 1, 5, 35, and 36 and the remarks recorded during the stake surveys (Table I). This is probably the area of confluence of the littoral drift from the north and west. The position of the rock groin is probably instrumental in fixing the position of the confluence. This area too may be a dump for the sand surpluses of the beach.

Ripple Marks and Saltation. As mentioned before, a feature of the coarse sand bottom between the canyon rim and the shoreline is the ripple marks (Figures 8 and 9). The orientation of the ripples was found to be always parallel to the beach. In areas where the trend of the canyon rim is generally east-west, the ripples are nearly perpendicular to the canyon rim. Ripples with wave lengths as long as 4 feet, having heights as much as 18 inches, were observed close to the shore. More characteristic dimensions are 18 to 20 inches in length and about 6 inches in height. They are distinctively uniform and long crested.

Diving observations provided an opportunity to view at first-hand the movement of sand grains on the surface of the ripple marks. When closely watched, the passage of a wave overhead produced a plume of fine sand about 3/4 of the way up the slope of the ripple mark. The height of the plume seldom exceeded the height of the ripple and very little sand was seen to spill into adjacent ripples. Sand loss to adjacent ripples is greatly increased by the presence of a kelp boa, but this condition is only of importance when large quantities of kelp are present.

Alternate lines of light and dark sand were observed below the canyon rim in the bowl-shaped canyon head where the bottom slope is about 35 degrees. The dark bands of sand are due to entrained silt whereas the light bands are relatively clean sand. These light and dark bands coincide with ripple mark troughs and crests respectively where they join at the canyon rim. It would appear that although the water motions which generate ripples operate on the 35 degree slopes of the canyon, the ripples cannot maintain lateral stability and become strung-out down the slope by gravity to produce the alternate light and dark bands which were noted.

Diving operations in the canyon head revealed that saltation of individual sand grains down the slopes of the canyon was effective in sediment movement. Under the influence of waves passing overhead, sand grains were observed to be lifted clear of the canyon slope and redeposited about 4 inches farther downslope. It is believed that this process is the major source of fine sand for the fine sand area and the sediment mat.

<u>Offshore-Onshore Sand Movement.</u> It is well known from numerous field studies that on most beaches on the California coast, sand is carried offshore during the winter season by a predominance of wind waves and young swell and is returned to the beaches in summer by old swell. Most of the change occurs in the nearshore zone in depths not exceeding 30 feet. This process

seems to be operating off Carmel River Beach and Monastery Beach. On the latter beach, a significant part of the sand transported off shore in the winter may be intercepted by the canyon and permanently lost to the beach.

Sediment Mat. The organic sediment mat found in the study area changes its dimensions depending on the availability of the fine sand and kelp which form it. During most of the diving surveys, the mat was restricted to the area of the canyon head between Stakes 12 and 14 (Figure 5). On November 2, the author was surprised to find that due to kelp supplied by storm waves, the mat had increased to cover the entire bottom between Stakes 7 and 16. The thickness of the new mat was no more than a foot. The tube worms which normally inhabit the fine sand in most of the area could be found below the new deposit.

It is believed that the life of a sediment mat consists of three stages. Initially the newly deposited kelp provides structural strength for the mat and acts as a trap for fine sand and silt which settle out of suspension. Later, tube worms, which have been covered by the new deposit, invade the mass from below. The third stage is the decomposition of the kelp within the mat. It is probable that decomposition products may facilitate slumping and slides by acting as a lubricant.

COMPARATIVE STUDIES

SEDIMENT SAMPLES

Appendix III contains data on sediment samples taken by Cohee (1938). For easier comparison with the data gathered in this study, the Cohee depths have been converted to feet and the grain sizes to phi units.

Only Cohee Samples 1, 2, and 3 are directly comparable with the data of this study. The locations of these three samples are plotted as stars on Figure 15. The remainder of Cohee's data is presented to complete the sediment picture in the area of the canyon head. The Cohee samples are consistent with those taken in this study.

BATHYMETRIC SURVEYS

Figures 16 and 17 represent plan view and profile comparisons between a recent bathymetric survey made by Keithley (1968) (see chart in pocket), and one made by Shepard and Emery (1941). Comparison of Keithley's survey with that shown on the U. S. Coast and Geodetic Survey smooth sheet (1933) was considered but rejected because the smooth sheet lacks sufficient detail for a meaningful comparison.

Depth contours of 20, 40, 100, 150, and 200 feet were chosen to give a representation of the following bathymetric features: the shallow nearshore area (20 feet), the canyon rim (40 feet), the slope in the canyon head (100 and 150 feet), and a deep reference (200 feet). The chart drawn by Shepard and Emery was contoured in 5-fathom increments, so new contours had to be drawn from the charted data for the comparison. It is believed that a certain amount of the difference shown in the two surveys is due to the methods of sounding. Keithley's survey was conducted using a continuous recording echo-sounder with a narrow beam while that of Shepard and Emery was accomplished with a lead line.

No conclusion as to overall loss or gain of sediment can be drawn from the figures presented although some highly localized gains and losses are evident. In particular, Keithley's survey shows the floor in the canyon head to be significantly shallower. It is notable that some small bottom features are shown on both surveys, for instance the inflection in the 40-foot contour which is the upper end of the slump scar noted while diving.

REFERENCE STAKE SURVEYS

Data taken from the stake array are contained in Table I. Due to time considerations only two sets of readings were made. For this reason, only general conclusions can be drawn from the data. Poor underwater visibility caused navigational difficulties during the first set of readings when four of the stakes could not be located.

From the data, there appears to have been a fill on the north end of the array and a loss on the south end. On the second set of readings, Stake 1 was found lying on the bottom. Because the stake was located near a popular diving area, it is believed that it was dislodged by sport divers and is not indicative of sediment movement.

SUMMARY AND CONCLUSIONS

SUBMARINE TOPOGRAPHY

The head of Carmel Submarine Canyon is cut into the granodiorite which underlies the entire area, and is the only canyon head on the California coast that is cut in granitic rock. The wide, bowl-shaped appearance of the canyon head is in contrast to the narrow, deeply-incised canyon heads which are cut in sedimentary rock.

The rim of the canyon is a well-defined break in slope which occurs at depths between 40 and 60 feet. From the canyon rim shoreward the bottom rises gently and is covered with coarse sand. Near shore the bottom slopes steepen. It is believed that the terrace represents an old wave-eroded surface like the two that are visible on the coast around the canyon head (Figure 3).

BOTTOM TYPES

The only rock type observed underwater was the Santa Lucia granodiorite. This rock forms part of the north wall of the canyon head and outcrops alongside Point Lobos peninsula. The granodiorite also outcrops intermittently along the slopes and rim of the canyon head, and on the south side forms a rock groin that may control sediment movements in that area (Figure 7).

The sands, which are the predominant sediment type, can be separated into categories of coarse and fine sand as defined earlier. The coarse sand is characteristic of the shallower water inshore of the canyon head, and can also be seen to continue seaward of the canyon rim in the form of three "rivers of sand." The fine sand is generally found within the canyon head and is also one of the constituents of the sediment mat (Figure 7).

Other bottom types are the silty clay and sediment mat shown in Figure 7. The silty clay has significant concentrations of biogenous material entrained within it and underlies the coarse sand in the area shown. The sediment mat is a mat of intertwined kelp and fine sand whose dimensions are variable depending on the availability of the kelp of which it is formed. Decomposition of the kelp in the mat is believed to lubricate slumping, which may be the chief means by which sediments deposited in the canyon head are transported to deep water.

SEDIMENT SOURCES AND MOVEMENT

Carmel Submarine Canyon is actively transporting sediments to deeper water. The chief source of sediments appears to be in the form of sand which is littorally transported to the canyon head from Carmel River. Some additional sand is contributed by submarine weathering and erosion of the local shoreline.

The primary means of transport within the canyon head appears to be the broad sand rivers which extend from the canyon rim down the canyon slope (Figure 7). Another significant means of transport appears to be slumping, evidence of which can be found in the old scar at Stake 13 (Figure 5).

Other less significant transport is provided by saltation of individual sand grains and movements of ripple marks. It is believed that saltation provides the chief source of fine sand for the sediment mat.

COMMENTS

As with most field studies, this one has posed more questions than it has answered. It would appear that one of the most pressing requirements not fulfilled by this survey is the collection of data on the character and magnitude of the littoral drift from Carmel River Beach southward. In addition, detailed exploration of the shallow portions of the canyon located to the north and south of the study area are required before a complete picture of the processes underway in the canyon head will be known.

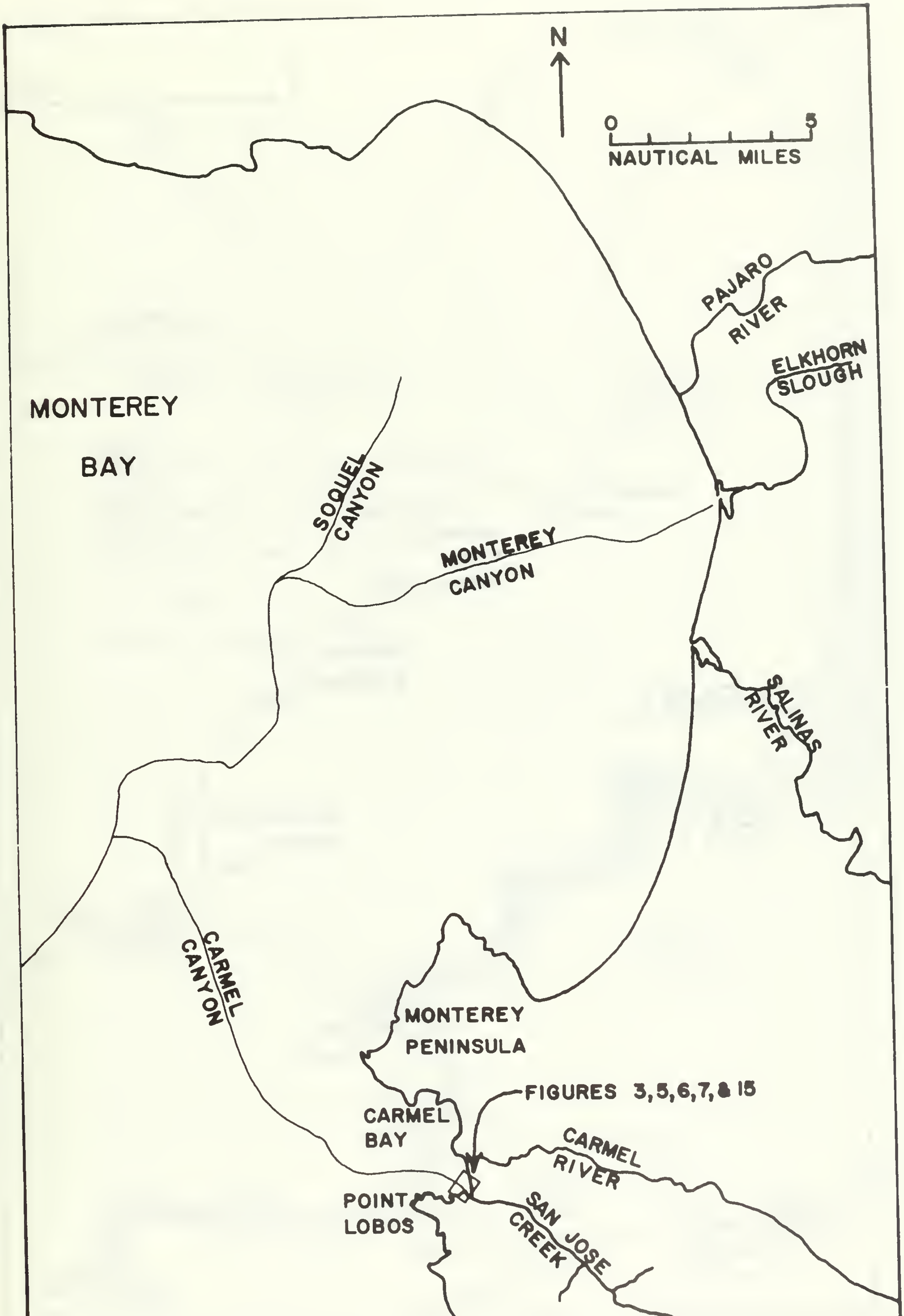


Figure 1. Map of the Regional Area

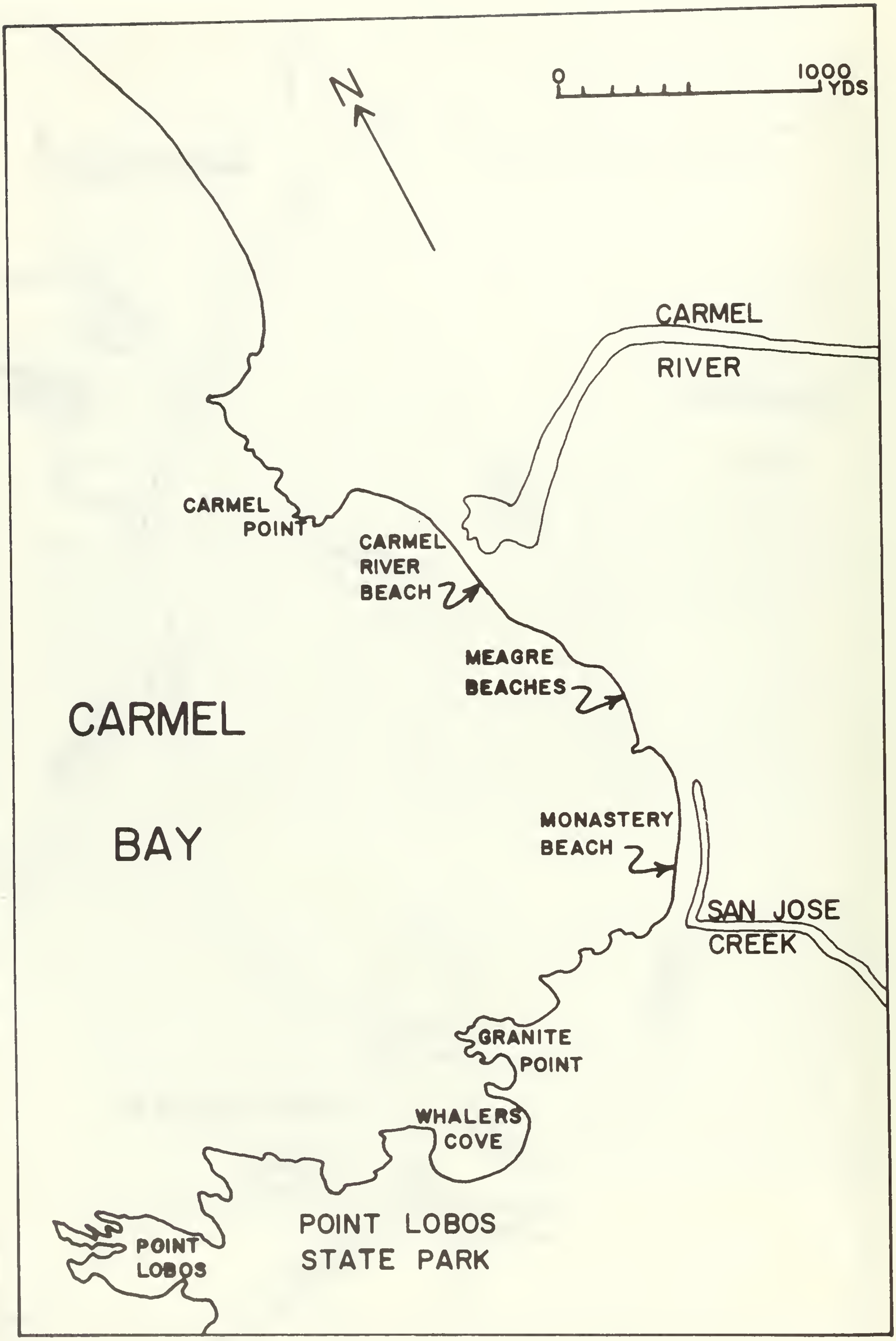


Figure 2. Map Showing Location of Study Area and Place Names Used in Thesis

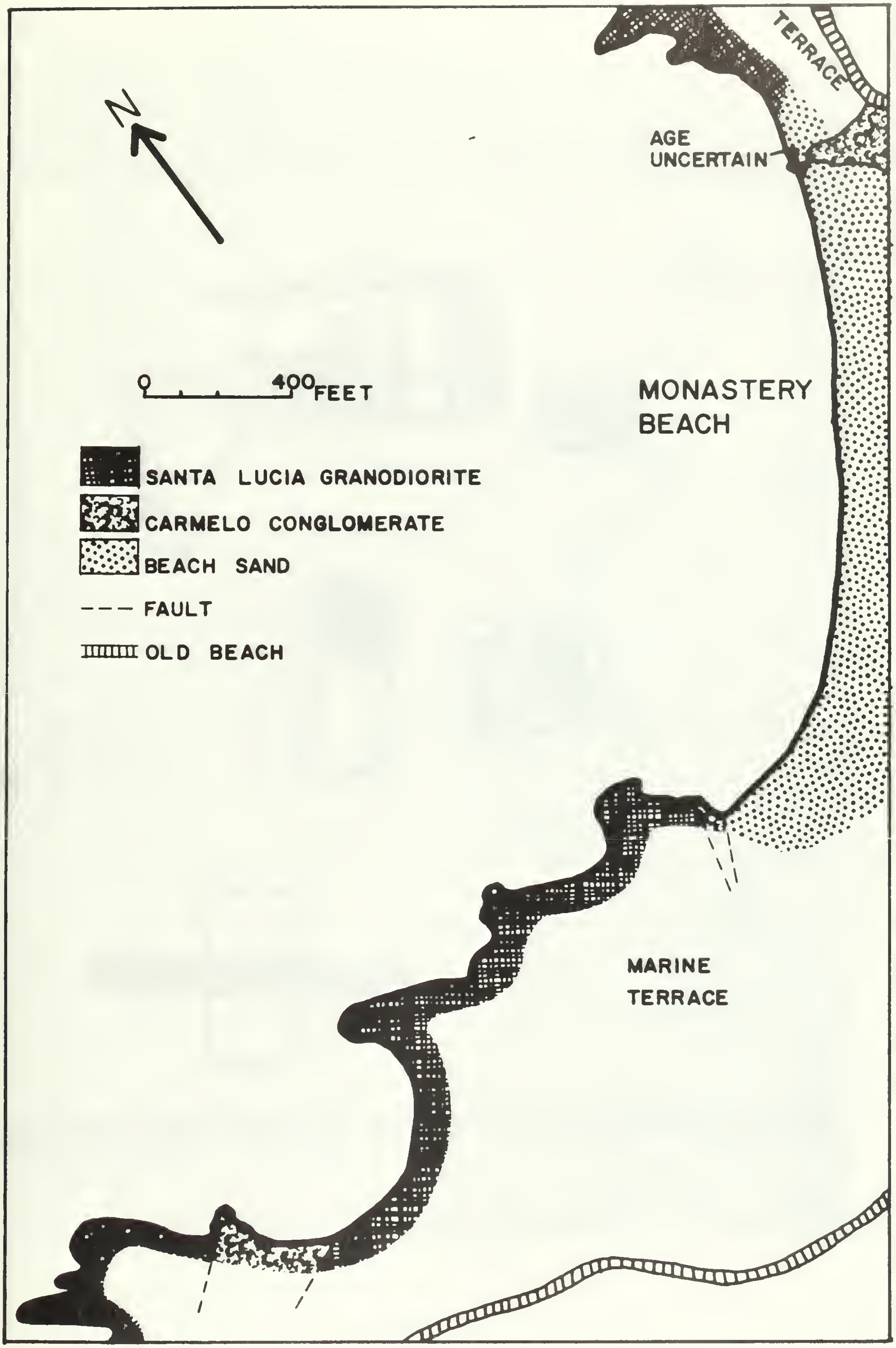


Figure 3. Map Showing Geology of Local Shoreline

Figure 4. Photo of Equipment Used

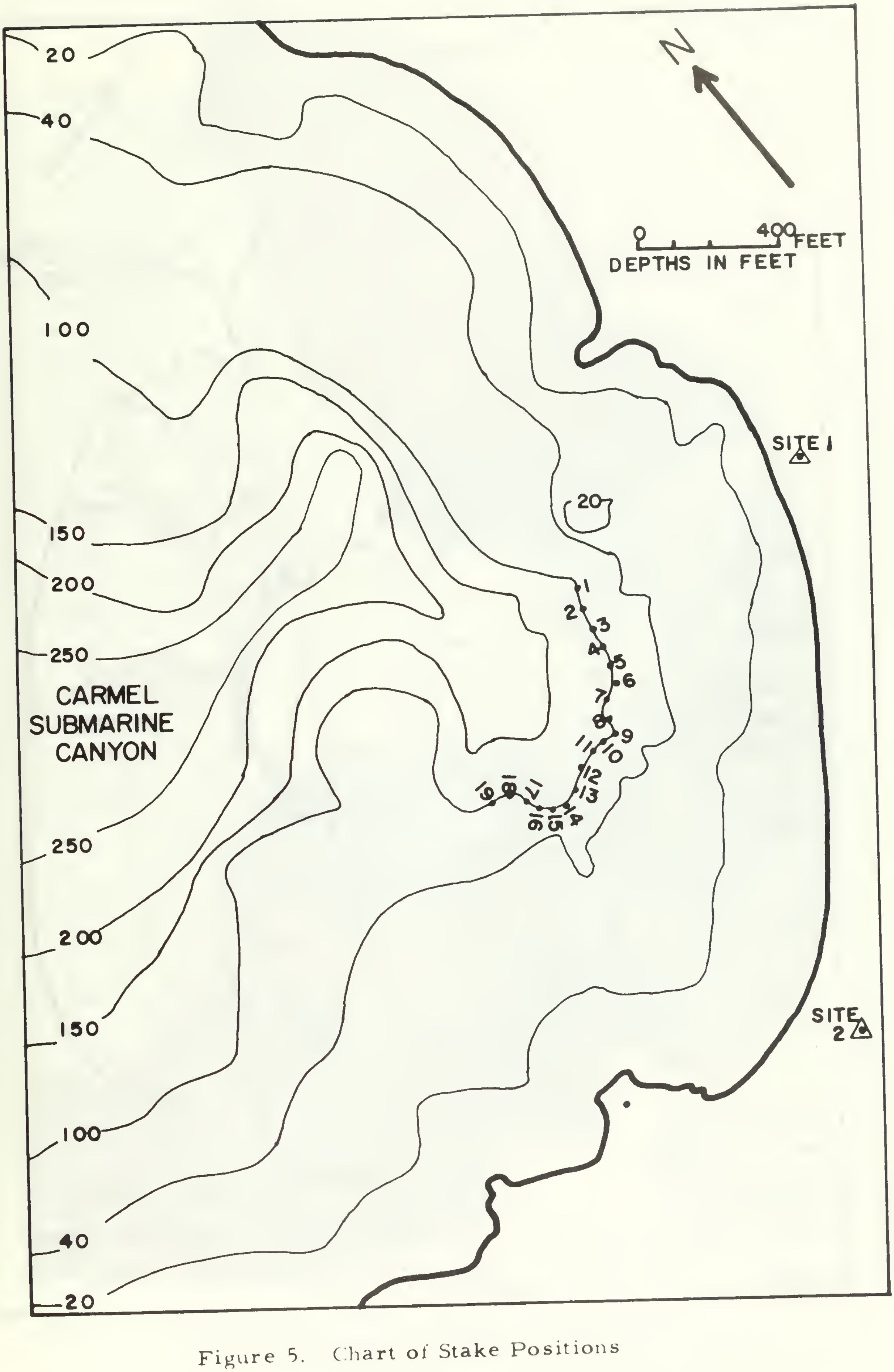


Figure 5. Chart of Stake Positions

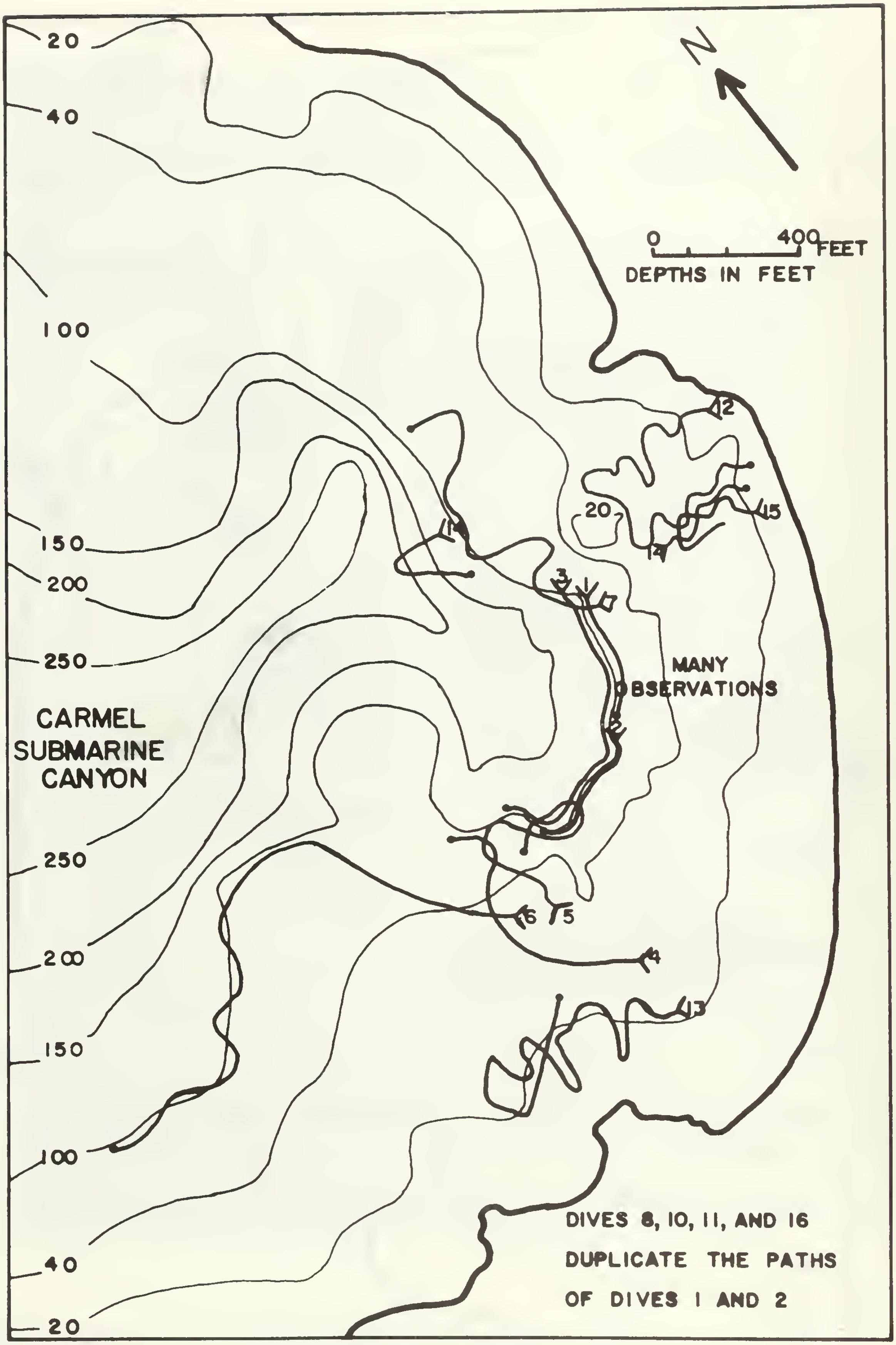


Figure 6. Chart of Dive Paths

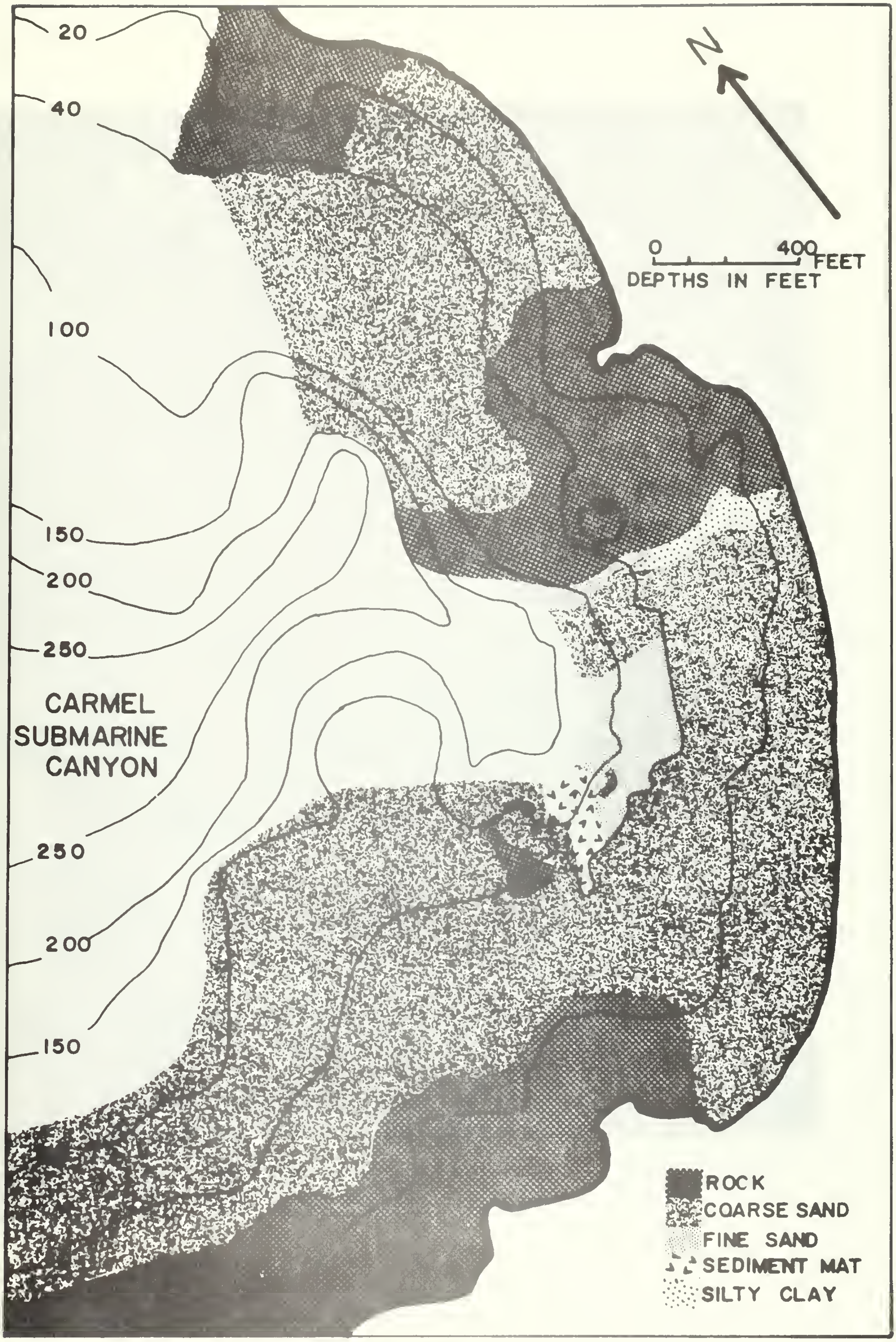


Figure 7. Chart of Bottom Types

Figure 8. Photo of Large Ripple Marks

Figure 9. Photo of Navigation Board and Ripple Mark

Figure 10. Photo of Tube Worms in Fine Sand

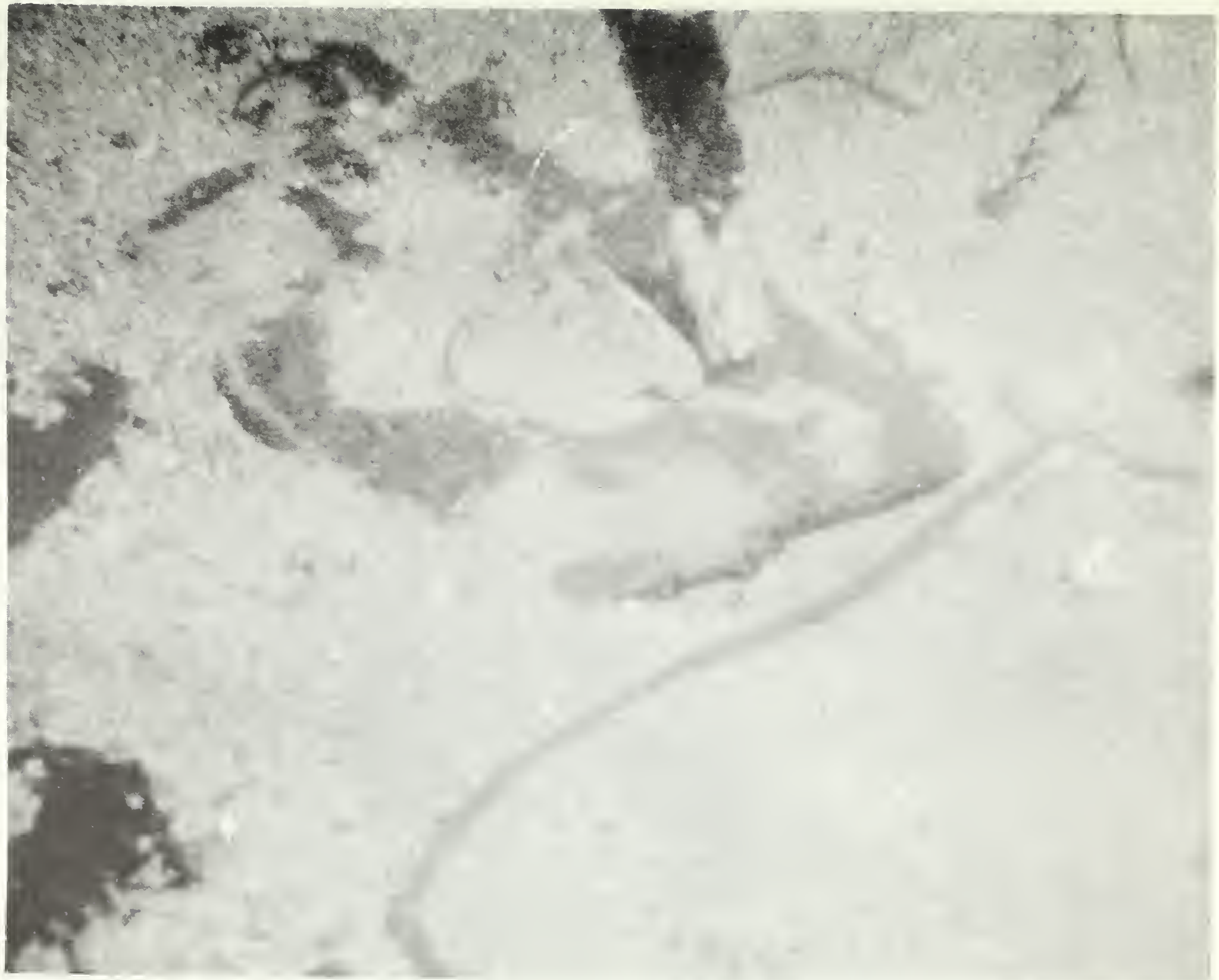


Figure 11. Photo of Silty Clay in Place Containing Fine Biogenous Material

Figure 12. Photo of a Broken Piece of Silty Clay Containing Coarse Biogenous Material

Figure 13 Photo of Kelp Fouled on Reference Stake

Figure 14. Photo of Beer Can on Sand Slope

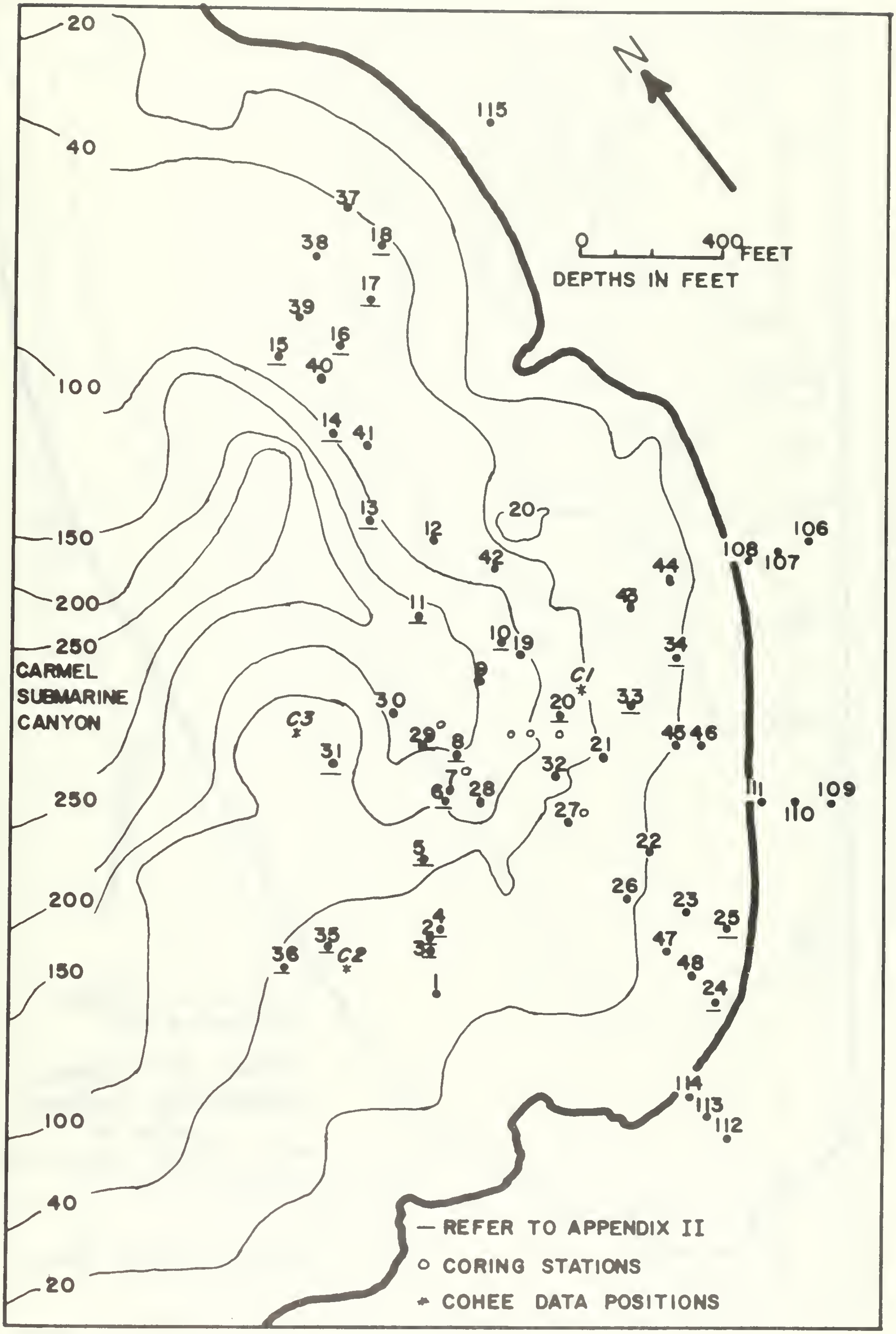


Figure 15. Chart of Positions of Samples and Cores

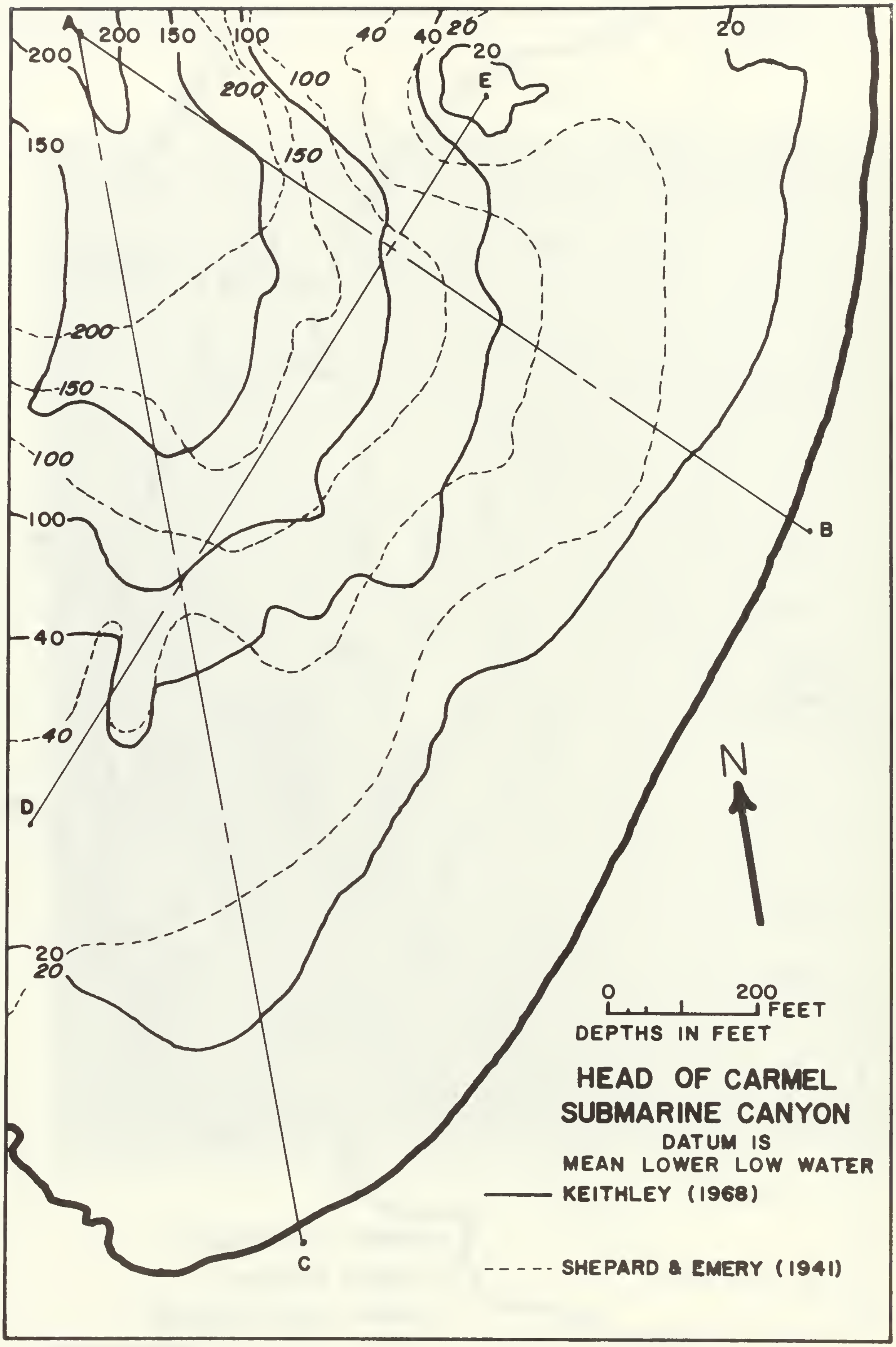


Figure 16. Bathymetric Chart Comparisons

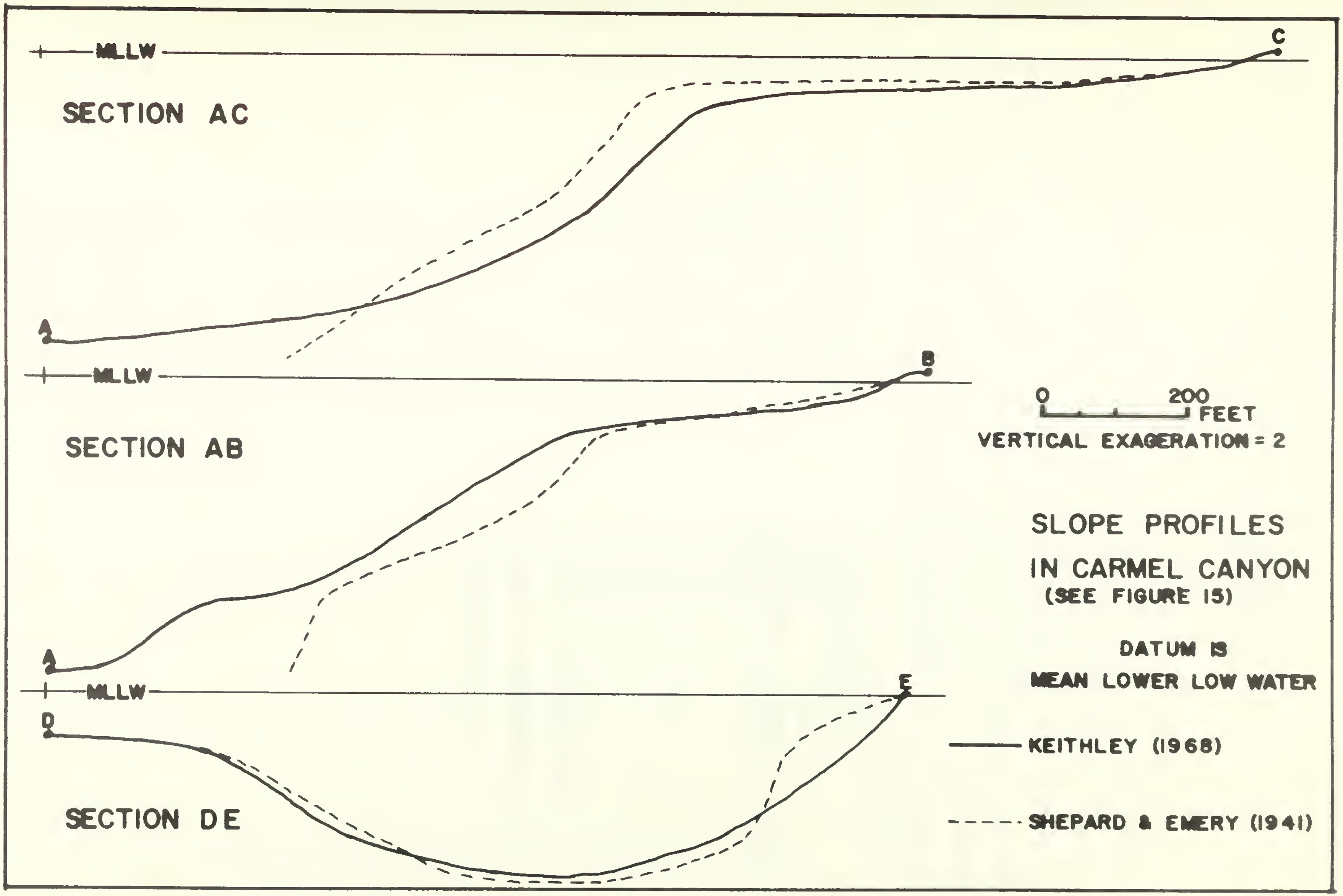


Figure 17. Bottom Profile Comparisons

TABLE I

BOTTOM SLOPE AND SAND LEVEL MEASUREMENTS AT REFERENCE STAKES

The first reading of the reference stakes was made in two segments; Stakes 1 through 12 were read on 20 August 1968 and Stakes 13 through 19 on 10 September. The notation "miss" indicates that the stake was not located due to low visibility. The second reading of the stakes took place on 2 November. Reported sand levels are measured from the base of the stake upward. Bottom slope was measured adjacent to each stake using the navigation board.

	Sand Level (ft)		Bottom Slope (deg)	
Stake	1st Reading	2nd Reading	1st Reading	2nd Reading
1	1.3	down	38	32
2	2.4	2.6	34	32
3	3.1	3.1	32	32
4	2.8	2.9	25	35
5	1.0	1.2	28	32
6	miss	1.5	miss	20
7	miss	1.3	miss	22
8	miss	2.5	miss	15
9	1.6	1.7	20	14
10	miss	1.8	miss	20
11	1.5	1.6	24	34
12	2.0	1.0	35	32
13	1.8	1.8	25	29
14	1.8	1.8	20	13
15	2.7	1.7	30	37
16	2.4	2.3	30	29
17	1.7	1.8	40	38
18	3.0	3.0	32	37
19	2.2	1.6	45	35

	Remarks	
Stake	1st Reading	2nd Reading
1	Canted over	Tube worms
2		Coarse sand
3		Coarse sand
4	Coarse gravel	Coarse sand
5		Tube worms
6		Tube worms
7		Sediment mat
8		Kelp bundle
9		Find sand
10		Sediment mat
11	Foot of outcrop	Rocks
12		Find sand
13	Sediment mat	Slump scar
14	Sediment mat	Sediment mat
15	Sediment mat	Sediment mat
16	Tube worms	Sediment mat
17		Canted, medium sand
18		Canted, medium sand
19		Medium sand

TABLE II

LITTORAL CURRENT OBSERVATIONS AT THE CENTER OF CARMEL RIVER BEACH

(Data provided by Mr. Donald Rich, Superintendent, Point Lobos State Park)

Date	Direction (to N or S)	Velocity (ft/min)	Date	Direction (to N or S)	Velocity (ft/min)
1967					
Aug.					
1	0	0	21	S	5
2	0	0	22	0	0
3	0	0	23	0	0
4	0	0	24	0	0
5	0	0	25	0	0
6	0	0	26	0	0
7	N	5	27	0	0
8	N	5	28	S	10
9	0	0	29	N	15
10	N	3	30	S	15
11	N	2	31	0	0
12	N	5	Sept. 1	0	0
13	N	5	2	S	10
14	0	0	3	S	15
15	N	8	4	S	10
16	S	5	5	N	15
17	S	15	6	0	0
18	S	10	7	S	20
19	S	10	8	0	0
20	0	0	9	0	0

Date	Direction (to N or S)	Velocity (ft/min)	Date	Direction (to N or S)	Velocity (ft/min)
Sep					
10	S	5	5	S	25
11	0	0	6	0	0
12	N	5	7	0	0
13	N	15	8	0	0
14	N	25	9	0	0
15	0	0	10	0	0
16	N	5	11	N	15
17	0	0	12	N	15
18	N	10	13	S	50
19	0	0	14	S	20
20	0	0	15	S	25
21	N	25	16	S	10
22	0	0	17	0	0
23	S	30	18	S	30
24	0	0	19	0	0
25	N	10	20	0	0
26	0	0	21	S	10
27	N	5	22	0	0
28	S	5	23	0	0
29	N	20	24	0	0
30	N	10	25	S	20
Oct 1	S	15	26	S	10
2	0	0	27	S	30
3	0	0	28	0	0
4	N	20	29	0	0

Date	Direction (to N or S)	Velocity (ft/min)	Date	Direction (to N or S)	Velocity (ft/min)
Oct 30	no observation		24	S	10
31	0	0	25	S	35
Nov 1	S	5	26	S	50
2	0	0	27	S	30
3	S	5	28	S	100
4	S	5	29	0	0
5	N	3	30	0	0
6	N	20	Dec 1	S	60
7	0	0	2	0	0
8	0	0	3	0	0
9	S	20	4	S	10
10	N	35	5	N	15
11	0	0	6	0	0
12	S	10	7	0	0
13	N	15	8	N	5
14	N	10	9	N	35
15	0	0	10	0	0
16	0	0	11	0	0
17	0	0	12	0	0
18	0	0	13	0	0
19	S	10	14	0	0
20	S	12	15	0	0
21	S	5	16	N	15
22	N	10	17	S	65
23	0	0	18	0	0

Date	Direction (to N or S)	Velocity (ft/min)	Date	Direction (to N or S)	Velocity (ft/min)
Dec 19	0	0	16	N	100
20	0	0	17	S	50
21	S	10	18	no observation	
22	0	0	19	S	60
23	0	0	20	S	10
24	N	100	21	S	100
25	0	0	22	N	60
26	0	0	23	S	20
27	0	0	24	S	10
28	0	0	25	0	0
29	S	10	26	no observation	
30	S	25	27	S	10
31	S	10	28	0	0
1968			29	N	30
Jan 1	N	50	30	S	20
2	0	0	31	S	20
3	0	0	Feb 1	no observation	
4	0	0	2	S	60
5	0	0	3	S	10
6	S	10	4	S	100
7	S	15	5	N	60
8	0	0	6	S	20
9	S	30	7	S	10
10	S	20	8	0	0
11	no observation		9	no observation	
12	0	0	10	S	10
13	0	0	11	N	15
14	S	10	12	N	25
15	S	10	13	0	0

Date	Direction (to N or S)	Velocity (ft/min)
Feb 14	no observation	
15	no observation	
16	no observation	
17	0	0
18	0	0
19	0	0
20	0	0
21	no observation	
22	no observation	
23	S	20
24	0	0
25	0	0
26	0	0
27	0	0
28	no observation	
29	no observation	
Mar 1	N	10
2	0	0
3	0	0
4	S	15
5	0	0
6	0	0
7	no observation	
8	no observation	
9	no observation	
10	no observation	
11	no observation	
12	no observation	

Date	Direction (to N or S)	Velocity (ft/min)
13	0	0
14	no observation	
15	0	0
16	0	0
17	0	0
18	0	0
19	0	0
20	no observation	
21	no observation	
22	0	0
23	no observation	
24	0	0
25	0	0
26	0	0
27	0	0
28	no observation	
29	0	0
30	0	0
31	0	0
Apr 1	0	0

BIBLIOGRAPHY

Bowen, O. E., 1965. Crown Jewel of the State Parks. Mineral Information Service, April.

Chamberlain, T. K., 1964. Mechanics of Mass Sediment Transport in Scripps Canyon, California. Univ. of Calif. at Los Angeles, Ph. D. dissertation.

Cohee, G. V., 1938. Sediments of the Submarine Canyons of the California Coast. Journal of Sedimentary Petrology, v. 8, no. 3, pp. 19-32.

Dill, R. F., 1964. Contemporary Erosion in Scripps Submarine Canyon. Univ. of Calif., Scripps Institution of Oceanography, Ph. D. dissertation.

Inman, D. L., 1952. Measures for Describing the Size Distribution of Sediments. Journal of Sedimentary Petrology, v. 22, no. 3.

Martin, B. D., 1963. Geology of the Monterey Submarine Canyon. Univ. of Southern California, Ph. D. dissertation.

Shepard, F. P. and K. O. Emery, 1941. Submarine Topography Off the California Coast; Canyons and Tectonic Interpretations. Geological Society of America, Special Paper No. 31, 171 pages.

Shepard, F. P., 1948. Investigations of the Head of Monterey Submarine Canyon. Hydrographic Office - Office of Naval Research Contract N6Orii-111, Scripps Institution of Oceanography, 15 pages.

National Marine Consultants, 1960. Wave Statistics for Seven Deep Water Stations Along the California Coast. U. S. Corps of Engineers, Los Angeles District.

Geologic Map of California, California Division of Mines and Geology, Santa Cruz Sheet, 1958. Olaf P. Jenkins Edition, NJ 10-12.

Keithley, C. L., 1968. Bathymetric Survey of Carmel Canyon. Naval Postgraduate School, Research Paper in Oceanography.

Appendix I

STATISTICAL SEDIMENT PARAMETERS DETERMINED FOR SAMPLES GATHERED IN AND AROUND THE HEAD OF CARMEL CANYON AND THE SURROUNDING BEACHES

Textural classification is according to Inman (1952).

Sample locations are shown in Figure 15.

Samples not listed here are found in Appendix II.

Part A: Sediment Parameters

Md_ϕ - phi median diameter

M_ϕ - phi mean diameter

σ_ϕ - phi deviation measure

α_ϕ - phi skewness measure

$\alpha_{2\phi}$ - 2nd phi skewness measure

β_ϕ - phi kurtosis measure

Sample Number	Sample Type	% Grav.	% Sand	% Silt	Md_ϕ	M_ϕ	σ_ϕ	α_ϕ	$\alpha_{2\phi}$	β_ϕ
1	snapper	.8	99.1	.1	-.16	.05	.55	.39	1.00	.85
7	snapper	.1	81.4	18.5	3.18	3.31	.75	.16	-.14	.65
9	snapper	.2	82.4	17.4	3.18	3.24	.40	.14	-.71	1.88
12	snapper	19.8	79.6	.6	.36	.72	1.83	.20	.26	.35
19	snapper	27.8	59.5	12.7	1.89	.68	2.79	-.43	-.38	.08
21	snapper	0.0	96.8	3.2	2.47	2.27	.79	-.26	-.49	.76
22	snapper	22.4	72.1	.5	1.94	.23	2.33	-.74	-.68	.11
23	snapper	.1	99.6	.3	1.94	1.98	.66	.06	.01	.68
26	snapper	43.9	56.0	.1	.42	-.11	2.05	-.26	-.16	.12

Sample Number	Sample Type	% Grav.	% Sand	% Silt	Md_ϕ	M_ϕ	σ_ϕ	α_ϕ	$\alpha_{2\phi}$	β_ϕ
27	snapper	.8	96.4	2.8	2.12	2.25	.93	.14	-.07	.70
28	snapper	0.0	93.1	6.9	2.74	2.75	1.31	.01	-.13	.34
29	snapper	0.0	88.4	11.6	2.94	3.09	.97	.15	-.11	.53
30	snapper	0.0	95.4	4.6	2.40	2.63	.69	.34	.24	.57
32	snapper	.5	91.1	8.4	2.25	2.41	1.23	.13	-.04	.51
37	diver	74.0	25.9	.1	-1.28	-1.23	.40	.13	.26	.59
38	diver	6.8	93.1	.1	-.28	-.39	.33	-.34	-.64	.79
39	diver	7.2	92.7	.1	-.39	-.43	.37	-.10	-.19	-.70
40	diver	8.9	90.2	.9	.06	.76	1.42	.49	.53	.58
41	diver	22.3	77.5	.2	-.39	-.23	.99	.16	.57	.97
42	diver	7.0	89.1	3.3	2.64	1.57	1.76	-.61	-.87	.34
43	diver	7.5	92.7	.2	-.04	-.01	.70	.04	.11	.69
44	diver	41.2	58.7	.1	-.90	-.95	.48	-.11	-.18	.59
45	diver	30.1	69.8	.1	-.70	-.73	.58	-.04	.07	.73
46	diver	33.8	65.5	.5	-.77	-1.18	.82	-.49	-.18	.45

Sample Number	Sample Type	% Grav.	% Sand	% Silt	Md_ϕ	M_ϕ	σ_ϕ	α_ϕ	$\alpha_{2\phi}$	β_ϕ
47	diver	9.4	90.5	.1	-.36	-.28	.52	.16	-.25	1.73
48	diver	27.5	72.4	.1	-.75	-.82	.40	-.18	-.42	.76
106	beach	32.8	67.1	.1	-.81	-.82	.37	-.04	-.16	.60
107	beach	43.6	56.3	.1	-.90	-.93	.43	-.10	-.16	.51
108	beach	8.8	92.1	.1	-.46	-.50	.33	-.12	-.23	.74
109	beach	59.5	40.4	.1	-1.18	-1.31	.67	-.20	-.19	.31
110	beach	30.4	69.5	.1	-.73	-.74	.52	-.03	-.31	.90
111	beach	24.2	75.7	.1	-.74	-.82	.30	-.26	-.40	.74
112	beach	52.2	47.7	.1	-1.01	-1.09	.44	-.17	-.19	.57
113	beach	48.4	51.5	.1	-.97	-1.02	.32	-.15	1.33	.65
114	beach	8.5	91.4	.1	-.56	-.59	.22	-.16	-.82	.81
115	beach	54.3	45.6	.1	-1.01	-1.04	.42	-.06	-.09	.53

Part B: Phi Percentiles

Sample Number	ϕ_{95}	ϕ_{84}	ϕ_{50}	ϕ_{16}	ϕ_{5}	Sample Number	ϕ_{95}	ϕ_{84}	ϕ_{50}	ϕ_{16}	ϕ_{5}
1	1.40	.60	-.16	-.50	-.63	37	-.55	-.83	-1.28	-1.63	-1.81
7	4.32	4.06	3.18	2.56	1.84	38	.10	-.06	-.28	-.72	-1.08
9	4.06	3.64	3.18	2.84	1.74	39	.17	-.06	-.39	-.80	-1.09
12	3.32	2.56	.36	-1.11	-1.65	40	3.06	2.18	.06	-.66	-1.44
19	3.84	3.47	1.89	-2.11	-2.20	41	2.12	.76	-.39	-1.22	-1.78
21	3.47	3.06	2.47	1.47	.69	42	3.47	3.32	2.64	-.19	-1.23
22	2.94	2.56	1.94	-2.09	-2.23	43	1.22	.69	-.04	-.71	-1.15
23	3.06	2.64	1.94	1.32	.84	44	-.21	-.46	-.90	-1.43	-1.75
26	2.40	1.94	.42	-2.16	-2.21	45	.34	-.15	-.70	-1.31	-1.67
27	3.64	3.18	2.12	1.32	.47	46	.27	.36	-.77	-2.00	-2.12
28	4.32	4.06	2.74	1.43	.81	47	.92	.23	-.37	-.80	-1.90
29	4.32	4.06	2.94	2.12	1.36	48	-.21	-.42	-.75	-1.22	-1.62
30	3.64	3.32	2.40	1.94	1.47	106	-.28	-.45	-.81	-1.19	-1.45
32	4.06	3.64	2.25	1.18	.34	107	-.31	-.51	-.90	-1.37	-1.62

Sample Number	ϕ_{95}	ϕ_{84}	ϕ_{50}	ϕ_{16}	ϕ_{5}	Sample Number	ϕ_{95}	ϕ_{84}	ϕ_{50}	ϕ_{16}	ϕ_{5}
108	.03	-.17	-.46	-.83	-1.11	112	-.41	-.65	-1.01	-1.53	-1.78
109	-.43	-.64	-1.18	-1.98	-2.18	113	-.55	-.70	-.97	-1.34	-1.61
110	.09	-.23	-.73	-1.26	-1.88	114	-.33	-.37	-.56	-.82	-1.14
111	-.33	-.52	-.74	-1.12	-1.39	115	-.41	-.62	-1.-1	-1.46	-1.69

Appendix II

REMARKS CONCERNING SEDIMENT SAMPLES NOT PROCESSED FOR TEXTURAL PARAMETERS

Reference locations are shown in Figure 15.

All of the following are snapper samples:

Sample	Remarks
2	No sample.
3	No sample.
4	No sample.
5	Granodiorite pebble with embedded biotite mica flecks.
6	No sample
8	No sample.
10	Three tube worms.
11	Worm tube (no worm). Tubes covered with silt. Not processed.
12	Piece of kelp in advanced state of decay. Sand gives off heavy H_2S odor. No gas analysis done. Processed.
13	Colloidal suspension of vegetable origin. Had not settled out after 2 weeks. Insufficient amount to process.
14	No sample.
15	No sample.
16	No sample.
17	Well-rounded quartzite pebble.
18	Very small amount of coarse sand. Uniform 1 mm diameter. Not processed.
19	Large amount of biogenous material in a semi-decayed condition. Shells and bryozoa entrained in compost. Prof. E. C. Haderlie identifies biogenous material as reeds and bull rushes. Some sand. Processed.
20	Large broken pieces of undecayed plants of the rock-dwelling variety. Small amount of silt and clay. Not processed
21	Two tube worms. Small amount of undecayed plant debris. Some very fine sand and silt. Processed.
24	Water rounded granodiorite pebble.
25	Well-rounded green metamorphic pebble.
27	Tube worm and some undecayed plant debris. Fine sediments. Processed.

Sample	Remarks
31	Rock-dwelling plant in fresh condition. Sea lettuce family.
32	Small amount of biogenous material in advanced state of decay. Sediment very fine with mica flecks prevalent. Processed.
33	Two rounded granodiorite pebbles.
34	No sample.
35.	Fragment of living sand dollar. Small amount of sand 1 mm in diameter.
36	Well-washed sand averaging about 1 mm in diameter. Flakes of mica. Insufficient amount to process.

Appendix III

SEDIMENT DATA FROM COHEE (1938), "Sediments of the Submarine Canyons of the California Coast."

Cohee Samples 1, 2, and 3 are plotted on Figure 15. Samples 7 through 10 are located in Carmel Canyon seaward of the area studied.

Sample	1	2	3	4	5	6
Depth	18	55	343	602	104	448
Class	Pebbles	V.C.S.	F.S.	V.F.S.	F.S.	V.F.S.
Median	-1.0	-.4	2.94	3.73	2.52	3.87
Sorting	1.00	1.32	1.80	1.63	1.44	1.92
Skewness	1.00	.87	.88	1.13	.87	.93
% Sand	100.0	98.7	77.0	56.5	70.0	25.0
% Silt	0.0	1.3	23.0	43.5	30.0	68.2
% Clay	0.0	0.0	0.0	0.0	0.0	6.8
Latitude	36°31.6'	36°31.6'	36°31.7'	36°31.7'	36°32.1'	36°31.8'
Longitude	121°55.6'	121°55.8'	121°55.7'	121°56.0'	121°55.9'	121°56.0'

Depths in feet.

Grain sizes in phi units.

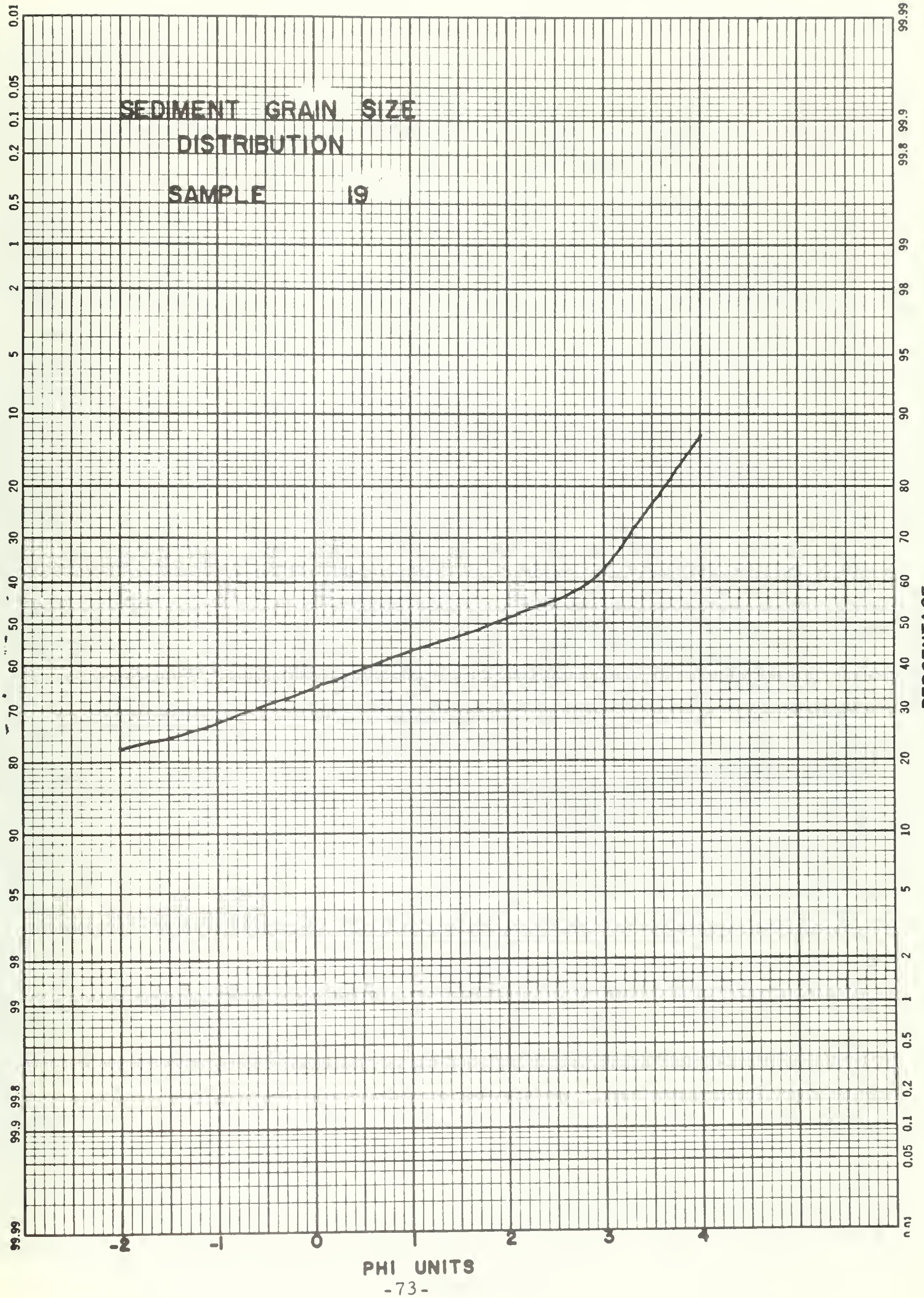
Sample	7	8	9	10
Depth	759.6	192.0	216.0	588.0
Class	V.F.S.	V.F.S.	V.F.S.	Silt
Median	3.79	3.39	3.67	4.42
Sorting	1.65	1.46	1.52	2.30
Skewness	1.26	.94	.95	.93
% Sand	54.6	75.5	60.3	35.8
% Silt	45.4	24.5	39.7	59.5
% Clay	0.0	0.0	0.0	4.7
Latitude	36°31.9'	36°32.0'	36°31.7'	36°31.7'
Longitude	121°56.2'	121°56.2'	121°56.3'	121°56.5'

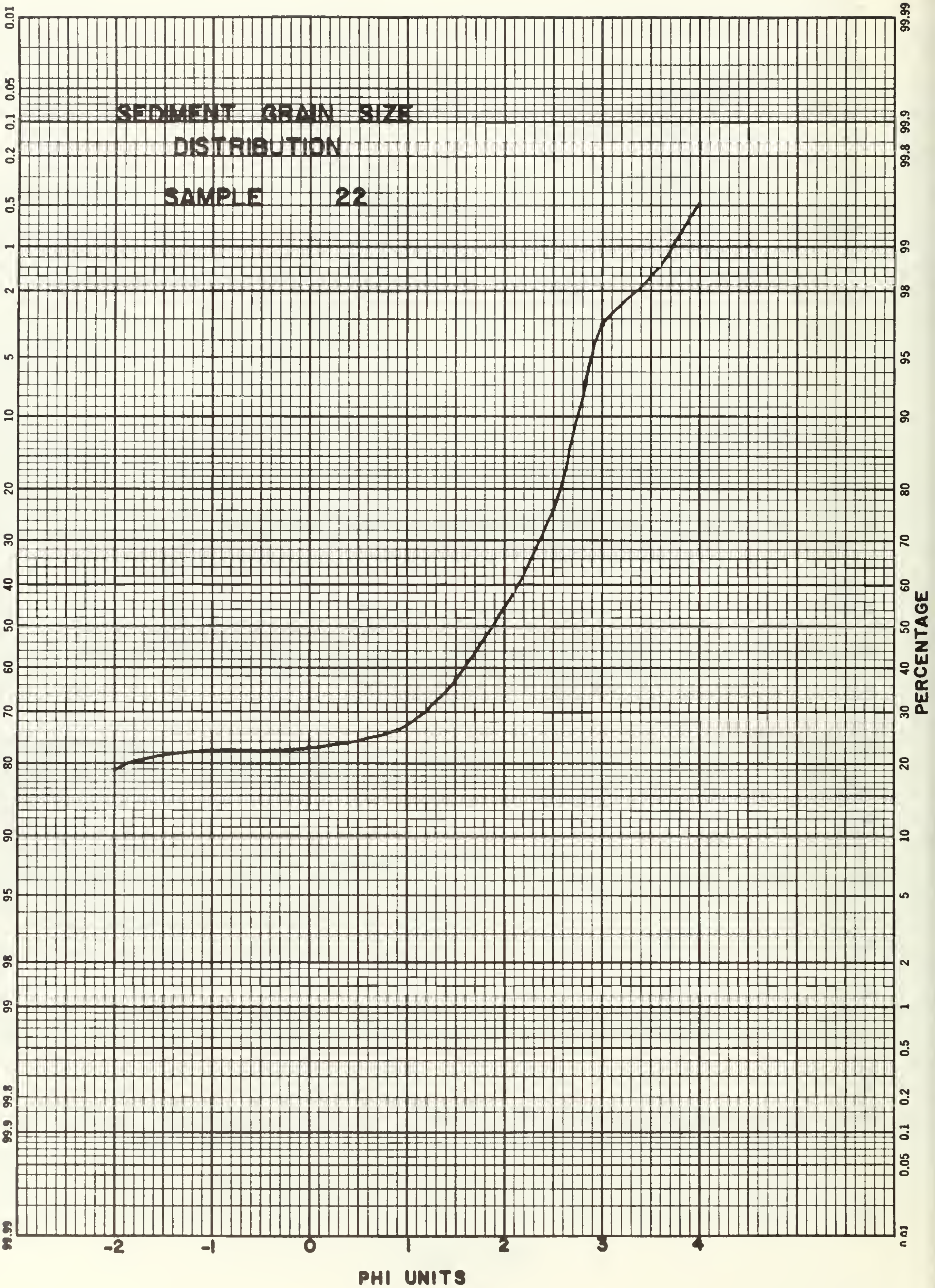
Depths in feet.
Grain sizes in phi units.

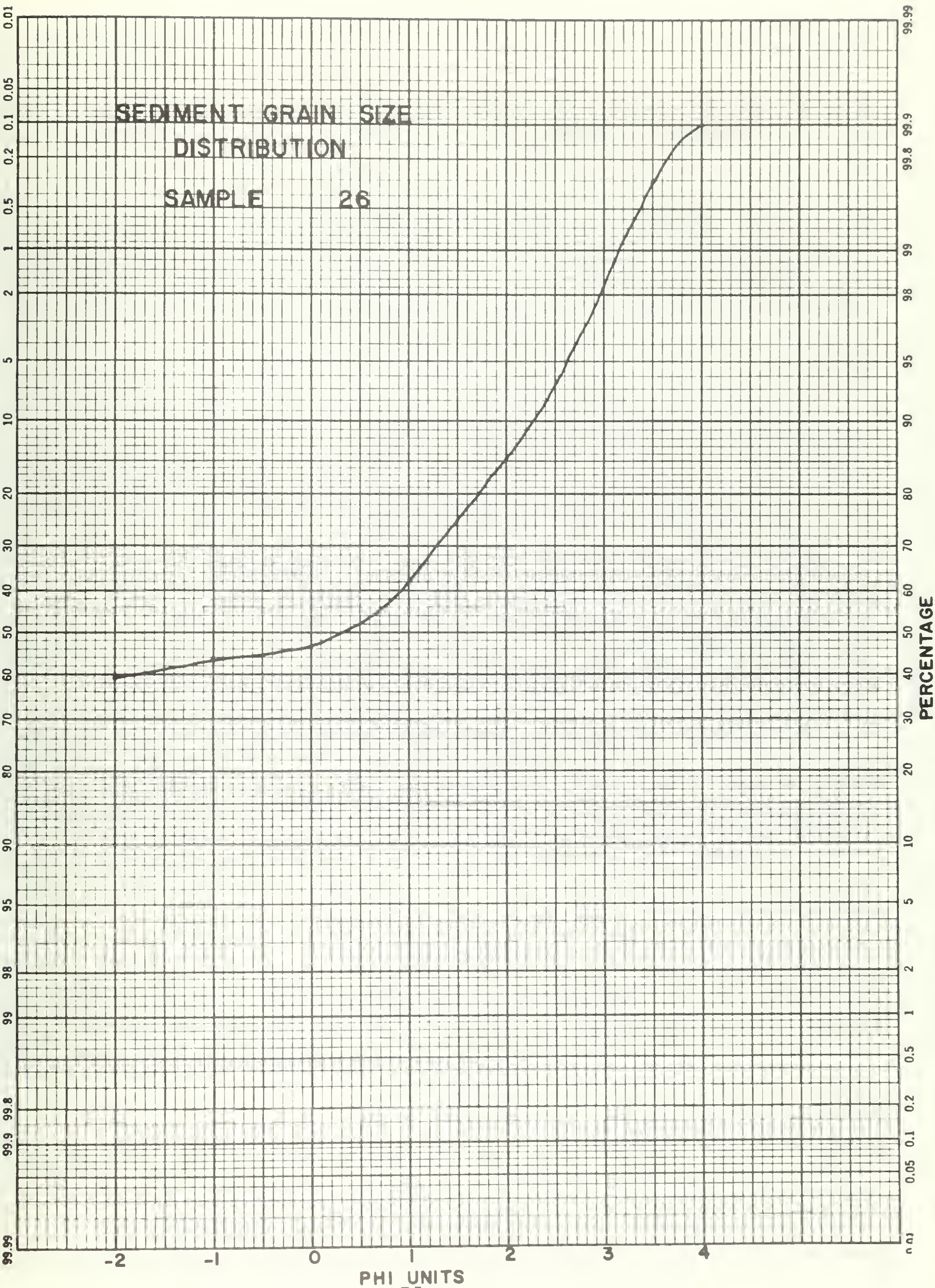
Appendix IV

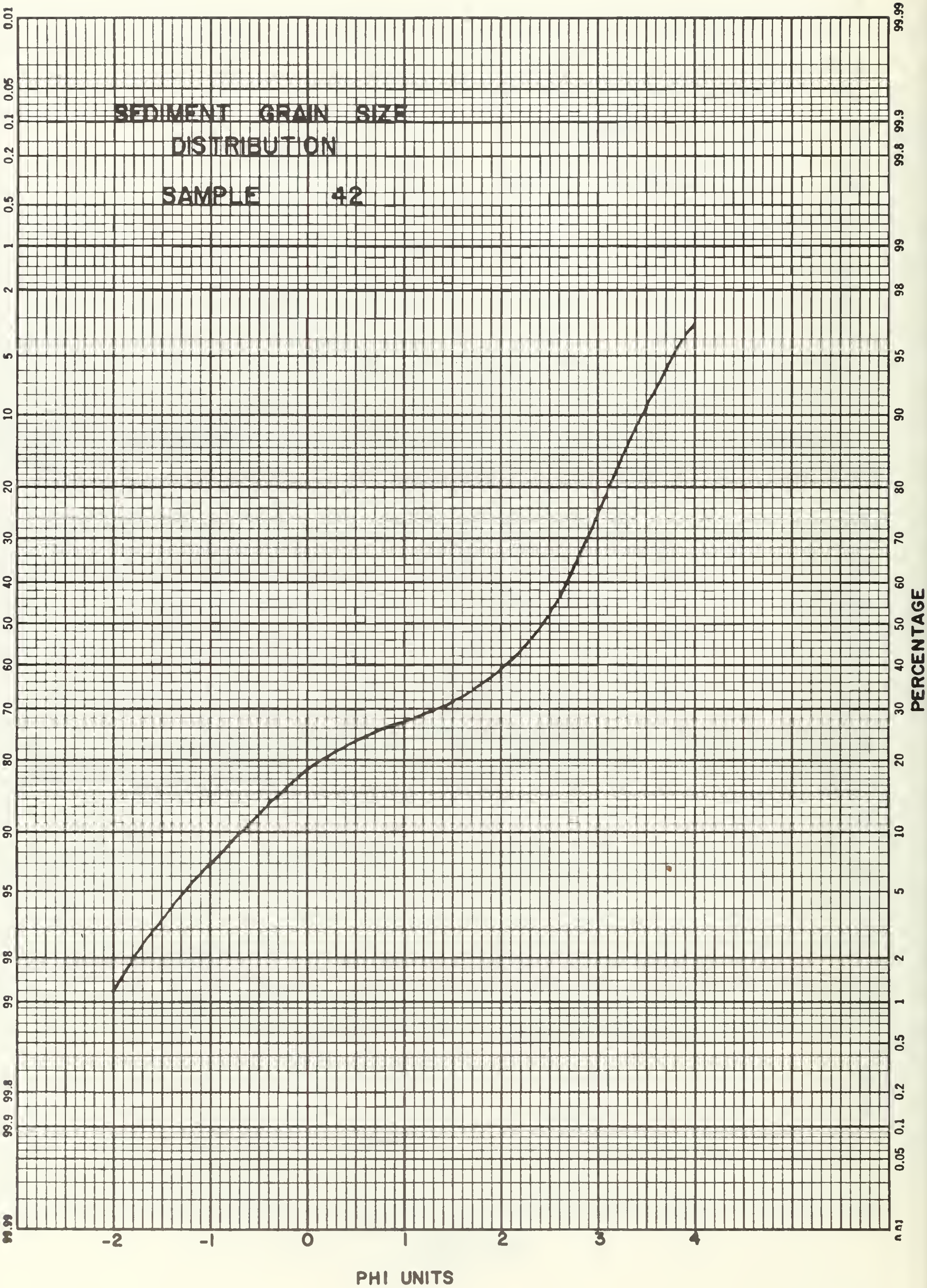
CUMULATIVE GRAIN SIZE PLOTS FOR SAMPLES SHOWING BIMODAL AND TRIMODAL DISTRIBUTIONS

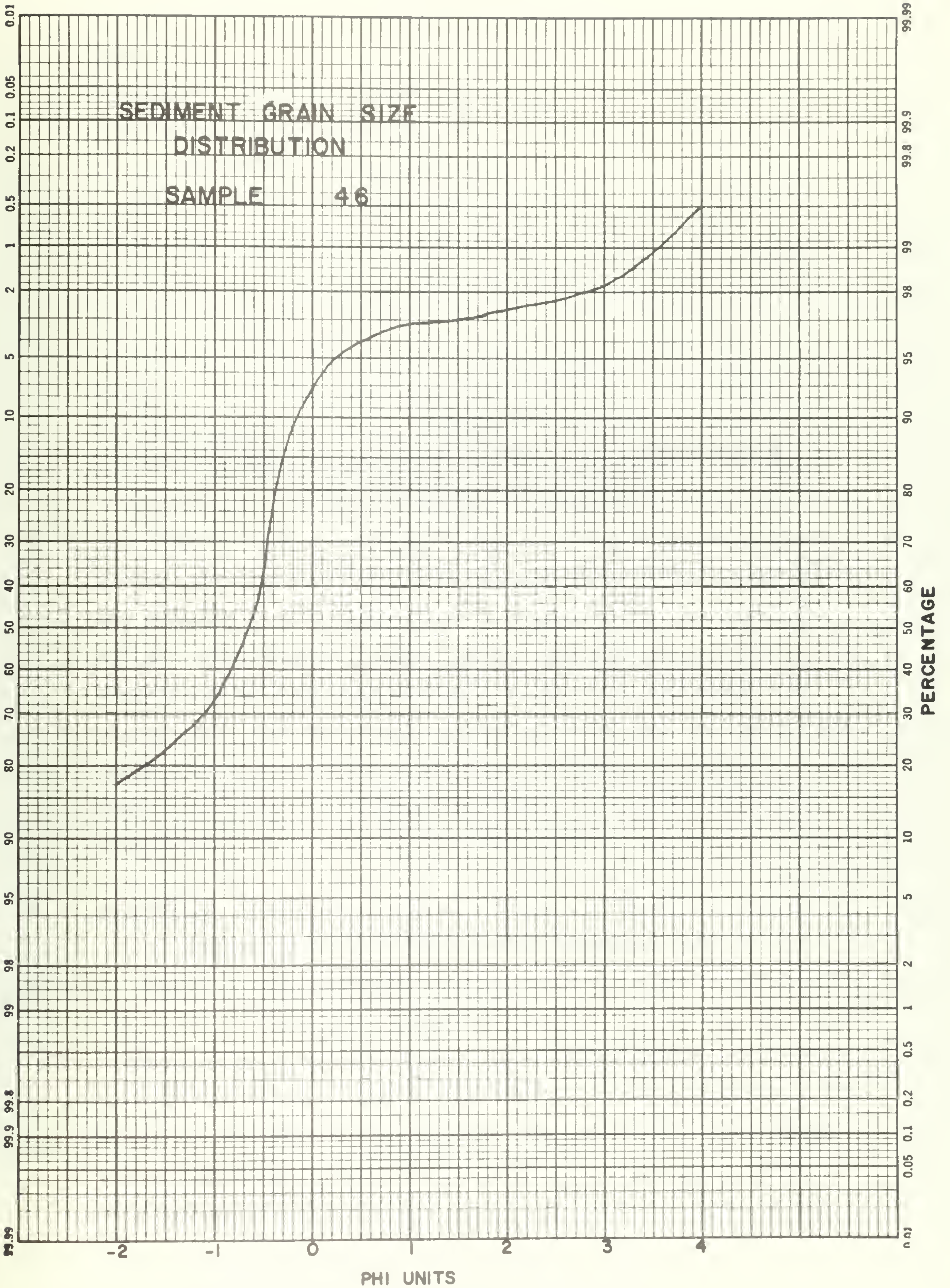
Samples 19, 22, 26, 42, and 46.


SEDIMENT GRAIN SIZE
DISTRIBUTION
SAMPLE 19
PHI UNITS
-2
-1
0
1
2
3
4
PERCENTAGE
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99


SEDIMENT GRAIN SIZE
DISTRIBUTION
SAMPLE 22
PHI UNITS
PERCENTAGE
-2
-1
0
1
2
3
4
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99


SEDIMENT GRAIN SIZE
DISTRIBUTION
SAMPLE 26
PHI UNITS
-2
-1
0
1
2
3
4
PERCENTAGE
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99


SEDIMENT GRAIN SIZE
DISTRIBUTION
SAMPLE 42
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99
99.99
99.9
99.8
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
-2
-1
0
1
2
3
4
PHI UNITS
PERCENTAGE


SEDIMENT GRAIN SIZE
DISTRIBUTION
SAMPLE 46
PHI UNITS
-2
-1
0
1
2
3
4
PERCENTAGE
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.8
99.9
99.99

Appendix V

FIELD NOTES OF SCUBA DIVES INTO THE HEAD OF CARMEL SUBMARINE CANYON

Dive No. 1

13 July 1968, 0930-1030 PDT, clear, calm

Divers: Team 1, Moritz, Ferrin

Team 2, Googins, Wallin

Moritz and Ferrin entered the water first abeam of the wash rock. They carried one marker stake, the navigation board, the stake hammer and the 20 yard measured line. The marker stake was set and the buoy released. When the buoy arrived at the surface, a pack of 5 stakes including one marker stake was lowered. On the bottom, the measured line was run out and the next stake placed and hammered down. Moritz and Ferrin placed 4 stakes and returned with the marker stake from the first pack.

Between diver teams the boat had drifted toward the beach. When Googins and Wallin went down, the bottom was contacted at 35 feet. Ferrin assisted in carrying gear down on the second dive and returned to the surface. Proceeding seaward, a steep scarp was found at a depth of 50 feet. This slope was covered with matted vegetation. At a depth of 85 feet, a gentle slope was again encountered, also covered with vegetation. The marker stake from the first pack and 3 stakes from the second pack were placed. Bottom time was about 15 minutes with a 72. It was decided that doubles should be used to increase bottom time.

Dive No. 2

16 July 1968, 1000-1100 PDT, clear, moderate surf

Divers: Team 1, Moritz, Ferrin

Team 2, Maudlin, Wallin

An 18 HP outboard motor was loaned by the Point Lobos Park Rangers. Moritz and Ferrin were the first to enter the water. The procedure was the same as 13 July. All divers were using double 72's to give a bottom time of 25 minutes at 100 feet which is the maximum allowable for surfacing without decompression. Moritz and Ferrin set the two remaining stakes of the last series from 13 July and then 5 more. Maudlin and Wallin then entered the water and upon reaching the bottom found only rock in which to drive the stakes. Wallin was too heavy to return to the surface and was forced to leave the stake hammer behind.

This dive puts a total of 16 stakes on the bottom with 4 buoyed stakes.

Dive No. 3

20 July 1968, 0945-1030 PDT, overcast, heavy surf

Divers: Ferrin, Wallin, Moritz

(As indicated below, the author was unable to complete the dive. The notes are from Lt. C. A. Moritz.)

Heavy surf action has thrown much kelp up on the beach, including holdfasts still attached to rocks about the size of basketballs.

Entered the water with double tanks through the surf at which time the navigation board carried by Lt. Wallin was ripped away by the surf action. The nylon line used to clip the board to his weight belt had parted. Lt. Wallin was tumbled severely by the surf and was unable to continue the dive.

The loss of the navigation board negated efforts to take slope and stake depth measurements.

Dive continued by Ferrin and Moritz. Reached approximate location of stake number 1. Could not find the buoy for that stake and submerged where we thought it should be located. Found number 1 immediately. Later discovered that all buoys had broken their lines during the previous weeks' heavy surf action.

Began attaching numbered aluminum tags to each stake. Between stakes 3 and 5, the bottom was clean with coarse sand. After stake number 5, the bottom was covered with fine pieces of kept and trash from the beach. The angle of repose between stakes 5 and 14, although not measured exactly, was somewhat shallower than that between 1 and 5. At stake number 16 was a rock ridge of as yet undetermined type. The sand bottom in this area was relatively clear of kelp debris.

I (Moritz) lost tags 15 and 16, so these stakes were not tagged. After stake number 16, we continued on along the 100 foot contour. Immediately adjacent to the rock ridge is a small area of small boulders with much kelp detritus. This area of boulders lasted about 20 yards. We soon came upon a sand ridge. This area was of coarse sand with a very steep angle estimated about 35 to 40 degrees. Its horizontal dimension is as yet undetermined. Its vertical extent is from about 60 feet on down past 100 feet. This area had an odd appearance in that it had vertical striations evident in it. I feel this is an indication of recent or perhaps continuous sand movement into the canyon. We attempted to set off a sand slide but were unsuccessful. At this point we ran out of air and surfaced.

A few of the stakes were canted over at an angle - not necessarily pointing down canyon. Reason unknown at this time. Could be due to action of the surf tearing away the buoys, other divers begin curious or sand movement.

Dive No. 4

3 August 1968, 1030-1145 PDT, fog, light surf

Divers: Moritz, Wallin

Divers entered the water together. We proceeded along the kelp line to the small embayment in the kelp on the south side where we made our descent. The bottom was contacted at a depth of 45 feet. The slope of the bottom was gentle and unvegetated. The sand was coarse with ripple marks about 3 inches high. Some of the swales of the ripples had a dark brown "syrup" of decomposing kelp. Other areas where kelp had stranded and decomposed in place were white in color as if the residue were ashes. The white stipe of a kelp was recovered from one of these ash heaps. The live kelp in the area was all attached to rock.

On the return trip, I repeatedly dropped down to the bottom to examine the ripple marks. The marks formed dune lines which were oriented parallel to the beach and exhibited a slight curvature which conformed to the beach curvature. Amplitude and wave length increased as I neared the beach.

Close to the beach were two intertwined conglomerations of kelp and other vegetation. These two "boas" were about 20 feet apart and extended out of sight both left and right. The "boas" were cylindrical in shape and about 18 inches in diameter. The "boas" rested in the swales between ripples and appeared to be actively eroding the ripples on either side.

Dive No. 5

6 August 1968, 0900-1000PDT, clear, light surf

Divers: Moritz, Wallin

Entered the water on the south end of the beach and swam to detached area of kelp and submerged. Bottom was contacted at a depth of 55 feet near the outcrop of rock which serves as the base for the kelp thicket. Ripple marks were in evidence and were oriented parallel to the beach. "Kelp syrup" was noticed in the swales of the ripples. Active movement of sand on the ripples was taking place but was small compared with other similar observations.

The rock outcrop was a series of elongated outcrops intruded into the sand and oriented in a generally northwesterly direction. The largest outcrop was about 60 feet long at the sand line and extended upward about 10 or 12 feet maximum. All outcrops were overgrown with surface cover. Samples of the outcrop showed them to be of the same granodiorite which is prevalent on Point Lobos.

This type of granodiorite is conspicuous for its high biotite mica content. It is noteworthy that the rock was erosion-rounded in all exposed areas but when samples were attempted, the rock was found to be fresh and nearly unweathered. Jointing was noted to be deep and extensive.

Considering the beach to represent upstream and the canyon to be downstream, it was noted that there appeared to be a lee effect downstream from the outcrops. This seems to exclude the possibility of massive movement of sand at least in this area at this time. These findings suggest a particle by particle transport as indicated by the ripple marks.

From the outcrops we proceeded north along the rim of the canyon noting that the ripple marks were for the most part oriented perpendicular to the rim. Angles of repose were taken but I'm not sure what they were; about 30 degrees I would guess. At one stop I carefully noted the bottom and found no movement of sand. The bottom at this point was inclined about 30 degrees. Upon closer inspection, I noticed grains of sand swept up from the bottom and redeposited on the slope about 4 inches below its original position on the slope. This observation may be of significance if the movement was caused by water motion generated from the swell above.

Stake number 13 and we swam to it and then on to 14, 15, and 16. Stake number 16 is 40 feet to the north of a rock outcrop (not before mentioned) and about 200 feet north of the detached area of kelp.

Dive No. 6

10 August 1968, 0915-1000 PDT, overcast, very light surf

Divers: Moritz, Wallin

Entered the water and proceeded as on 6 August. This time we had the 6-man life raft, which, since the surf was only 8 inches, was well worth the effort to get it to the water's edge.

The raft was tied off to the detached area of kelp and we set out to the west along that portion of the canyon rim than runs parallel to the coastline of Point Lobos.

It was apparent that there is a plateau of significant width between the shore and the canyon rim. At least within the 40-foot wide arc visible to us there were no rock outcrops except those observed immediately under the kelp thicket. The bottom was generally featureless, sand covered and devoid of biological habitation. Angles of repose were measured at several places on the canyon slope at a depth of 100 feet. These measurements were a minimum of 30 degrees and a maximum of 45.

Two distinct shoreward trends of the canyon rim were noted but slide scars and other evidence of mass movement were missing.

A kelp frond was watched closely to determine if it was moving on the canyon slope. The frond, reacting to some hydrodynamic force which repeatedly raised it off the bottom, traveled down-slope at a respectable rate on the order of inches per minute.

Dive No. 7

13 August 1968, 0910-1000 PDT, overcast, light surf

Divers: Moritz, Wallin

Entered the water on the north end of the beach and swam to a point due south of the wash rock.

Bottom was contacted at a depth of 70 feet on sand held by organisms. To the north rose a steep wall of fallen boulders forming what appeared to be some sort of talus pile. The boulders did not appear to be consolidated in any way. Farther around to the north, the boulders gave way to outcrops and a combination of the two. At points there were what appeared to be rivulets of sand resting between the rocks.

At a point due west of the wash rock we swam over the edge of a vertical cliff whose top was at 100 feet. We could not see the bottom or any place where the slope leveled.

The rocks in the area appear to describe a cone about the wash rock. The nominal base of the cone lies at about 100 feet and is either markedly more percipitous at this point or is interrupted by sand.

At a point northwest of the wash rock an extensive area of coarse to medium sand was encountered. Air supply ran out but the character of the bottom was like that found in the rest of the canyon head except that there were fewer ripple marks. All rocks were granodiorite.

Dive No. 8

20 August 1968, 0905-0945 PDT, clear, moderate surf

Divers: Moritz, Wallin

(From Lt. Moritz' notes)

Submerged at stake number 1. Visibility was less than 10 feet above a depth of 60 feet and about 10 - 15 feet felow a depth of 60 feet. Found stake number 1 with no problem and began taking stake readings.

Between stakes 3 and 5 there was no bottom growth at all and the sand was of a very coarse consistency with some small gravel. This is a definite change from before. There were striations or patterns in the sand which indicated that it had been moving directly downslope. From number 5 on we found tube worms and other growth on a very fine sand bottom. The only change in this area was that less dead kelp was found lying on the bottom than previously observed This consisted mostly of frond parts and some of these pieces could be seen being moved down the slope by the action of the swell. The swell also caused a slight movement in some of the fine sand particles. The abundance of tube worms,however kept any significant sand movement from occurring. Some areas were more heavily covered with kelp.

I (Lt. Moritz) believe last week's heavy weather caused some sand movement off the beach and down the slope between stakes 3 and 5. There were no other areas of active sand transport found. We ran out of air at stake number 12 and surfaced.

Dive No. 9

24 August 1968, 0939-1015 PDT, overcast, moderate swell

Divers: Lennox, Wallin

Launched the boat from Whaler's Cove and proceeded to the detached kelp patch. Both divers donned a set of doubles and descended. Bottom was contacted at 60 feet.

Swam along the canyon rim trying to locate the kelp stipe placed as a marker on a previous dive. It has apparently been swept away. Descended the slope and found stake number 14. Continued to swim south and tagged stakes 15 and 16.

Surfaced to get stake driving equipment. Descended with stakes and driving equipment and missed the slope. Overshot to a depth of 125 feet and had to swim hard to avoid being swept into the canyon.

Approximately 20 feet from the location of stake number 16 is the beginning of a rock (granodiorite) ridge. This ridge is in such a position as to disturb the slope and any down-canyon flow of sediment along this section of the slope. This area required much more investigation.

Placed stakes number 17, 18, and 19 along sand slope on inboard side of the ridge. Stake number 19 is at the foot of an outcrop; presumably, the outcrop which hosts the detached kelp patch.

The bottom in the area of stakes 17, 18, and 19 is sand with no appreciable growth or sediment mat. It can possibly be inferred that the sediment is in motion.

Dive No. 10

7 September 1968, 0915-1000 PDT, clear, light surf

Divers: Moritz, Wallin

(From Lt. Moritz' notes)

Diving for sand samples in various parts of the canyon head. We were towed by a boat from area to area, then dived to obtain a sample in a small jar. Location was marked by sextant angle by the boat operator. Sixteen samples were taken in this manner.

Then went to look at the south rock outcropping. It begins in about 60 feet of water and continues to about 110 feet of water. It consists of boulders and masses with sand between. At 110 feet it appears to drop off sharply as sand at an angle of about 35 degrees. A few yards to the northeast at 110 feet begins another outcropping consisting of a single rock mass (i. e., not boulders), about 20 yards in length, and 15 yards in width. On the canyon side of this rock is a steep cliff extending nearly vertically past 130 feet to an unknown depth. At this point we ran out of air and surfaced.

Dive No. 11

10 September 1968, 0845-0930 PDT, clear, light surf

Divers: Moritz, Wallin

Entered the water from the south end of the beach and swam to the area of detached kelp. Submerged and contacted the bottom at 55 feet on the shoreward side of the rock outcrop. Swam through outcrop and kelp to the rim of the canyon and over. Located stake number 19 in 105 feet of water and tagged it. Bottom in this area appears to be in motion. Swam to stake number 18 and discovered I had lost tags number 17 and 18 so I marked the numbers on in grease pencil. Visible down-canyon from stakes 17, 18, and 19 is a large rock outcrop which interrupts sediment flow from above and causes it to split into two streams around the outcrop. The point of divergence was found to be the north end of the outcrop directly opposite stake number 17. Bottom detritus consisted of broken fresh kelp and a large number of beer cans. The actual divergence point appeared to be a dead area.

Swam to stake number 13 where the general topography looks like an old slide scar that through action of water movement (probably waves) has become rounded in its features. Returned to stake number 17 and ascended. On ascent an overall view of the outcrop area showed that all of the rocks outcropping had a general trend toward the northwest and were separated by sand chutes and overflowing sand.

Dive No. 12

14 September 1968, 0850-0940 PDT, overcast, moderate surf

Divers: Moritz, Wallin

Entered the water on the small stretch of beach near transit site number 1. The route and depths were noted. Just before turning left, the water was filled with air bubbles from waves breaking on the wash rock. At the seaward end of the route the bottom was covered with cobbles. The cobbles were well rounded and well bedded resembling a cobble street in the middle east. All cobbles were about the same size and no loose cobbles were noted. In the open areas the sand was continuous, broken intermittently by rocks. On the south side of the kelp bed, actual sand chutes were visible through which sand was apparently flowing. In one of these chutes, a sedimentary rock was found but it didn't appear to be "in place." The 25-foot depth contour appears to be a "magic number" for the bottom to the south of the area in question. There was very little detritus.

Dive No. 13

12 October 1968, 0910-1000 PDT, overcast, moderate surf

Divers: Moritz, Wallin

(From Lt. Moritz' notes)

Due to the high surf which precluded diving on 8 October, the beach face was noticeably chewed back. The foreshore seemed to be flattened with a very steep backshore.

We entered the water on the south end of the beach and submerged at the near edge of the kelp bed in 22 feet of water. Rock masses and boulders were found immediately.

There was much detritus on the bottom being moved by the surface swell. The sand level on the rocks was about 6 - 8 inches higher than would be expected in that marine growth extended 6 - 8 inches below the present sand level, at which point fresh rock was found. Barnacles on some rocks had been broken off near the sand level as if the sand might have scoured them off.

There was a heavy surge between outcrops which visibly moved large amount of detritus. In most heavy surge areas, the bottom consisted of well-rounded granodiorite cobbles.

As on the northern side, there seems to be a rock table at a depth of 22 - 30 feet with a thin veneer of sand in some areas between outcrops. Vegetation on the rocks and general geological characteristics appeared to be the same as the northern outcropping except that surf grass was found growing on one outcropping in the southern area. I (Lt. Moritz) pulled loose some surf grass and found that the roots were anchored in about 3/4 inches of sponge and other growth. Some rock grains came with the undergrowth. Numerous worms were found within the roots.

<u>Dive No. 14</u>

26 October 1968, 0915-1040 PDT, overcast, moderate surf

Divers: Ferrin, Moritz

(From Lt. Moritz' notes)

Attempted today to dive on an area where Cdr. Ferrin has witnessed a sand fall. This area is about 60 yards northwest of the wash rock on the northern side. In addition, we (Ferrin and Moritz) planned on following the slope down to a depth of 200 feet.

Submerged at suspected sand fall point. Reached bottom at about 70 feet on a precipitous rocky cliff. These rocks were of large boulder size or could have been part of the outcrop mass. The angle was very steep at about 50 - 60 degrees. This continued downward for an undetermined distance. We stopped the descent at 200 feet. The light attenuation was great at this depth and we were unable to see without the aid of a light. The rocks at this depth were covered with a fine silt very much like dust. The slightest turbulence created by swimming would stir up the silt like a dust cloud. The encrusting organisms could not be identified, but the rocks were definitely covered with growth.

The time allowed for a 200-foot dive is limited to 5 minutes counted from the surface. For this reason, the dive was a "bounce dive," or a rapid descent to 200 feet and then an immediate ascent.

A sand contact with the rocky cliff was not found. Cdr. Ferrin believes we were about 50 yards south of where the sand fall had been seen.

On the swim back to the beach, I (Lt. Moritz) submerged again at the edge of the kelp bed about 50 yards from shore in about 25 feet of water to look for the shale or conglomerate boulders found on a previous dive. These boulders were not found. In this location, however, at the edge of the rocky bottom area, a black sedimentary substance was found in the bottom between the crests of ripple marks. It appeared as though the ripple marks were formed over a bed of this black substance. The substance was about the consistency of molding clay. I (Lt. Moritz) dug up a piece of it and found that as I moved it through the water, it disintegrated due to the turbulence of the water. I feel certain that it consisted almost entirely of black mica flakes although I was unable to bring back a piece for analysis.

About 15 yards in closer to the beach, another area was found which appeared to have the same type of sub-stratum. This again was in 25 feet of water at the edge of the rocky bottomed area. Another sample was dug up and disintegration occurred as before. There was a difference, however, in composition. The deposit nearest shore contained a considerable amount of fine vegetable material homogeneously distributed within the mica.

Dive No. 15

31 October 1968, 0845-0945 PST, overcast, moderate surf

Divers: Moritz, Wallin

Entered the water inshore of the wash rock on the edge of the kelp. Swam seaward. Bottom heavily rippled with wave lengths about 4 feet and height of 18 inches. Gradation of sediment sizes on the slopes of the ripples was very much in evidence. There appears to have been a loss or movement of sand in this area in that many of the ripple mark troughs bottomed out on the base material in the area. This base material was humis-like which graded to finer textures seaward. Samples of this material were taken. Once again, the characteristic depth in this area is between 25 and 30 feet. The reason for making this dive was to recover a piece of a sedimentary rock seen on a previous dive. This rock, however, was not found. Sand chutes were found to be considerably fuller and with less exposed worm tubes than on the last dive in this area. Very little detritus of any kind was seen.

Dive No. 16

2 November 1968, 0925-0948 PST, overcast, light surf

Divers: Bond, Wallin

Launched the Boston Whaler at Whaler's Cove and proceeded to a point 20 yards south of the wash rock. Entered the water with double 72's and contacted the bottom at 65 feet depth. Swam down-slope to the location of stake number 1. Stake number 1 was found at the correct location but lying on the bottom. No portion of the stake was penetrating the bottom and the buoy line which was on this stake at last sighting was gone. The stake was probably pulled up by another diver. The bottom in this area and to a point half-way between stakes 4 and 5 is a very coarse sand with considerable pebble content. There is a very sharp transition at this point from coarse sand to fines held by worm tubes. By the time we got to stake number 4, the bottom was covered with broken kelp and fine sand. This bottom condition continued until shortly before stake number 16. Stake number 16 was placed in fine sand held by worm tubes. Half-way between stakes 16 and 17 there was another sharp transition to medium sand which continued to the end of the stake array at number 19. The detritus collection area just downslope from stake number 17, as previously noted, was completely clean with nothing but medium sand in the entire area. Noted readings from stake number 19 at 20 minutes elapsed time since submergence. Ascended canyon slope between the rock outcrops to the canyon rim at 70 foot depth. Surfaced after 23 minutes. All stakes were found and recorded. Upslope from stake number 13 there appears to be an old slump or slide scar which extends upward to the rim. The "For Sale" sign seen in previous dives was not seen on this dive - possibly covered by kelp.

DISTRIBUTION LIST

		No. Copies
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22314	20
2.	Library U. S. Naval Postgraduate School Monterey, California 93940	2
3.	Professor W. C. Thompson Department of Oceanography U. S. Naval Postgraduate School Monterey, California 93940	5
4.	Lt. S. R. Wallin 111 Afton Avenue Norfolk, Virginia 23505	4
5.	Oceanographer of the Navy The Madison Building 732 N. Washington Street Alexandria, Virginia 22314	1
6.	Naval Oceanographic Office Attn: Library Washington, D. C. 20390	1
7.	Director, Coast and Geodetic Survey Department of Commerce Attn: Department of Oceanography Washington, D. C. 20235	1
8.	Commander D. R. Ferrin, USN (Ret.) 3059 Phillip Circle Marina, California 93933	1
9.	State of California Dept. of Parks and Recreation Regional Planning Office (Attn: Mr. Charles Mehlert) 2211 Garden Road Monterey, California 93940	2
10.	Point Lobos Reserve State Park Attn: Mr. Donald Rich Carmel, California 93921	1

		No. Copies
11.	Dr. J. H. McLean Curator of Invertebrate Zoology Los Angeles County Museum of Natural History 900 Exposition Blvd. Los Angeles, California 90052	1
12.	Lt. C. A. Moritz USS Salmon (AGSS-573) FPO San Francisco, California 96601	1
13.	Professor R. W. Andrews Department of Oceanography U. S. Naval Postgraduate School Monterey, California 93940	1
14.	Dr. Francis P. Shepard Scripps Institution of Oceanography University of California at San Diego La Jolla, California 92038	1
15.	Dr. J. B. Hersey, Director Ocean Science and Technology Group (Code 408) Office of Naval Research Naval Research Laboratory 4555 Overlook Avenue, S. W. Washington, D. C. 20360	1
16.	Mr. F. D. Jennings, Director Oceanography Branch (Code 408P) Office of Naval Research Naval Research Laboratory 4555 Overlook Avenue, S. W. Washington, D. C. 20360	1
17.	Miss Evelyn L. Pruitt, Director Geography Branch (Code 414) Office of Naval Research Washington, D. C. 20360	1
18.	Mr. H. A. O'Neal, Director Ocean Technology Branch (Code 408T) Office of Naval Research Naval Research Laboratory 4555 Overlook Avenue, S. W. Washington, D. C. 20360	1

No. Copies

19. Mr. Thorndike Saville, Jr., Research Director — 1
Corps of Engineers, U. S. Army
Coastal Engineering Research Center
5201 Little Falls Road, N. W.
Washington, D. C. 20016

UNCLASSIFIED

Security Classification

DOCUMENT CONTROL DATA - R & D		
Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)		
1. ORIGINATING ACTIVITY (*Corporate author*) Naval Postgraduate School Monterey, California	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED	2b. GROUP
3. REPORT TITLE THE SEDIMENTS IN THE HEAD OF CARMEL SUBMARINE CANYON		
4. DESCRIPTIVE NOTES (*Type of report and inclusive dates*) Master's Thesis		
5. AUTHOR(S) (*First name, middle initial, last name*) Wallin, Steven R., Lieutenant, United States Navy		
6. REPORT DATE December 1968	7a. TOTAL NO. OF PAGES 96	7b. NO. OF REFS 10
8a. CONTRACT OR GRANT NO. b. PROJECT NO. c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (*Any other numbers that may be assigned this report*)	
10. DISTRIBUTION STATEMENT Distribution of this document is unlimited.		
11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Naval Postgraduate School Monterey, California	

13. ABSTRACT

Carmel Submarine Canyon is cut into the Santa Lucia granodiorite formation and is the only canyon on the California coast which is cut in granitic rock. The innermost head of the canyon exhibits a wide, bowl-shaped appearance, not unlike a glacial cirque.

Granodiorite outcrops on the submarine terrace on the north and south sides of the canyon and in the north canyon wall. Much of the terrace and upper canyon sides are covered by coarse sand while the interior of the canyon head is covered with fine sand.

The canyon is actively transporting sediment to deeper water at the present time. The chief source of sediments is coarse sand which is littorally transported from the mouth of Carmel River. This sand enters the canyon by way of three "rivers of sand" which extend over the canyon rim and down the slopes. Additional transport of sediment within the canyon head may be the result of slumps and slides lubricated by decomposition of vegetable matter incorporated in the sediments.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6811

UNCLASSIFIED

Security Classification

A-31408

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Submarine Canyon						
Submarine Canyon Head						
Sediments in Submarine Canyon						
Carmel Submarine Canyon						
California Submarine Canyon						
Diving Observations in Canyons						
Monterey Canyon, Branch of						
Granitic Rock in Submarine Canyons						

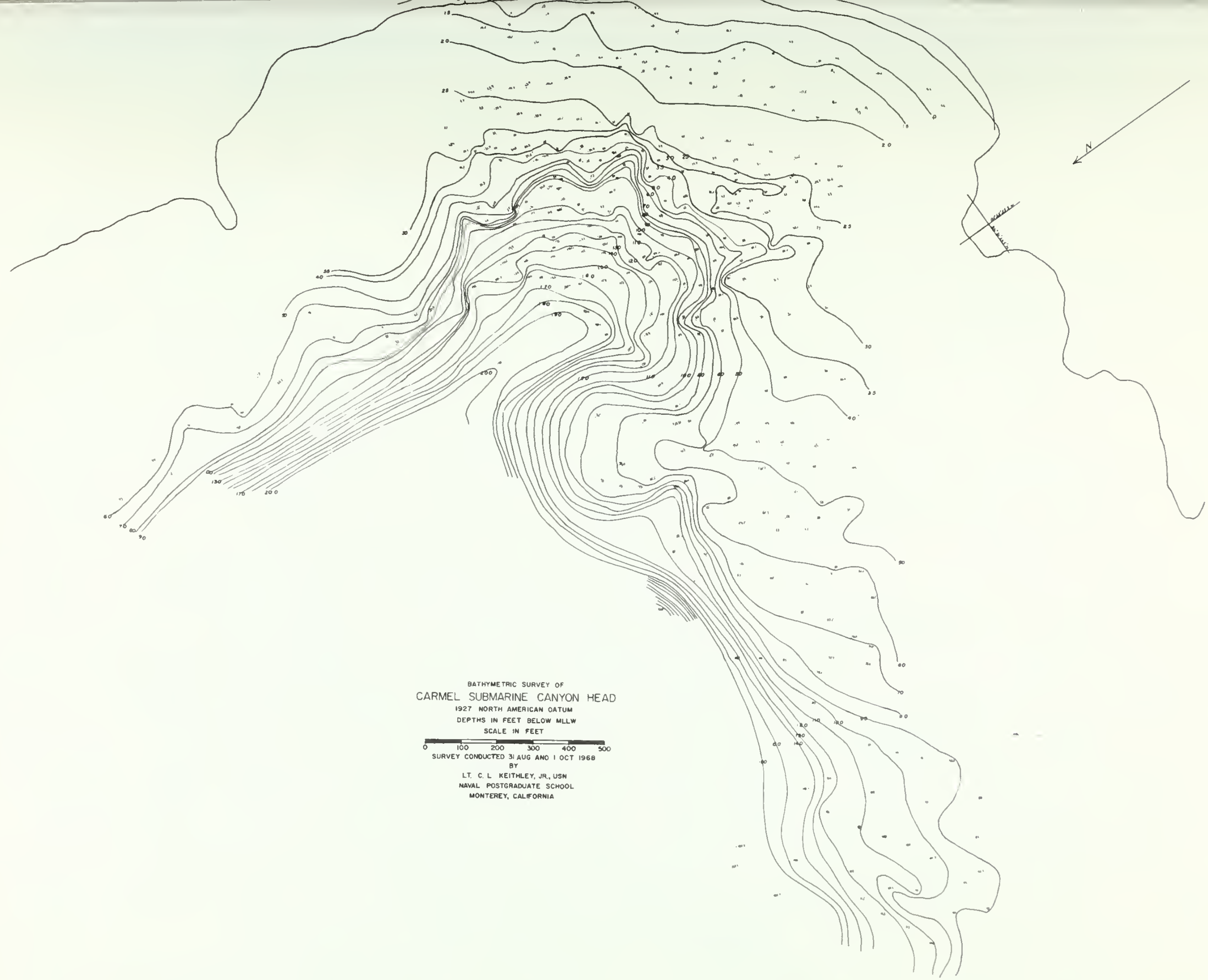
DD FORM 1 NOV 65 1473 (BACK)

S/N 0101-807-6821

UNCLASSIFIED

Security Classification

A-31409


BATHYMETRIC SURVEY OF
CARMEL SUBMARINE CANYON HEAD
1927 NORTH AMERICAN DATUM
DEPTHS IN FEET BELOW MLLW
SCALE IN FEET
0 100 200 300 400 500
SURVEY CONDUCTED 31 AUG AND 1 OCT 1968
BY
LT. C. L. KEITHLEY, JR., USN
NAVAL POSTGRADUATE SCHOOL
MONTEREY, CALIFORNIA
N