NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

SAND MOVEMENT ALONG CARMEL
RIVER STATE BEACH, CARMEL, CALIFORNIA

by

Buford Fredrick Howell

Thesis Advisor: R. S. Andrews

September 1972

Approved for public release; distribution unlimited.

T149572

Sand Movement Along Carmel

River State Beach, Carmel, California

by

Buford Fredrick Howell
Lieutenant, United States Navy
B.S., United States Naval Academy, 1966

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL
September 1972

Author Buford Fredrick Howell

Approved by: Robert S. Andrews
Thesis Advisor

Leroy R. Berkelman
Reader

Dale F. Leipper
Chairman, Department of Oceanography

Milton U. Clauser
Academic Dean

ABSTRACT

The direction of sand movement along the Carmel River State Beach was qualitatively determined by diving observations, a bathymetric survey, wave refraction diagrams and a sediment size analysis of 18 samples.

The primary source of sediments for the beach appears to be the Carmel River which flows only seasonally. Sedimentary material is introduced into the bay after winter precipitation provides a sufficient amount of run-off to warrant the opening of the river mouth by bulldozer.

The fine sedimentary material is lost offshore and the coarser material is either redeposited on the beach or is carried south with the littoral drift and deposited at the nodal point in the sand transport pattern. This node is located on the northern edge of the head of the Carmel Submarine Canyon.

Winter storms probably induce slumping or gravity sliding and much of the material is carried to deeper water by the canyon.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

ACKNOWLEDGEMENTS

The author is indebted to Dr. Robert S. Andrews of the Department of Oceanography, Naval Postgraduate School, Monterey, California for his assistance. Diving assistance was provided by Lt. B.S. Cronyn, USN, Cdr. Don Ferrin, USN (Ret.), Lt. Richard Krapohl, USN, Lt. John Millward, USN, Mr. Larry Leopold of San Jose State College, and Mr. Jack C. Mellor. Mr. Mellor's assistance in almost every aspect of this study was indispensable. Assistance in data collection is gratefully acknowledged from Lcdr. Richard Heffernan, USN, Cdr. Karl Schriner, USNR, Mr. Dana Mayberry, and the Master and crew of the R/V ACANIA. Grateful acknowledgement is made to Mr. Don Rich, California Department of Parks, Point Lobos State Reserve, the rangers of Point Lobos State Reserve, and Mr. John Hudson of Carmel, California.

Acknowledgement is also made to Miss Sharon D. Raney of the W.R. Church Computer Center at the Naval Postgraduate School for assistance in the preparation of computer programs used in this study. Grateful acknowledgement is also made to my wife who assisted in typing and the preparation of figures and tables.

Partial funding for this study was provided to Dr. Andrews through the Naval Postgraduate School Research Foundation under an Office of Naval Research Contract.

I. INTRODUCTION

A. OBJECTIVE

This study was undertaken in order to determine the direction of sand movement along the Carmel River State Beach, Carmel, California, and provide an insight into the methods by which this sand is introduced into the Carmel Submarine Canyon. In order to accomplish these objectives, the area of study was examined by the author using SCUBA, a bathymetric survey was conducted, wave refraction diagrams were constructed, an attempt was made to measure bottom currents, and sediment samples were taken for textural analysis.

B. AREA DESCRIPTION

Carmel Bay, located about 9 km south of Monterey Bay on the central California coast (Fig. 1), is an embayment that contains the head of the Carmel Submarine Canyon (Fig. 2). It is a very open, rectangular-shaped bay with dimensions of 4.3 km by 3.6 km in the north-south direction and east-west direction, respectively.

Neighboring communities include Pebble Beach and Carmel, California. At the southern end of the bay is Point Lobos State Reserve. Two watercourses, the Carmel River and San Jose Creek, drain a land area of approximately 670 km^2 and terminate near the head of the Carmel Canyon. [California State Department of Water Resources, 1969].

The study area (Fig. 3 and 4) is bounded by Carmel (Abalone) Point to the north and San Jose Creek to the south. A depth of 75 ft was arbitrarily chosen for the western boundary and the beach face formed the eastern boundary.

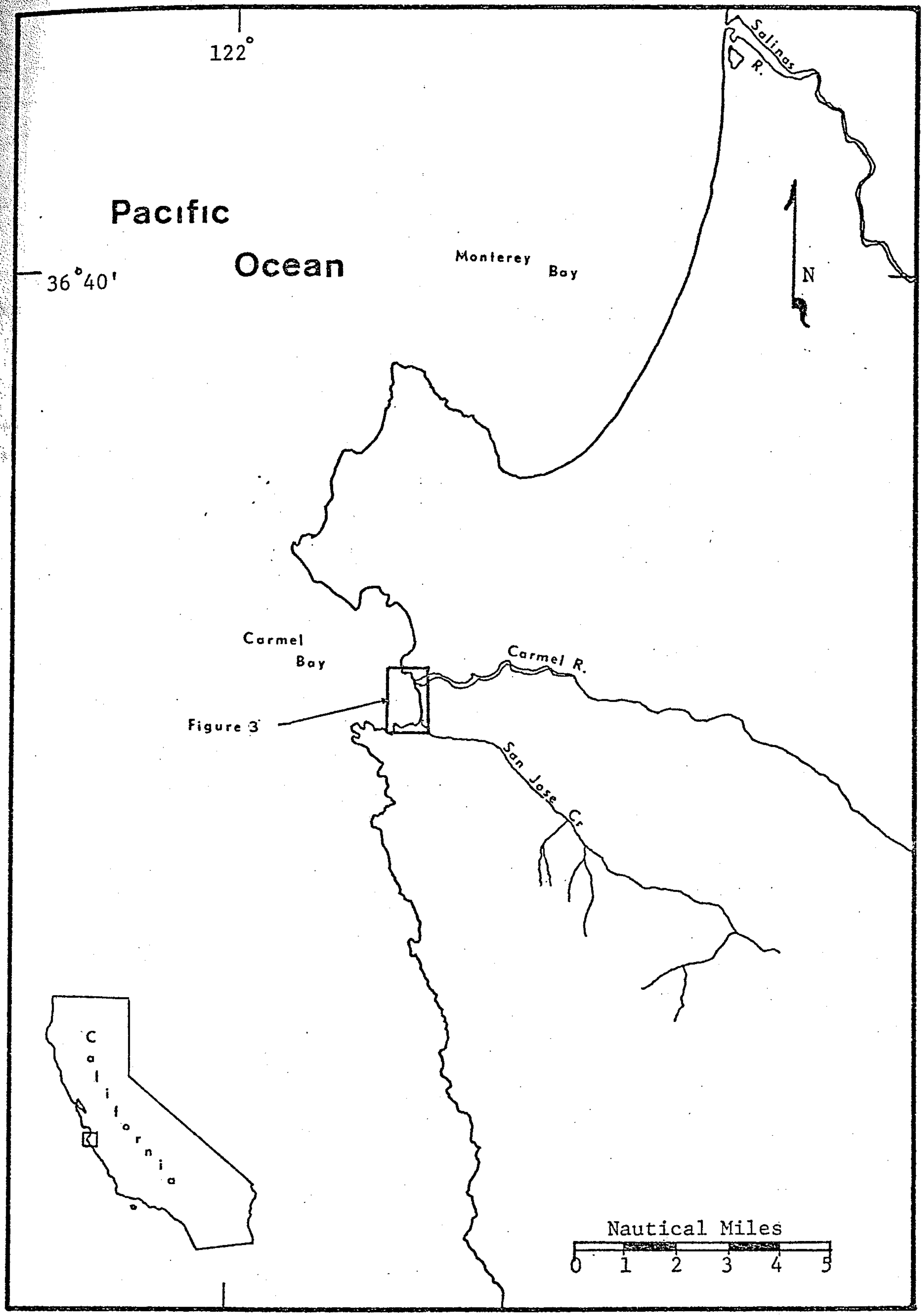

Figure 1. Location of Carmel Bay Showing Watercourses that Drain into It.

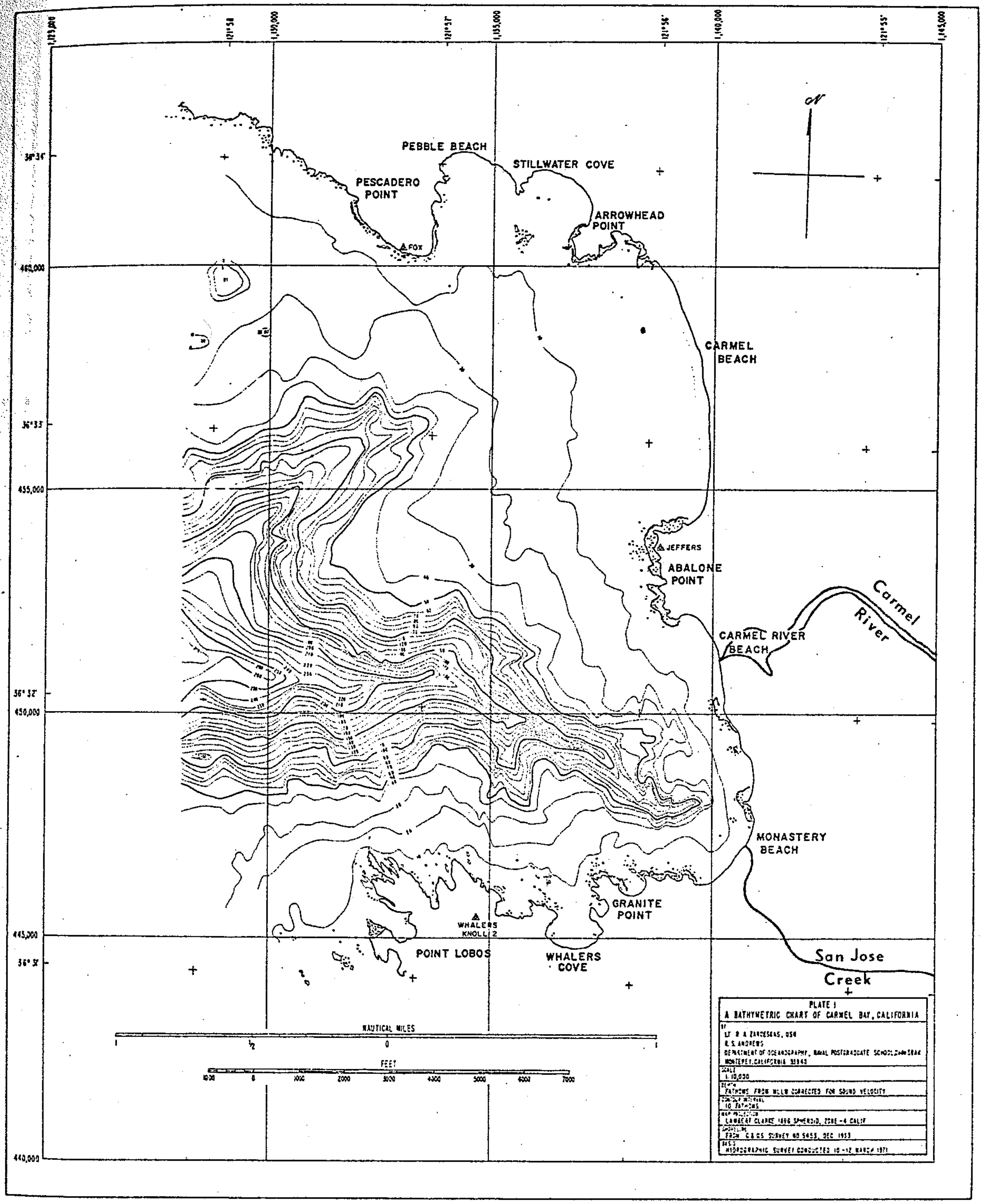

Figure 2. Carmel Bay Bathymetry (Contour Interval - 10 fm) (After Zardeskas, 1971).

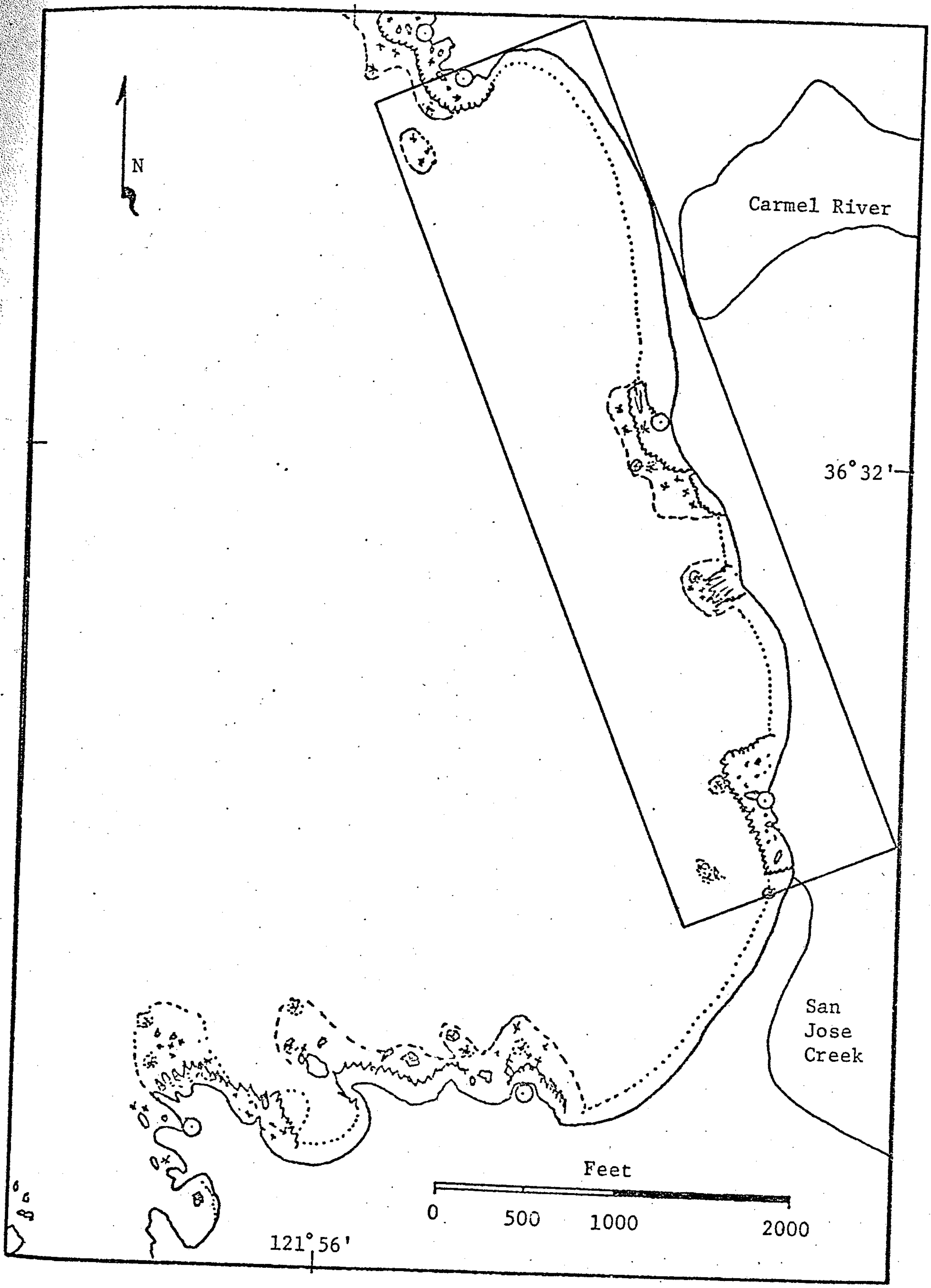

Figure 3. Area of Study.

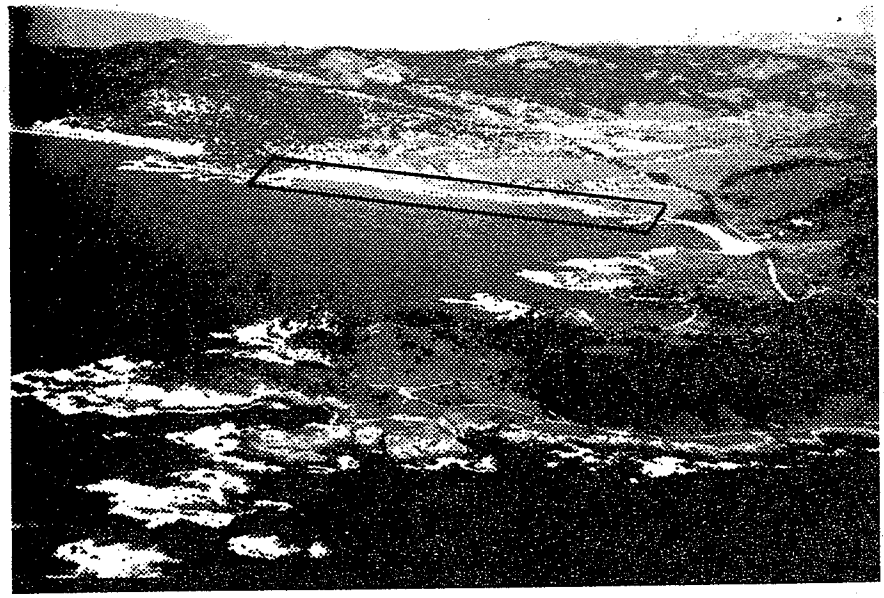

Figure 4. Aerial Photograph of Southern End of Carmel Bay Showing the Area of Study.

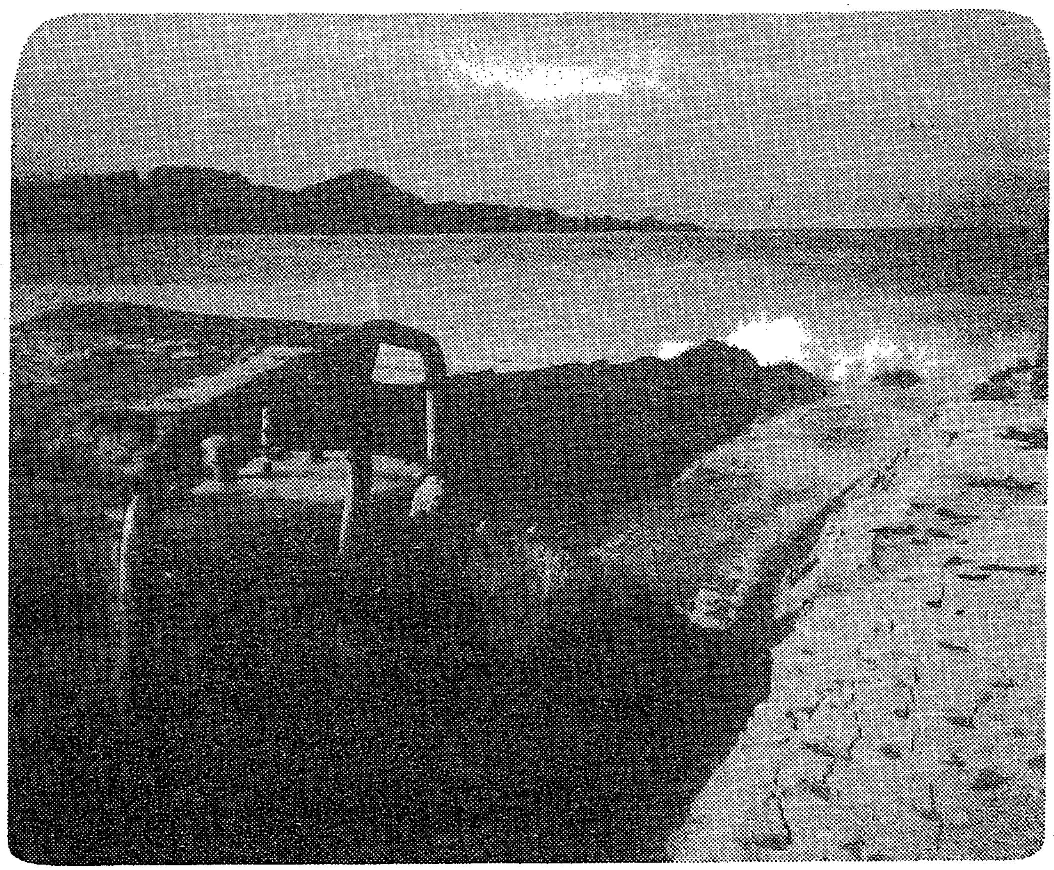

Figure 5. Bulldozer Opening the Mouth of the Carmel River.

The primary source of sediments for the study area was assumed to be the Carmel River. Sand is introduced by the river primarily during the winter and spring when rainfall is sufficient to maintain a flow. During the summer and fall, the beach closes the river and a brackish lagoon forms behind the beach, thus ceasing the river-carried sand supply. A secondary source of sediment is the shoreline-outcropping rock.

When the winter rains have supplied a sufficient amount of precipitation to produce a steady flow in the river and the lagoon is filling, the mouth of the river is opened by a bulldozer (Fig. 5). Failure to open the river at the proper time could result in flooding of homes at the lower end of the Carmel Valley. This operation is performed under the direction of the head ranger at Point Lobos State Reserve and normally occurs once or twice each winter. During the winter of 1966-1967, this operation was repeated 25 times because of alternating rainy and dry periods. The possibility exists that heavy rains coupled with heavy surf, a high tide, and a strong onshore wind might prevent this opening and flooding would occur [Mr. Don Rich, personal communication].

One cut is all that is required as the flow of the river widens the cut until the river is at least 100 ft wide at the beach (Fig. 6). The author estimated that, at the point of maximum opening, 10,000 to 20,000 cubic yard of sediment had been removed from the beach.

Much of the fine sediment material was observed moving out into the bay and was obviously lost to the study area. The coarse sediment undoubtedly settled quickly and was either moved with the littoral drift or redeposited on the beach by wave action when the river mouth was closed again.

Figure 6. Mouth of the Carmel River After Flow Has Widened the Bulldozer Cut.

C. PREVIOUS WORK

The geology of the area in the vicinity of Carmel Bay has been described in some detail by Lawson [1893], Beal [1915], Bowen [1965], Nili-Esfahani [1965] and Simpson [1972]. Of interest to this study are the formations that are in the study area or are associated with the Carmel River and San Jose Creek waterbeds. The Santa Lucia porphyritic biotite granodiorite (Cretaceous) is apparently the most important source of sediments for the area. The Carmelo Series (Paleocene), interbedded pebble conglomerate, sandstone, and siltstone, and Monterey shale (Upper Miocene), a silicious shale, provide a smaller amount of sediments. Sur Series metamorphic gneisses (pre-Cretaceous) apparently contribute significantly to the heavy minerals supplied to the area as they dominate the upper regions of the Carmel River watershed [California State Department of Water Resources, 1969].

Diver description of the study area has been almost nonexistent. Numerous dives have been conducted in and around the head of the Carmel Submarine Canyon. Shepard and Dill [1966], McLean and Peckham [1961], Moritz [1968], and Wallin [1968] have provided descriptions of San Jose Creek beach and the head of the canyon. Sand falls and slump scars have been noted by Moritz.

Bathymetric surveys of the bay were accomplished by the U.S. Coast and Geodetic Survey (USCGS) in 1883 (No. 1548a) and 1933 (No. H5453). Shepard and Emery [1941] have conducted a lead line survey of the head of the Carmel Submarine Canyon. Zardeskas [1971] conducted the first bathymetric survey using electronic navigation and echo-sounding equipment. This survey is considered to be more accurate than previous surveys but does not provide sufficient detail inside the 10-fm contour.

Studies of the currents in the bay are almost non-existent. Tides of the bay are the mixed type that is characteristic of the Pacific Coast. Diurnal differences between mean higher high water and mean lower low water average 5.2 ft [U.S. Coast and Geodetic Survey, 1971].

Bascom [1964] conducted a study of the seasonal changes in the profile of the Carmel River State Beach. These seasonal changes were of little significance in this study. However, these seasonal cycles show that sand is moved from the beach to an offshore bar by winter storms and is carried back onto the beach by summer swell.

Carter [1971] studied the marine sediments of the bay using grain-size analysis techniques and Griffin [1969] has conducted a heavy-mineral analysis of the beaches in the bay.

II. METHODS OF DATA ACCUMULATION

A. BATHYMETRY

1. Survey

A bathymetric survey of the area was conducted on May 12, 1972. This survey was undertaken in order to provide information for comparison with previous surveys by the USCGS and the Naval Postgraduate School (NPS). Large depth discrepancies between the various surveys could provide an indication of slumping. Additionally, the survey provided an accurate nearshore chart for wave refraction diagrams.

Four transit locations along the beach in the study area labelled A, B, C, and D (shown on the finished chart, Fig. 13) were located using the U.S. Geological Survey Horizontal Control Station "Whaler's Knoll Number 2" (Fig. 2), the new Carmel Mission Spire, and the references used in the 1933 USCGS survey that were designated "Hudson" and "Granite Point" on the finished chart. Two Dietzgen 6000 Series land surveying transits were used, first at locations A and B and last at locations C and D, to determine the position of the survey boat. A large marker was placed on Whaler's Knoll Number 2 which could be seen from the transit locations. This served as a zero reference for the transit operations and all angles were measured relative to this marker.

An Apelco Model MR-201B fathometer was mounted on the transom of a 13-ft small craft powered by a 9.5-hp outboard motor. An aluminum pole painted international orange was mounted vertically above the fathometer transducer. Communication between the survey boat and the transit operators was maintained with 1-w two-way radios at each location. The position of the survey boat was determined at least every minute during the survey.

Track lines were intended to be perpendicular to the beach at 30-yard intervals. This was difficult to maintain because of large amount of kelp (Macrocystis pryifera) and difficulty in seeing prelocated beach reference marks.

2. Depth Corrections

All depths on the finished chart were corrected to mean lower low water datum. In order to correct for the depth of the transducer, differences in calibrated sound velocity, and instrument error, comparisons between the fathometer readings and lead-line readings were made periodically over a known flat bottom.

A tidal correction was applied using the NPS tide gage located on Monterey Municipal Wharf Number Two in Monterey Bay (just north of Carmel Bay) as a reference. Tidal differences between Monterey Bay and Carmel Bay rarely exceed 0.5 ft [Dr. W.C. Thompson, personal communication]. Since the fathometer sound beam spreads spherically within its beam width, a correction is required if the bottom is not horizontal.

True slope of the bottom was obtained by plotting the various data points and measuring the distance between two points across the slope. The fathometer readings are known at each point and the slope is easily obtained. A correction for slope was applied using tables prepared by Zardeskas [1971].

B. DIVER OBSERVATIONS

An examination of the study area was made over a 7-month period using SCUBA, during which 23 dives were made in the area. A log of six of the more interesting dives is contained in Appendix A. On all dives an effort was made to record general bottom types, sand thicknesses, unusual features, bottom slopes and, when applicable, sediment and rock samples were taken.

C. LITTORAL DRIFT

Littoral drift was qualitatively determined using statistical wave data from National Marine Consultants (NMC) [1960], and wave refraction methods given in U.S. Naval Hydrographic Office [1958] Publication Number H.O. 234. No attempt was made to quantitatively determine the longshore sand transport because of insufficient wave data and because empirical relationships to determine volume transported are based on a smooth and straight beach [Bowen and Inman, 1966]. The beach in the study area is broken in numerous places by large granodiorite outcrops.

1. Statistical Wave Data

The wave data used are the results of hindcasting from weather map analyses for the three years 1956, 1957 and 1958 (Fig. 7). Sea and swell data are given by period, deep water wave height, frequency of occurrence and direction. Direction is given in 22.5° increments (W, WNW, NW, etc.).

None of the seven stations along the California Coast for which the data are presented were located in the vicinity of Carmel Bay. The data of the nearest station to the north (Number 3), located approximately 50 nm west of the entrance to San Francisco Bay (Latitude 37.6° N, Longitude 123.5° W), and the nearest station to the south (Number 4) (Latitude 35.5° W, Longitude 122.0° W), showed no significant differences. For this reason, the data from Station 4 were used.

The NMC information is incomplete because it is based on synoptic meteorological data from the North Pacific and does not consider:

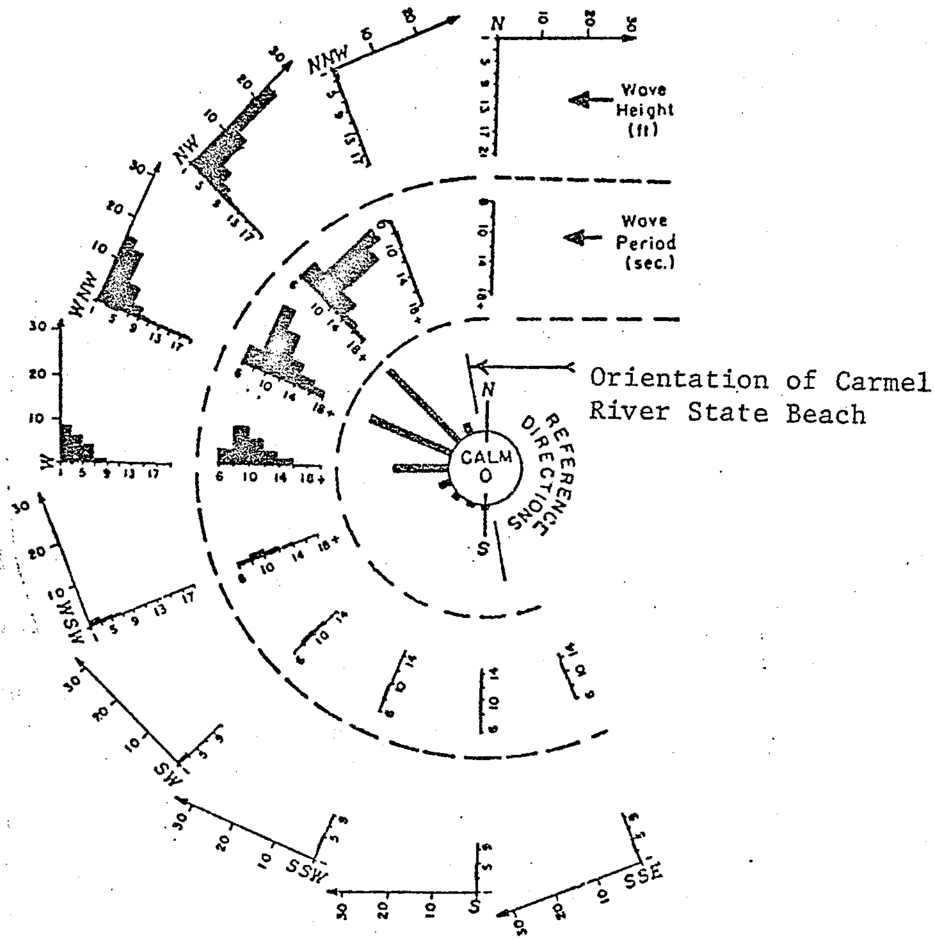

Figure 7. Swell Data from National Marine Consultants for Station 4. (after Cherry, 1965).

a. local waves generated by the diurnal sea breezes, and

b. southerly swell.

The first, local waves, could be of considerable significance in sand movement. The second, because of the great amount of refraction that would be involved, would probably not contribute significantly to the sand transport.

The data show that over 80% of the deep water wave energy that arrived off the coast comes from the directions of west, west-northwest and northwest. Over 40% of the total energy comes from the northwest alone [Cherry, 1965].

2. Construction of Wave Refraction Diagrams

Wave refraction diagrams were constructed for waves from the west, west-northwest and northwest by the author and by previous investigators [Wallin, 1968]. The methods given in H.O. 234 were used. All calculations were accomplished using a computer program that eliminates the need for tables to determine the ratio of the depth of the water to the deep water wave length. A copy of the computer program, formats for data cards and a sample of the output are listed in Appendix B.

Direction of transport for San Jose Creek Beach, located just south of the study area, and Carmel River State Beach were determined. Refraction diagrams were considered more accurate than previous diagrams because of the improved bathymetric data provided by Zardeskas [1971] and the author's own nearshore survey.

A wave refraction diagram for swell from the west-northwest with a period of 11 sec is shown in Fig. 8.

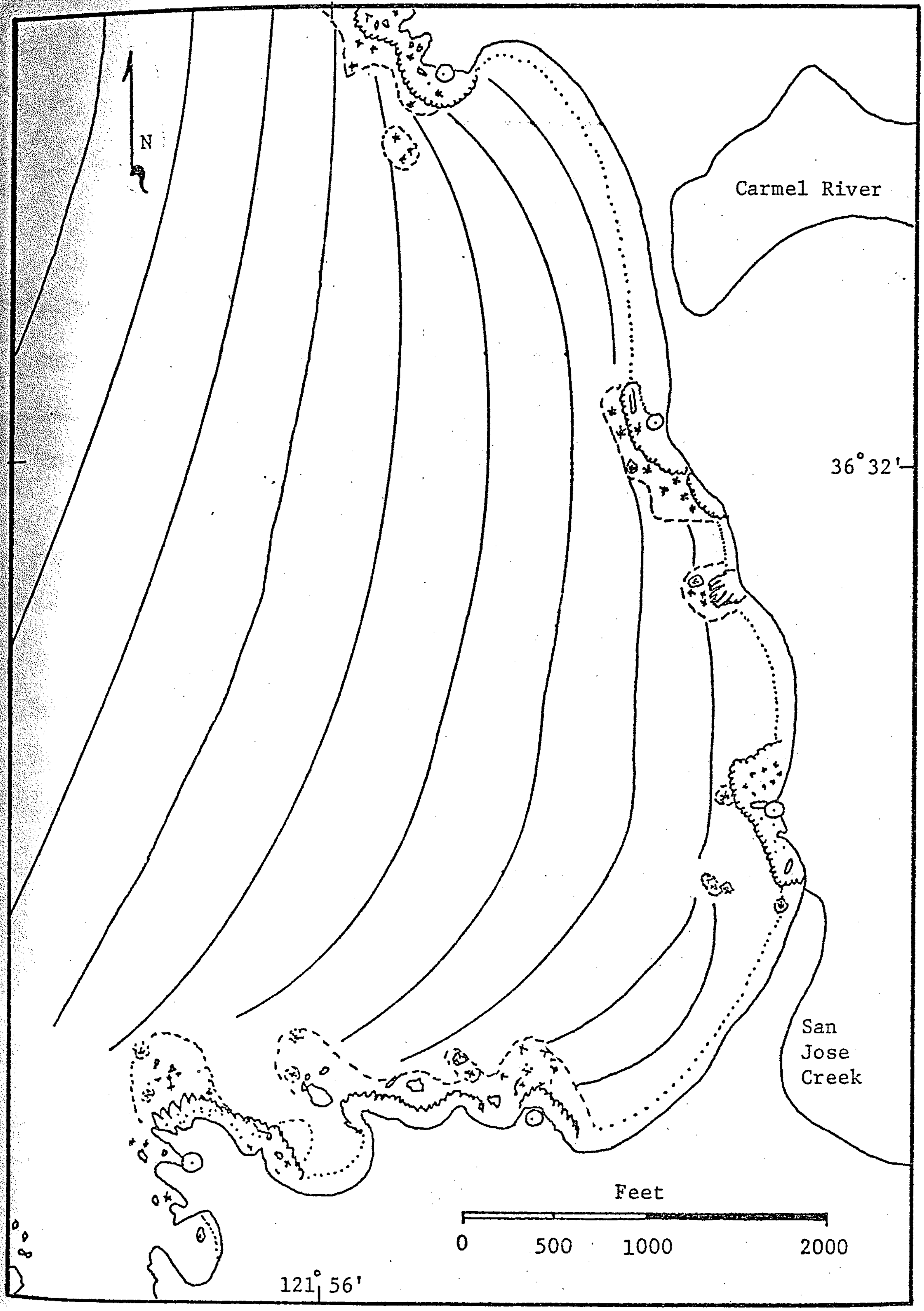

Figure 8. Wave Refraction Diagram for West-Northwest Swell with a period of 11 sec.

D. CURRENT STUDIES

1. Savonius Rotor Current Meter

Two attempts were made to measure bottom currents outside the surf zone. The first involved the use of a Hydro Products Model 501 in situ current recording system. This instrument measures current speed with a Savonius rotor and current direction with a direction vane. Direction, speed, and temperature are recorded with a Rustrak recorder. Current speed in shallow water can be measured with this sytem only if the water surge component is negligible compared to the current [Dr. E.B. Thornton, personal communication]. For this reason, the meter was operated for 1 week in the spring with the hope that 1 or 2 days of minimal wave activity might ensue.

The meter required a vertical orientation in order to eliminate any gravity component on the directional vane when recording. Since the bottom slope was 14° at the chosen location, the vane was fitted with a small glass floatation chamber to eliminate this problem when submerged in salt water. Additionally, the meter was equipped with a plexiglass cover for diver observation of the recorder.

A 550-lb rectangular (18 inch x 18 inch x 2 inch) lead base imbedded with stainless steel studs for meter attachment was prepositioned using the R/V ACANIA in 60 ft of water in the center of the study area. One of the sediment samples (Number 6, Fig. 11) was taken next to this base. The meter was lowered from a small boat and bolted to the base by divers (Fig. 9).

2. Ducted Current Meter

The second effort used a Marine Advisor's ducted current meter system attached to a base fabricated at the machine facility of NPS (Fig. 10). This system, unlike the Savonius rotor model, can essentially

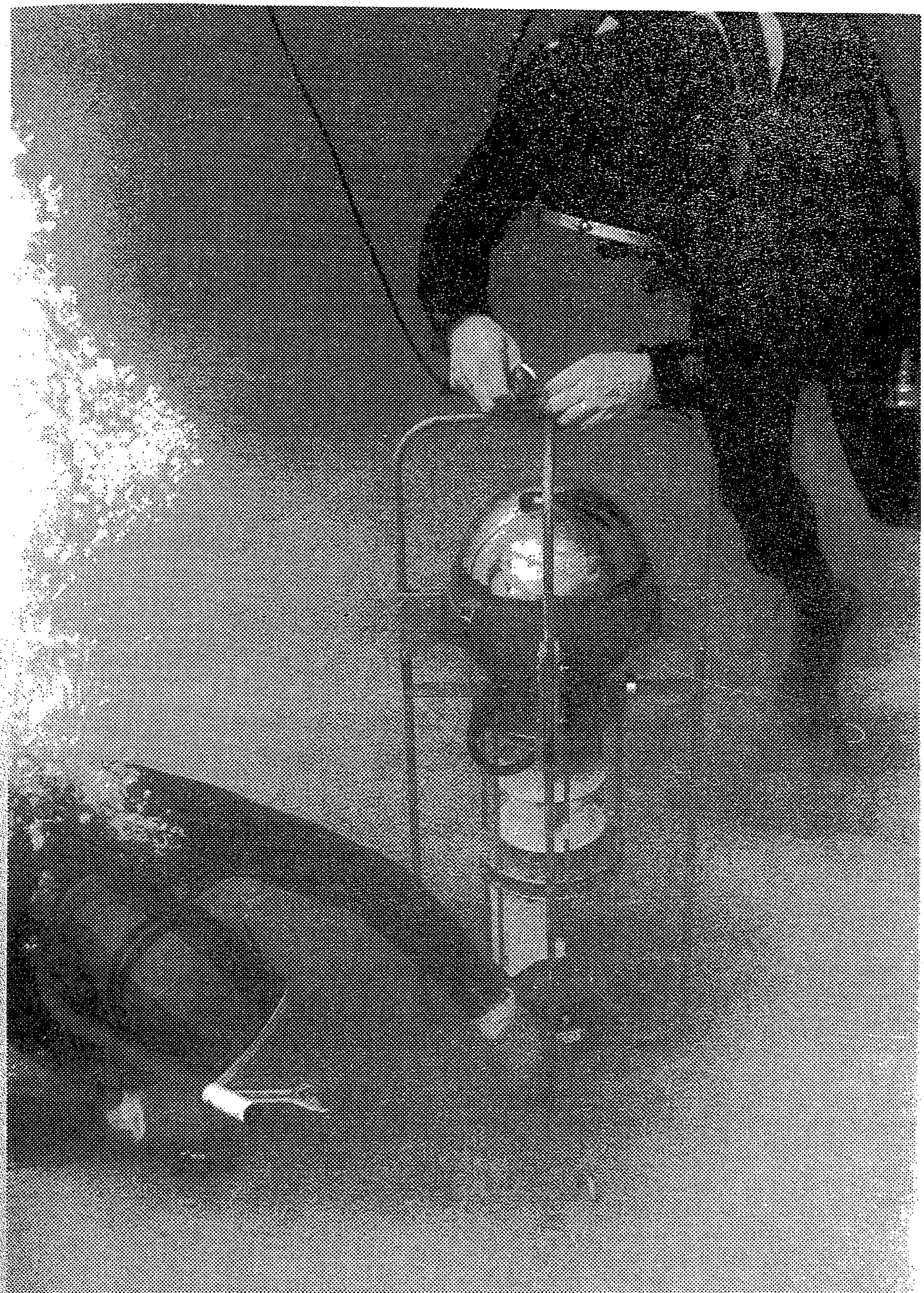

Figure 9. Divers Installing Savonius Rotor Current Meter.

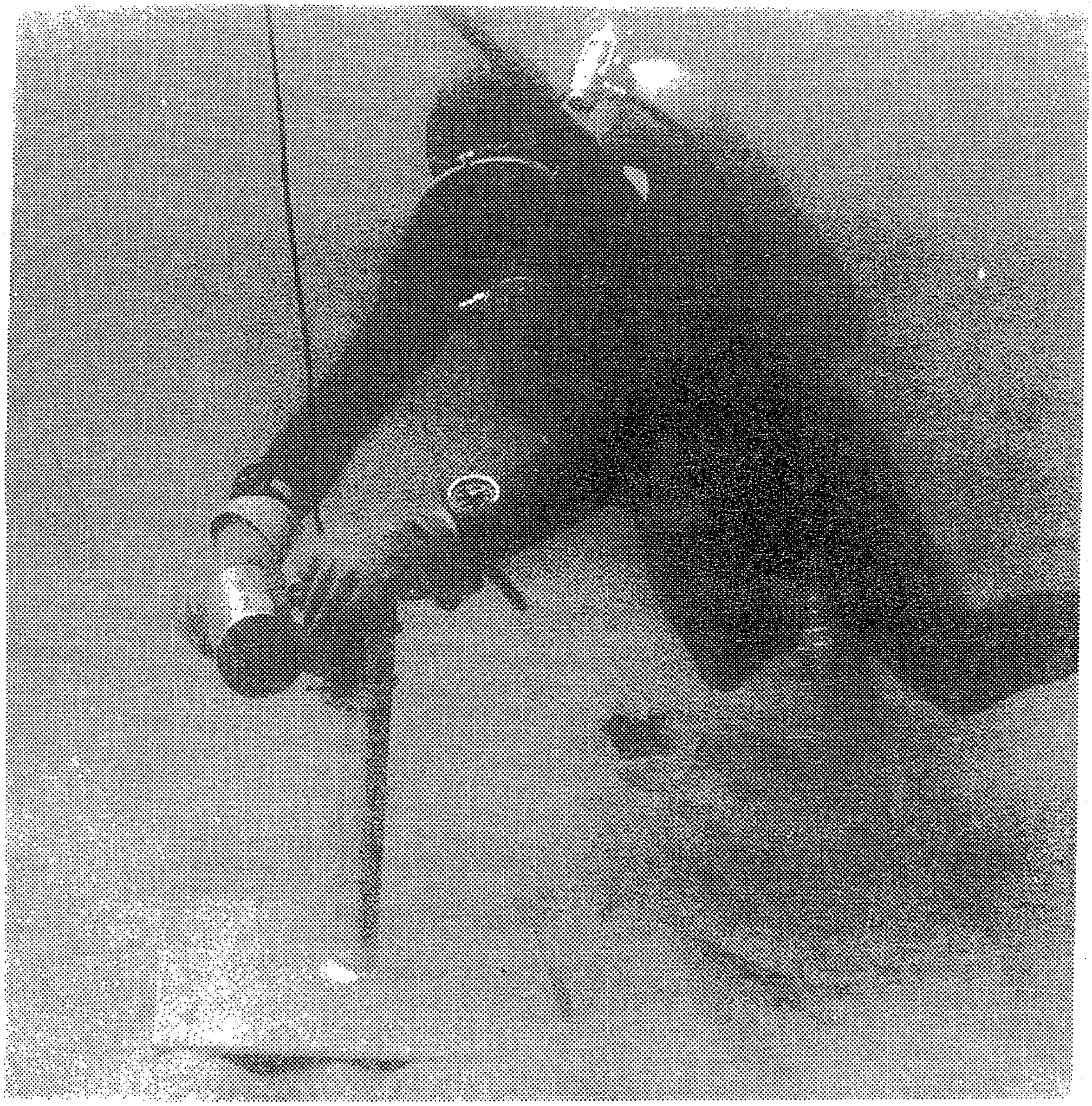

Figure 10. Diver Placing Ducted Current Meter and Base on the Bottom.

eliminate the wave surge component simply by physically aligning the axis of the meter parallel to the crests of the wave-induced sand ripples. Its major disadvantage is the requirement for surface recorders. The power for the recorders was supplied by a 12-v automobile battery and a DC/AC inverter. The recorders consisted of a ducted current meter read-out Model S-6A (0-15 knot range) and a Varian Model G-11A strip chart recorder adjusted for a full scale deflection of 2 knots. The meter was placed in 60 ft of water directly seaward of the Carmel River lagoon. The axis of the ducted meter was oriented so that the wave surge component was minimal. Data was taken for periods of approximately 30 min..

E. SEDIMENT SIZE ANALYSIS

1. Collection and Analysis Procedures

Eighteen sediment samples were taken in the area and grain-size analyses were conducted using the procedures outlined in Krumbein and Pettijohn [1938]. Twelve of the samples were taken by the author using SCUBA, five were taken at selected locations along the beach, and one (sample Number 18) was taken in the bed of the Carmel River in the vicinity of the U.S. Geological Service River Gaging Station near the bridge of California Highway 1 (Fig. 11). All diver samples, with the exception of sample Number 12, were taken across the crests of sand ripples to insure uniformity (Fig. 12). Samples Number 11 and 12 were taken in a crest and adjacent trough respectively for comparison.

From each sample a subsample of approximately 40 g was taken. The subsample was washed with distilled water in order to remove the salt, allowed to settle, and the excess water was decanted. The subsample was then wet sieved through a stainless steel 4Ø screen. No fine fraction (> 4Ø) of any significance was noted for any of the samples.

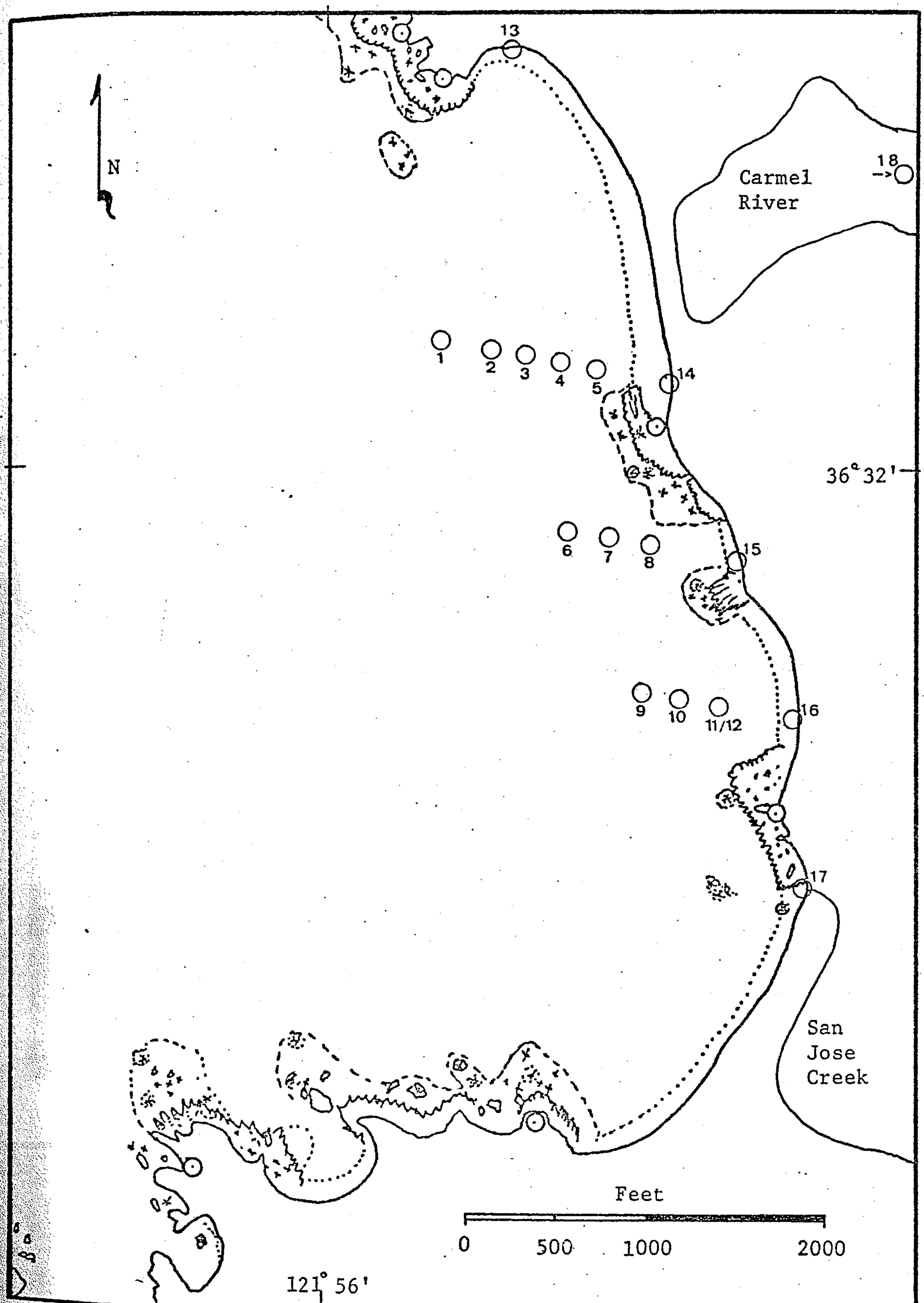

Figure 11. Locations of Sediment Samples.

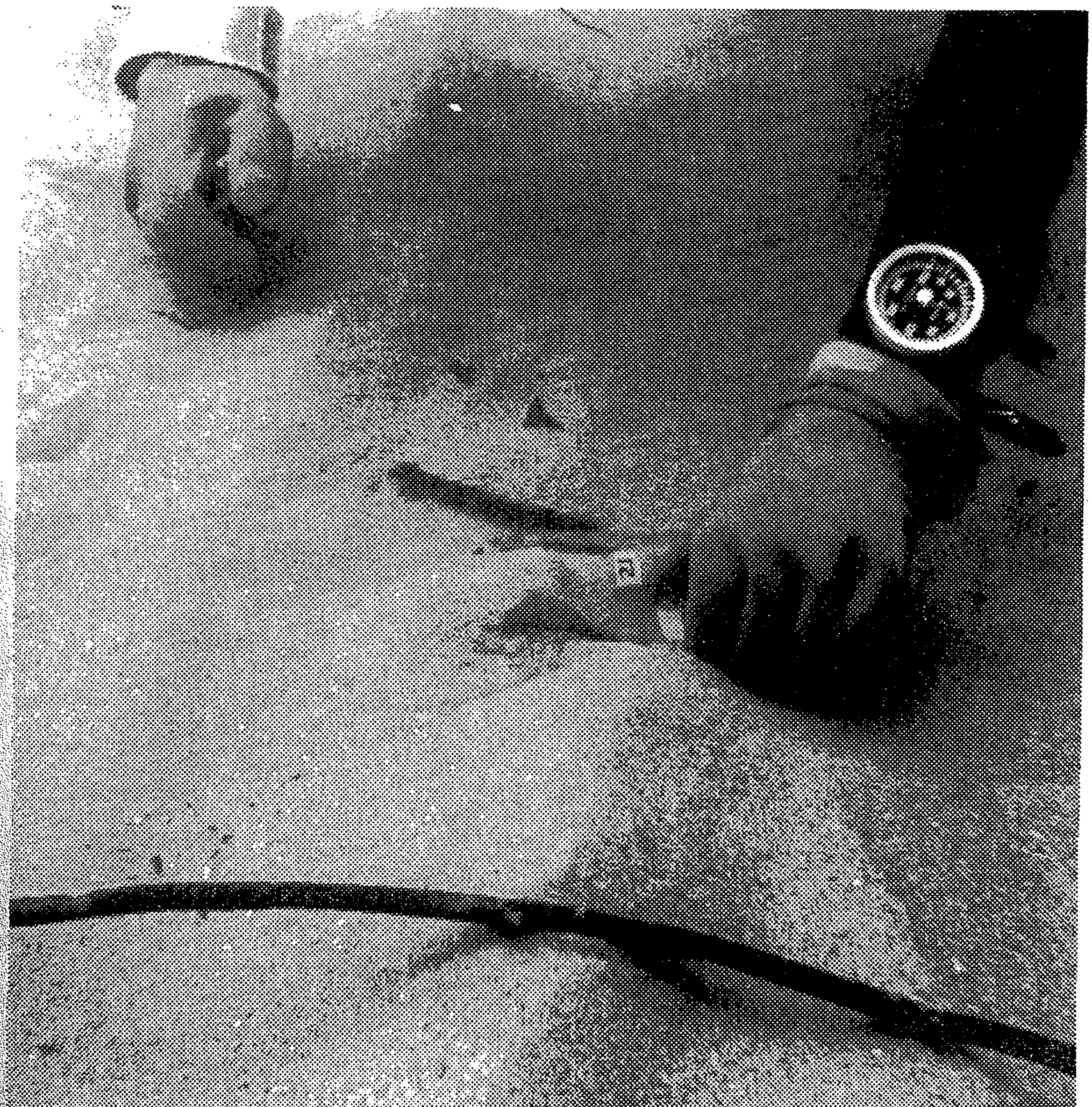

Figure 12. Diver Taking Sediment Sample.

The coarse fraction was placed in a beaker, dried and weighed. After weighing, the coarse fraction was dry sieved through 8-inch U.S. standard screens at 0.5Ø intervals using a Ro-Tap automatic shaker. The fraction retained on each of the screens was then weighed to the nearest 0.1 mg. Finally, the cumulative weight of fractions was compared to the original weight to check for gross errors.

2. Computer Analysis

Folk and Ward [1957] statistical parameters were calculated using an IBM 360 computer and a computer program prepared by W. R. Anikouchine [Dinger, 1970, p. 31] and slightly modified by Miss Sharon Raney (NPS Computer Facility). A copy of the computer program, formats for data cards and a sample of the output are listed in Appendix B.

III. RESULTS

A. BATHYMETRY

Chart preparation was accomplished by first preparing a smooth sheet. This required the plotting of all fixes that had been taken on a 1:5000 scale sheet, printing the corrected depths on the plotted positions and contouring the sheet in increments of 10 ft. The contours range from 20 ft to 100 ft. The 10-ft contour was omitted because of insufficient data. Moderate surf activity on the day of the survey precluded boat operations very near shore. The shoreline for the chart was obtained from the USCGS 1933 smooth sheet.

The finished chart (Fig. 13) was prepared on tracing paper from the smooth sheet. It has been reduced for inclusion in this paper.

Of interest is the shoreward trend of the contour lines between transit locations B and C. This might possibly be due to a deprivation of sediment supply caused by a large granodiorite outcrop. Additionally, there exists a slight seaward extension of contour lines just offshore of transit location C. This might be caused by a larger rate of sediment supply and/or an underlying formation. This seaward bend of contour lines is dramatically shown in Fig. 2.

Comparison of the finished chart with the USCGS 1883 and 1933 surveys revealed no significant depth changes. The study areas of this chart and that of Shepard and Emery [1941] did not sufficiently overlap and thus provided little useful correlation. The 1971 survey (Fig. 2) did not, because of limitations of the towed sounder, survey this close to shore. The 10-fathom curve of the 1971 survey was taken from the USCGS 1933 survey.

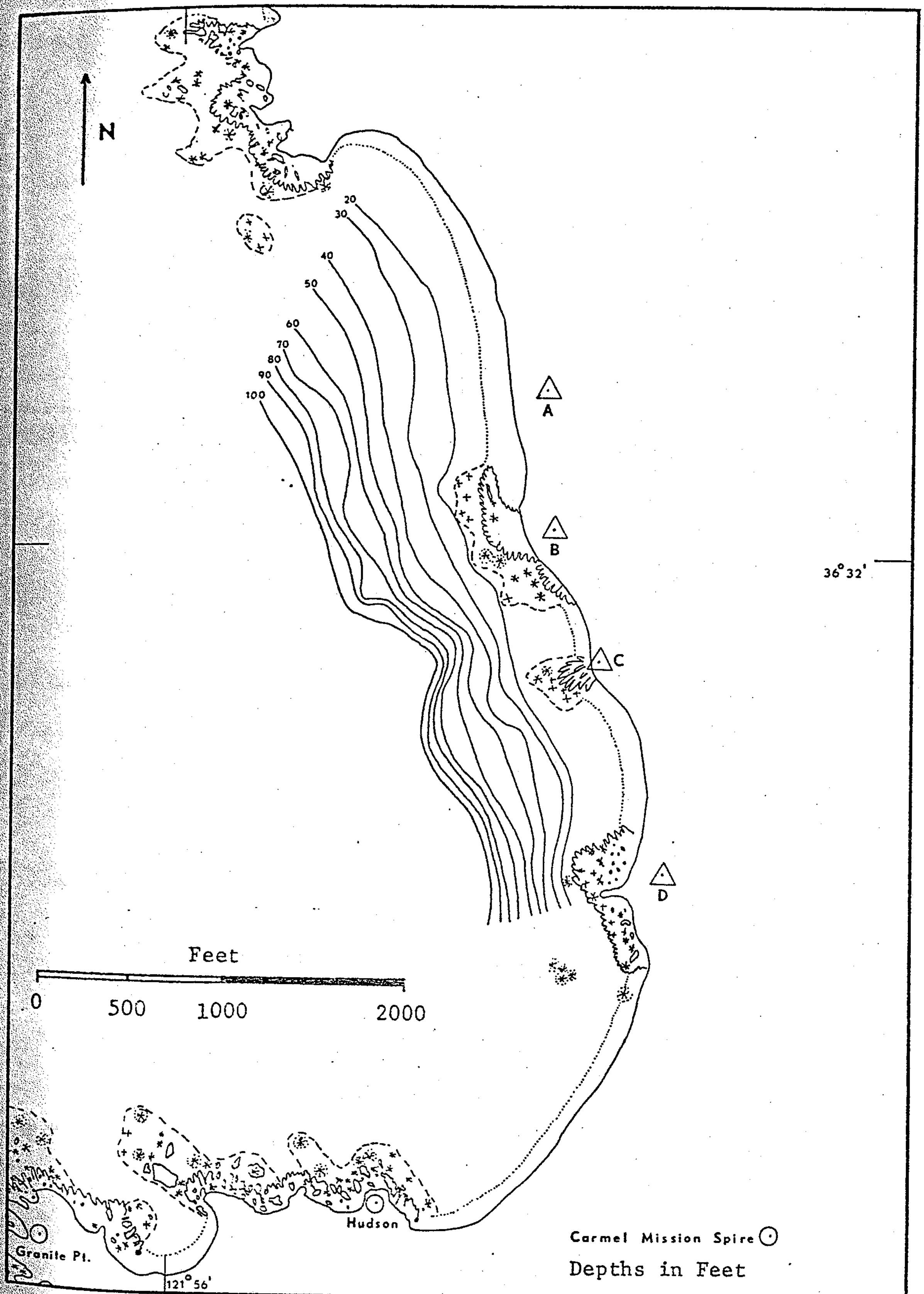

Figure 13. Nearshore Bathymetric Chart. (10-ft contour omitted because of insufficient data).

Shepard and Emery had previously compared their survey and the USCGS 1883 survey and shallower soundings near the canyon head (south of the study area) indicated that a slide or a slump had occurred.

B. DIVER OBSERVATIONS

The area of study was broken into Subareas 1 through 7 (Fig. 14) in order to describe observations by the author using SCUBA.

Subarea 1 was entirely granodiorite from the shoreline to a depth of 65 ft. There appears to be no way that sediments could be transported across this barrier. Wave refraction studies [Dr. W.C. Thompson, personal communication] and heavy mineral analysis [Griffin, 1969] reinforce this assumption.

Subarea 2 is almost entirely covered with a thick layer (greater than 5 ft) of fine to coarse sand. One small granodiorite outcrop exists in approximately 25 ft of water just west of the Carmel River. Bottom slopes in the area range from nearly horizontal in shallow areas to 25° -30° in the southwestern corner of the area.

Subarea 3 is a combination of rock and sand bottom. There is no physical barrier to sand movement in any direction in this area.

Subarea 4 is entirely sand with the exception of one large granodiorite outcrop. This outcrop is narrow (25 ft to 50 ft) and long (approximately 100 yards) and is oriented parallel to the beach. On the western side of this unbroken outcrop, bottom slopes range from 5° to 20°. The bottom on the eastern side has very gentle slopes. Sand sizes on the western side are noticeably finer than on the eastern side. This large outcrop precludes any significant sediment transport in a westerly direction. Sediment movement in the area appears to be confined to the area between the beach and the outcrop and is generally in a southerly direction. The grain size of the sand gave evidence of much local erosion.

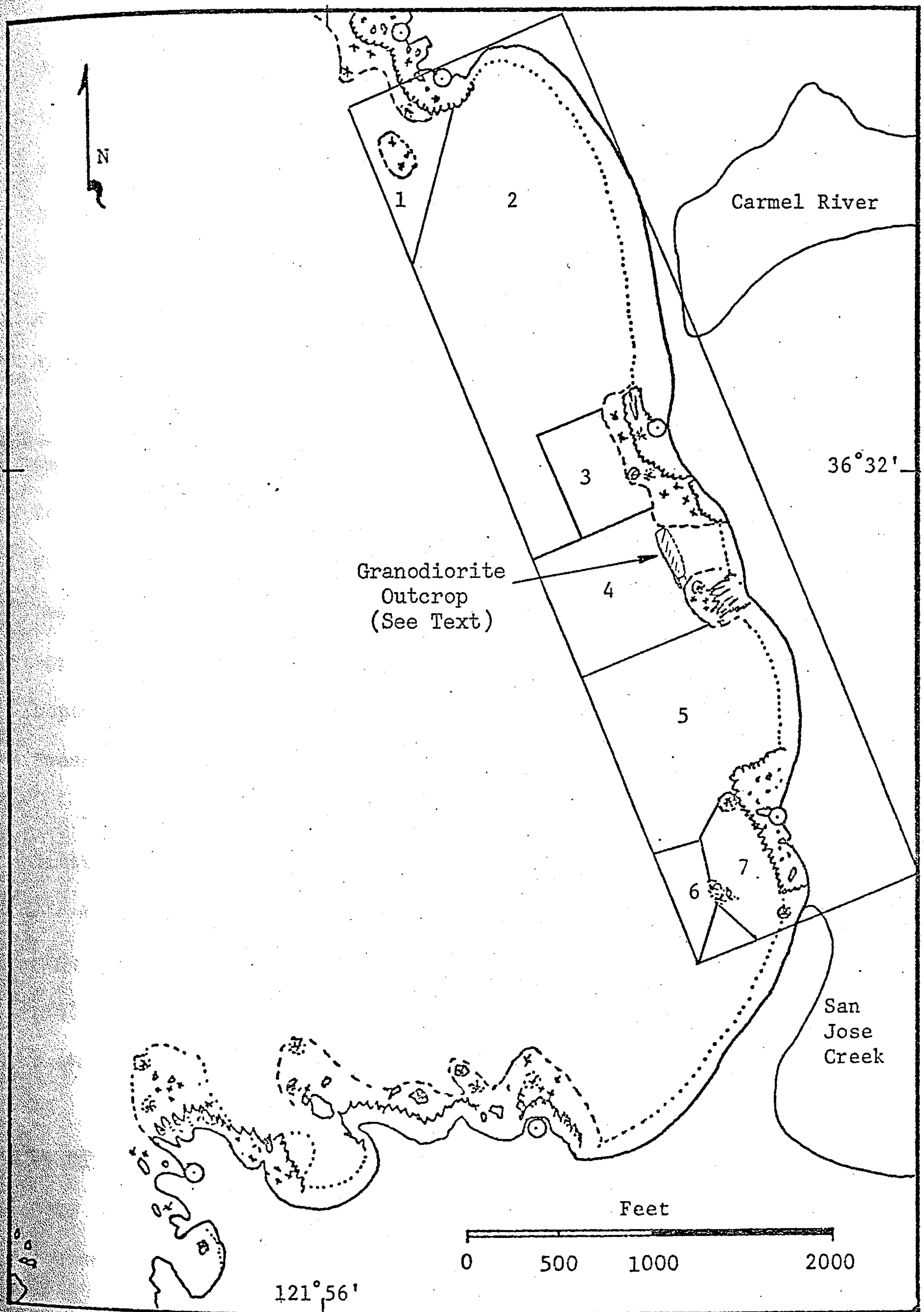

Figure 14. Subareas Surveyed Using SCUBA.

Subarea 5 contains the southern end of the granodiorite outcrop described in Subarea 4. The outcrop is broken in several locations near the end. Through these breaks there was evidence of sediment movement as large fans or aprons of sedimentary material existed at the base of each of the breaks. Some sediment movement was observed by the author. It is presumed that a large swell is required before large amounts of sediment are moved. The remainder of the area is covered with a very thick layer of very coarse sand.

Subarea 6 is located just seaward of a large rock outcrop that is west of the entrance on San Jose Creek. This outcrop is awash about 3 to 4 ft at low tide and is called the "washrock" by local divers. This area contains the head of the Carmel Canyon. Slopes in this area are no less than 40°. The bottom, although sides would probably be a more appropriate term, is entirely made up of large granodiorite boulders. Depths in the area reach 120 ft within a few tens of yards from the "washrock".

Subarea 7 is almost entirely rock covered. There appears to be little or no sediment transport across this area.

Subarea 5 is the most interesting area observed. Previous studies have described "sand chutes" along the north wall of the canyon head [Wallin, 1968]. The author noted some minor changes in the depths of the southern end of the subarea over the several dives that were accomplished. Significant changes in depth (greater than 25 ft) have been noted by Cdr. Don Ferrin, USN (Ret.) [personal communication] several times over the past 12 years. The subarea is almost entirely covered with coarse sand. Much of this appears to have been derived from outcrops in the near area.

C. LITTORAL DRIFT

Wave refraction diagrams constructed indicated that the littoral drift in the study area is south. Additionally, the drift along San Jose Creek Beach is to the north and a node exists just north of the head of the Carmel Canyon. The area of this node was described in a previous section (Subarea 5).

Stream mouths generally tend to migrate in the direction of littoral drift [U.S. Army Coastal Engineering Research Center, 1966]. Evidence of the southerly drift in the study area was given by a southerly migration of the mouth of the Carmel River after opening. The rate of this drift was observed to be dependent upon the wave activity and angle of incidence of the waves upon the beach. Further southward migration of the river mouth is prevented by rock outcrops. Evidence of the northerly drift along San Jose Creek Beach is given by the long-term northward migration of the mouth of San Jose Creek (Fig. 3).

D. CURRENT STUDIES

Current data obtained from the Savonius rotor meter was judged to be invalid. Moderate to heavy swell persisted during the entire week that the meter was in place. The bottom wave surge induced by this swell produced an excessive amount of scatter and an unreadable record resulted.

The ducted meter produced better results than the Savonius rotor model. Currents at the chosen station for the period that the meter was on the bottom were less than 0.2 knots and this, because of its oscillatory nature, was judged to be a component of wave surge. Currents in water less than 20 ft depth could not be obtained because of the hazards to divers and equipment in the surf zone.

Even minimal currents can be detected by a diver who is required to swim against them. During the entire study with the more than 20 dives that were completed, no currents were noted except when entering and leaving the surf zone. This observation reinforces the results obtained using the ducted meter.

E. SEDIMENT SIZE ANALYSIS

The tabulated results as obtained from the computer program are presented in Table I.

1. Mean Grain Size

The mean grain size of the samples taken ranged from 2.71Ø to -1.58Ø. Six of the samples were classified as fine sand, two as medium sand, three as coarse sand and seven as very coarse sand.

Sand-silt-clay-gravel relationships were computed and plotted on a sand-silt-gravel diagram similar to the tetrahedron scheme of Krumbein and Sloss [1963] (Fig. 15). "Gravel" refers to particles with mean grain sizes coarser than -1.0Ø and finer than -6.0Ø.

In general, mean grain size was larger nearshore and in the southern end of the study area (Fig. 16). Data from Carter [1971] were used to assist in the locating of the 3Ø contour. The seaward bend of the mean grain size contours in Subarea 5 probably indicates than sediments are being transported seaward in this area.

2. Standard Deviation

The values of standard deviation ranged from 0.41Ø to 1.35Ø. One sample was classed as poorly sorted. Two samples were well sorted, and 15 samples were moderately sorted. No trends were noted in this statistical measure. A mineral analysis of the samples might provide an insight into this parameter.

TABLE I

SEDIMENT SAMPLE SIZE STATISTICS

Sample No.	Latitude N	Longitude W	Depth ft	Folk and Ward Values: Mean phi	Dev. phi	Skew.	Kurt.
1	36-32.12	121-55.87	95	2.71	0.66	-0.13	0.97
2	36-32.11	121-55.81	80	2.44	0.57	-0.11	1.04
3	36-32.10	121-55.87	60	2.52	0.56	-0.11	1.05
4	36-32.10	121-55.75	40	1.76	0.69	0.01	0.91
5	36-32.09	121-55.72	20	-0.40	1.35	0.31	1.37
6	36-31.94	121-55.72	65	2.12	0.59	-0.17	1.12
7	36-31.93	121-55.68	40	2.24	0.46	-0.07	1.05
8	36-31.92	121-55.63	26	2.15	0.55	-0.07	0.99
9	36-31.79	121-55.63	70	0.64	0.54	0.05	1.01
10	36-31.78	121-55.59	50	-0.48	0.83	0.23	0.98
11	36-31.78	121-55.55	30	-0.69	0.84	-0.37	3.21
12	36-31.78	121-55.55	30	-0.94	0.98	0.26	2.48
13	36-32.38	121-55.79	00	1.18	0.71	-0.16	0.98
14	36-32.08	121-55.61	00	0.52	0.73	-0.16	1.01
15	36-31.90	121-55.53	00	-0.77	0.82	0.63	2.00
16	36-31.77	121-55.47	00	-1.58	0.41	-0.38	1.92
17	36-31.62	121-55.46	00	-1.57	0.56	-0.43	1.53
18	36-31.11	121-55.11	00	0.04	0.90	-0.08	1.03

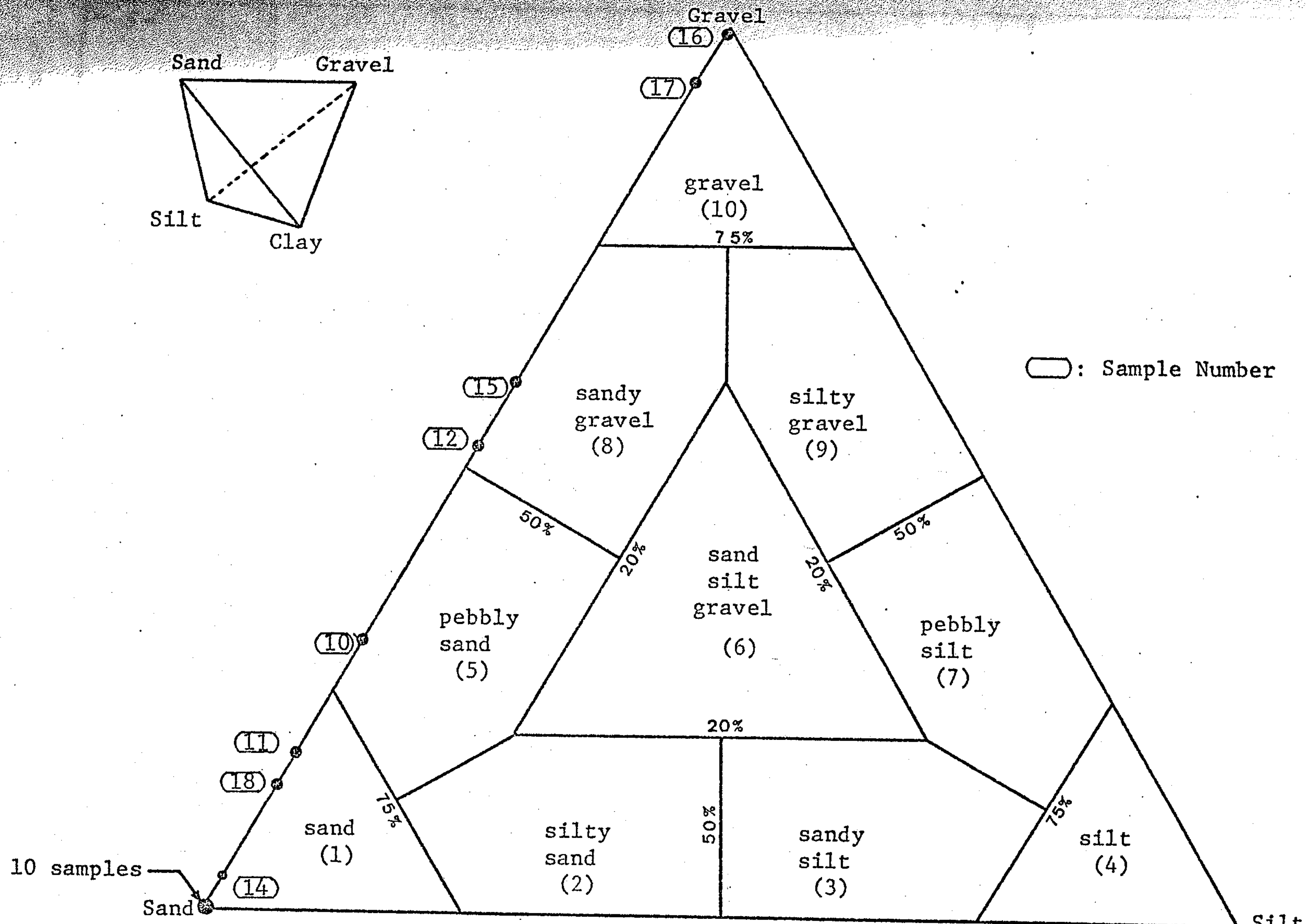

Figure 15. Tertiary Diagram: Sand-Silt-Gravel Relationships.
(After Krumbein and Sloss, 1963)

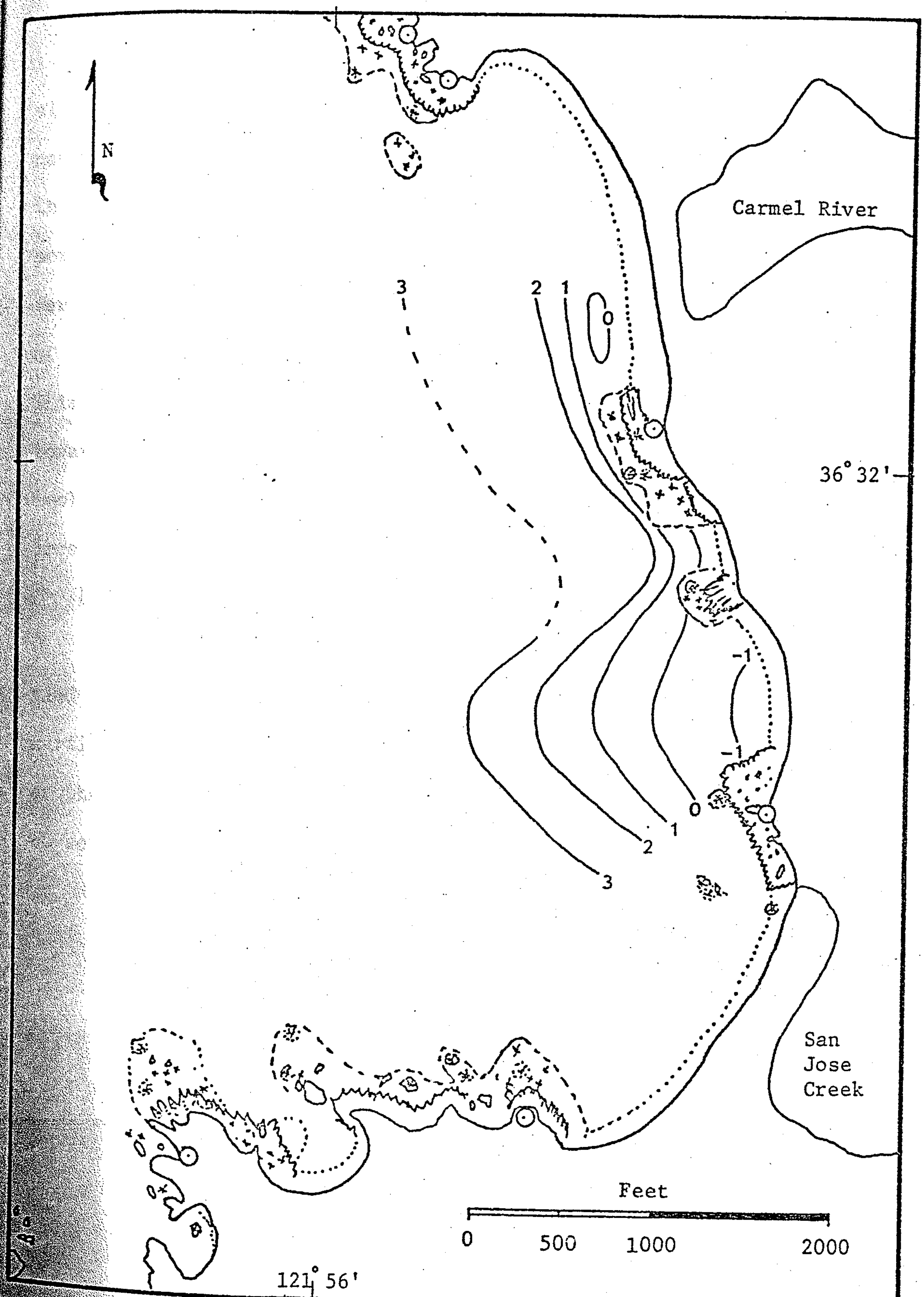

Figure 16. Sediment Mean Grain Size Distribution. (3Ø contour based partially on data from Carter, 1971.)

3. Skewness

Skewness values ranged from -0.43 to 0.63. Three samples were classified as very negatively skewed, six as negatively skewed, five as nearly symmetrical (one of these was sample Number 18 that was taken in the bed of the Carmel River), two were positively skewed and two very positively skewed. Sample Number 11, taken across a ripple crest, was very negatively skewed (-0.37). Sample Number 12, taken in the trough of the ripple from which sample Number 11 was taken, was positively skewed. This can be readily understood since positive skewness implies skewed toward the fine (more coarse material than fine) and negative skewness implies toward the coarse. The wave surge turbulence is greater at the crests, thus producing negative skewness.

4. Kurtosis

Kurtosis values ranged from 0.91 to 3.21. One sample was classified as extremely leptokurtic, four as very leptokurtic, three as leptokurtic and eleven as mesokurtic. The samples taken in the southern half of the study area and either in shallow water or on the beach face tended to be of a leptokurtic nature.

IV. SUMMARY AND CONCLUSIONS

Diver observations in the area showed that the sand transport in the study area is generally southward. This was both observed in the surf zone and surmised from the evidence of previous sand movement in the southern end of Subarea 4 and the northern end of Subarea 5.

The bathymetric survey provided an indication of sand deprivation in Subarea 4 and a slight seaward bending of depth contours in Subarea 5. Comparisons of the author's bathymetric chart with previous charts provided no real evidence of slumping or sliding. Previous studies have given some evidence for this [Shepard and Emery, 1941].

Littoral drift was determined by wave refraction diagrams to be south in the study area and north along San Jose Creek. A nodal point for sand transport exists just north of the head of the Carmel Canyon (Fig. 17).

Sediment size analysis reinforced the existence of a nodal point for sediment transport.

The two major sources of sedimentary material for the study area appear to be the Carmel River and local erosion of granodiorite outcrops. The Carmel River provides sediments only during the winter when precipitation is sufficient to create a flow. Local erosion of outcrops is continuous but larger during the winter when winter storms produce increased wave activity.

Materials provided by the Carmel River are moved south with the littoral drift, mixed with locally derived sediments and deposited along the north wall of the Carmel Canyon. Sediments provided by local erosion of outcrops south of San Jose Creek Beach are moved north with the

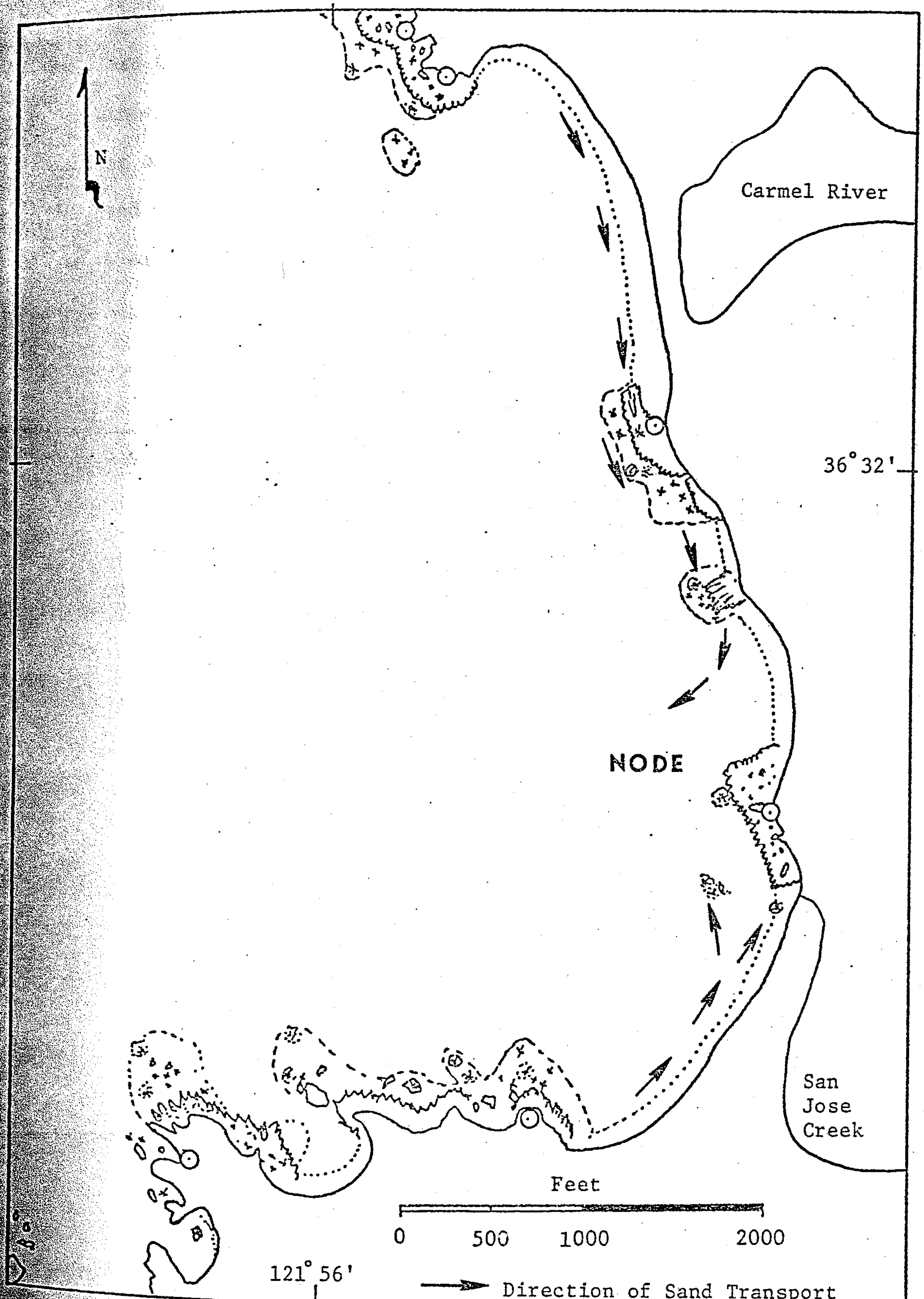

Figure 17. Summary of Sand Transport in the Area.

littoral drift, mixed with the small amount of sediments provided by San Jose Creek, and injected into the Carmel Canyon.

Winter storms probably provide the necessary energy to induce gravity sliding or slumping of deposited material. This material is dumped into the head of the Carmel Submarine Canyon for eventual deposition in the deep ocean.

V. SUGGESTIONS FOR FURTHER STUDIES

The following studies are presently being conducted within the bay:

1. sediment migration within Whaler's Cove (L. Leopold, San Jose State College, in progress);
2. gravity survey of Carmel Bay (A. Souto, NPS, in progress).

Future beneficial studies of the marine environment of the bay might include:

1. currents and tagged sand studies;
2. seismic refraction measurements;
3. heavy mineral analysis;
4. carbon, carbonate, and organic nitrogen analysis of sediments;
5. a sand budget for the bay.

APPENDIX A: SELECTED DIVER LOGS

DIVERS: Howell, Cronyn DATE: 16 October 1971

Subareas 4 and 5 were examined during this dive.

The divers entered the bay through the surf via a pocket beach approximately 300 yards south of the Carmel sewer outfall. Approximately 50 yards from the beach is an outcrop of granodiorite that is about 20 yards wide and ranges from 10 to 40 ft in depth. It is heavily encrusted with numerous encrusting organisms. The outcrop is lengthy and unbroken in its north-south direction and appears to act as a barrier to the sand not allowing beach sand to be transported seaward. Seaward of the outcrop the sand is noticeably finer and slopes gently downward until a depth of 60 ft, at which depth there was a marked increase in the slope.

DIVERS: Howell, Millward DATE: 23 October 1971

Subarea 3 and the southern end of Subarea 2 were examined during this dive.

The divers entered the bay through the surf via a pocket beach approximately 300 yards south of the Carmel sewer outfall. The break in the slope was located and the divers followed this slope in a northerly direction for about 200 yards. A 5-ft pole was pushed into the sand at regular intervals in order to determine sand thickness. In all cases the sand cover was greater than 5 ft. The divers then surfaced and swam to end of the temporary trestle that was being used to lay the Carmel sewer outfall line. Seaward of the trestle the bottom was similar to other sand bottoms in the area with small ripple marks and gentle slopes with an increase in the slope at approximately 60 ft depth.

DIVERS: Howell, Cronyn DATE: 29 October 1971

Subareas 6 and 7 were examined during this dive.

The divers entered the bay through the surf in the vicinity of San Jose Creek. After submerging just south of the wash rock, a very steep slope in the sand was noted. Although no angle measuring device was used, the slope appeared to be greater than 25°. Minor slides were readily started with just a kick of a flipper. The western portion of the wash rock is heavy granodiorite boulders with a very steep slope. No leveling out was noted up to a depth of 120 ft.

DIVERS: Howell, Cronyn, Millward DATE: 30 October 1971

Subarea 6 was examined during this dive.

The divers entered the bay through the surf in the vicinity of San Jose Creek. The bottom from the beach to the wash rock was checked for the sand channels that were previously noted by Wallin [1968]. These channels were not found nor were any significant sand deposits noted directly east of the wash rock. The dive commenced at the same location as the dive of 29 October 1971. A thorough investigation of the western side of the outcrop revealed no possible passages for sand to be transported. The sand on both sides of the outcrop contained large amounts of detritus (crab shell, broken kelp, etc.) and supported a substantial tubeworm population (approximate density 20 per ft^2). It was concluded that most of the sand introduced into the bay must be lost into the canyon north of San Jose Creek.

DIVERS: Howell, Mellor DATE: 30 November 1971

The divers attempted to launch the boat in Whaler's Cove, Point Lobos State Reserve, but were prevented because of high swell. During the night and early morning these swells had destroyed approximately one half of the trestle that had been erected for construction of the 600-ft Carmel sewer outfall. Large planks(approximately 6 inches x 8 inches) that had been bolted to piles driven into granite were destroyed. Needless to say, a dive was considered inappropriate. It was noted that the high tide for that day was an exceptionally high spring tide. This in conjunction with the large swell was the reason for the destruction.

DIVERS: Howell, Mellor DATE: 9 December 1971

Subarea 4 was examined during this dive.

The divers entered the bay via the boat ramp at Whaler's Cove at Point Lobos State Reserve in the boat. The purpose of the dive was to locate a position for placement of current meters. A position was located in 65 ft of water on a sand bottom with a slope of 17°, approximately 300 yards south of the Carmel sewer outfall pier. The bottom was very clean with fine white sand and small wave induced ripples.

APPENDIX B: COMPUTER PROGRAMS

COMPUTER DATA CARD FORMATS

WAVE REFRACTION PROGRAM

Card 1: Scale Card

Col. 1-10 chart scale (FORTRAN F10.4 format)

Example:

```
833.33
```

∴ scale: 833.33 ft = 1 inch

Card 2: Period and Crest Interval

Col. 1-2 wave period in sec

8-11 crest interval

Example:

```
10      2.0
```

period: 10 sec
crest interval: 2.0

SEDIMENT SIZE ANALYSIS PROGRAM

Cards 1 & 2: Title cards

Col. 1-80 of each card contain alphanumeric information to appear at the top of the output.

Card 3: Identifier for sample

Col. 1-9 cruise number
10-12 sample number
13-18 sample type
19-20 depth
21-22 month
23-24 day
25-28 year

Columns 1-28 can contain any legal keypunch character.

```
Col. 29-34 latitude    (XX XX.XX)
     35-40 longitude   (XX XX.XX) (First digit of longitude is
                                   determined from octant.)
     57-61 depth from top of core(XXXXX.)
     62-66 length of core (XXXXX.)
        79 octant (see below)
```

Example:

```
72-HOW-01 10DIVER 50 5251972363178215559                1
```

Cruise Number: 72-HOW-01

Sample Number: 10

Sample Type: DIVER

Depth: 50

Date: 5/25/1972

Latitude: 36°31.78'

Longitude: 121°55.59'

Card 4: Sample Detail Cards

```
Col. 41-44  phi size (absolute value) F4.2 (decimal assumed)
        45  sign of phi size (+ or -)
     50-56  fraction weight F7.4 (decimal assumed)
        80  end of data flag
            =8 if last phi size for this sample
            =9 if last phi size for all samples
```

Example:

```
                    100+          39456          8
```

Phi Size: +1.0

Sample Weight: 3.9456 g

Flag: 8

Coding for Octant of Geographic Position

Longitude East / Longitude West

	0° – 100°E	100°E – 180°W	180°W – 100°W	100°W – 0°
Latitude North (90°N – 0°)	6	5	1	2
Latitude South (0° – 90°S)	8	7	3	4

Sample of Computer Output for Wave Refraction Program.

WAVE PERIOD = 11 SECONDS WAVE LENGTH = 619.52 FEET

N = 1.00 SCALE: 1 IN. = 833.3 FEET

DEPTH		D/LO	L/LO	WAVE LENGTH		NL
FM.	FT.			ACTUAL FT.	CHART IN.	CHART IN.
1	6	0.010	0.244	150.86	0.18	0.18
2	12	0.019	0.341	211.15	0.25	0.25
3	18	0.029	0.413	255.90	0.31	0.31
4	24	0.039	0.472	292.37	0.35	0.35
5	30	0.048	0.522	323.38	0.39	0.39
6	36	0.058	0.566	350.42	0.42	0.42
7	42	0.068	0.604	374.36	0.45	0.45
8	48	0.077	0.639	395.79	0.47	0.47
9	54	0.087	0.670	415.12	0.50	0.50
10	60	0.097	0.698	432.65	0.52	0.52
15	90	0.145	0.807	500.00	0.60	0.60
20	120	0.194	0.878	543.78	0.65	0.65
25	150	0.242	0.924	572.17	0.69	0.69
30	180	0.291	0.953	590.13	0.71	0.71
40	240	0.387	0.981	607.69	0.73	0.73
50	300	0.484	0.990	613.61	0.74	0.74
60	360	0.581	0.993	615.46	0.74	0.74

Sample of Computer Output of the Sediment Size Analysis Program.

MARINE SEDIMENTS NEAR CARMEL RIVER STATE BEACH, CARMEL, CALIFORNIA

BUFORD F. HOWELL

CRUISE 72-HOW-01 SAMPLE NUMBER 5 DEPTH 20

SAMPLER TYPE DIVER DATE 5/25/1972 LAT. 36-32.09N LONG. 121-55.72W
DEPTH FROM TOP OF CORE 0. MM. LENGTH OF CORE 0. MM.

PHI SIZE	SAMPLE WEIGHT	FRACTION PERCENT	ACCUMULATED PERCENT
-3.00	1.9983	4.33	4.33
-2.50	0.4966	1.08	5.41
-2.00	1.3831	3.00	8.41
-1.50	3.0940	6.71	15.12
-1.00	10.5151	22.81	37.93
-0.50	11.0373	23.94	61.87
0.0	4.7591	10.32	72.19
0.50	3.2197	6.98	79.18
1.00	2.0965	4.55	83.72
1.50	2.5737	5.58	89.31
2.00	2.0364	4.42	93.72
2.50	1.7854	3.87	97.60
3.00	0.8432	1.83	99.43
3.50	0.2150	0.47	99.89
4.00	0.0499	0.11	100.00

POST-ANALYTICAL WEIGHT IS 46.1032

PHI SIZES AT PERCENT LEVEL OF

1 (C)	5	16	25	50 (M)	75	84	95	
-5.21	-2.68	-1.46	-1.21	-0.81	0.17	1.03	2.15	4 PT.
-5.21	-2.68	-1.47	-1.25	-0.75	0.19	1.02	2.13	LINEAR

SAND, SILT, CLAY, RELATIONSHIPS

GRAVEL	SAND	SILT	CLAY	TOTAL	SAND/MUD	TYPE
37.93	62.07	0.0	0.0	100.00	9999.99	SAND

TRASK VALUES 4 PT. PHIS

Q1	Q2	Q3	SO	LOG SO	SKG
2.305	1.756	0.887	1.613	0.208	0.81

INMAN VALUES

MEDIAN	MEAN	DEV.	SKEW.	2ND SKEW.	KURT.
-0.81	-0.22	1.24	0.48	0.44	0.94

FOLK AND WARD VALUE

MEAN	-0.42	VERY COARSE SAND
DEVIATION	1.35	POORLY SORTED
SKEWNESS	0.35	VERY POSITIVELY SKEWED
KURTOSIS	1.44	LEPTOKURTIC

TRASK VALUES LINEAR PHIS

Q1	Q2	Q3	SO	LOG SO	SKG
2.384	1.679	0.876	1.649	0.217	0.86

INMAN VALUES

MEDIAN	MEAN	DEV.	SKEW.	2ND SKEW.	KURT.
-0.75	-0.23	1.25	0.42	0.38	0.93

FOLK AND WARD VALUE

MEAN	-0.40	VERY COARSE SAND
DEVIATION	1.35	POORLY SORTED
SKEWNESS	0.31	VERY POSITIVELY SKEWED
KURTOSIS	1.37	LEPTOKURTIC

```
C*************************************************************
C
C         THIS PROGRAM IS DESIGNED TO OUTPUT THE NECESSARY
C         INFORMATION REQUIRED FOR MANUAL CONSTRUCTION OF
C         WAVE REFRACTION DIAGRAMS USING THE METHOD GIVEN IN
C         H. O. PUBLICATION 234. THE ONLY INPUTS REQUIRED
C         ARE:
C
C                    1. CHART SCALE
C                    2. WAVE PERIOD
C                    3. CREST INTERVAL
C
C         THE RATIO L/LO IS PROVIDED BY A SUBROUTINE THAT
C         USES THE NEWTON-S ITERATION METHOD TO SOLVE THE
C         EQUATICN L/LO=TANH(2*PI*D/L).
C
C*************************************************************

C
      COMMON/INPUT/PERIOD,DEPTH
      READ(5,50) SCALE
   50 FORMAT(F10.4)
      DO 1000 I=1,5
      READ(5,100)IPER,ZN
  100 FORMAT(I2,5X,F4.2)
      PERIOD=FLOAT(IPER)
C
COMMENT: CALCULATE THE DEEP WATER WAVE LENGTH (ZLO).
C
      ZLO=5.12*IPER**2
C
COMMENT: PRINT A TABLE HEADING.
C
      WRITE(6,200)I,IPER,ZLO,ZN,SCALE
  200 FORMAT('1'///42X'TABLE',I2,//15X'WAVE PERIOD = 'I2,
     *' SECONDS',10X,'WAVE LENGTH = 'F7.2,' FEET'//15X'N = '
     *F4.2,26X,'SCALE: 1 IN. =',F6.1,' FEET'/)
      WRITE(6,205)
  205 FORMAT(' '/,18X,'DEPTH'8X,'D/LO',6X,'L/LO',9X,'WAVE',
     *' LENGTH',7X,'NL',//,15X,' FM.  ',3X,'FT.',27X,'ACTUAL'
     *,'    CHART     CHART'/54X,' FT.      IN.       IN.')
      K=0
C
COMMENT: PROVIDE DEPTHS.
C
      DO 800 J=1,200
  210 IF(K.LE.9) GO TO 300
  220 IF(K.LE.25) GO TO 320
  230 IF(K.LE.90) GO TO 330
  240 IF(K.LE.1000) GO TO 340
  300 K=K+1
      GO TO 400
  320 K=K+5
      GO TO 400
  330 K=K+10
      GO TO 400
  340 K=K+25
  400 IFT=K*6
      RAT=IFT/ZLO
C
COMMENT:IF D/LO IS GREATER THAN .6, GO TO THE NEXT TABLE.
C
      IF (RAT.GT..6) GO TO 1000
      DEPTH=FLOAT(IFT)
C
COMMENT:CALL SUBROUTINE TO CALCULATE L.
C
      CALL WAVE (WAVEL)
C
COMMENT: CALCULATE L/LO.
C
      RATIO=WAVEL/ZLO
```

```
C
CCMMENT: CALCULATE DATA FOR CONSTRUCTION OF DIAGRAM.
C
      CHART=WAVEL/SCALE
      ANL=ZN*CHART
C
CCMMENT: PRINT RESULTS.
C
  600 WRITE(6,700)K,IFT,RAT,RATIO,WAVEL,CHART,ANL
  700 FORMAT('0',14X,I3,3X,I4,6X,F5.3,5X,F5.3,6X,F7.2,3X,
     *F4.2,5X,F4.2)
  800 CCNTINUE
      WRITE(6,900)
  900 FCRMAT(' ',/,130(1H-))
 1000 CCNTINUE
      STOP
      END


      SUBROUTINE WAVE(WAVEL)
      CCMMCN/INPUT/PERIOD,CEPTH
      EXTERNAL FCT
      DDPTH=DEPTH
      CALL ZERO(WAVEL,FV,DERF,FCT,DDPTH,.005,200,IER)
      RETURN
      END


      SUBROUTINE ZERO(X,F,DERF,FCT,XST,EPS,IEND,IER)
C
C           PURPOSE
COMMENT:    SOLVE THE GENERAL NCN-LINEAR EQUATIONS CF THE FORM
C           F(X)=0 BY MEANS OF THE NEWTCN-S ITERATICN METHOD.
C
      IER=0
      X=XST
      TOL=X
      CALL FCT(TOL,F,DERF)
      TCLF=100.*EPS
      DO 6 I=1,IEND
      IF(F.EQ.0.) GO TO 7
      IF(DERF.EQ.0.) GC TC 8
    2 CX=F/DERF
      X=X-DX
      TCL=X
      CALL FCT(TOL,F,DERF)
      TCL=EPS
      A=ABS(X)
      IF(A.GT.1.) TOL=TOL*A
      IF(ABS(DX).GT.TOL) GO TO 6
      IF(ABS(F).LE.TOLF) GC TO 7
    6 CCNTINUE
      IER=1
    7 RETURN
    8 IER=2
      RETURN
      END


      SUBRCUTINE FCT(X,F,CERF)
      COMMON/INPUT/PERIOD,DEPTH
      CATA GG/32./,TWOPI/6.28318/
      ARG=DEPTH*TWOPI/X
      F= GG*PERIOD**2/TWOPI-X/TANH(ARG)
      DERF=(-TANH(ARG)-ARG/COSH(ARG)**2)/TANH(ARG)**2
      RETURN
      END
```

```
C*************************************************************
C
C       SEDIMENT SIZE ANALYSIS MAIN PROGRAM
C
C*************************************************************
C
      COMMON /BLK1/PHIS(8,2),NINM,NFAW,NSSC,SUMNL,NTRSK
      REAL NEG/'-    '/
      DATA ANORTH/'N    '/,SOUTH/'S    '/,EAST/'E    '/,
     *WEST/'W    '/
      DIMENSION FRWT(100),PRCT(100),CRMC(20),STMC(20),
     *EXMC(20),CRMB(20),STMB(20),EXMB(20),ICR(20),JCR(20),
     *TATLE(20),TITLE(20)
      REAL*8    CRUZ,CRUZR,CRMB,CRMC,SMPLR
      DIMENSION T(100),PHI(100),ACPC(100)
      DATA KKK/0/,MAT/0/,MBT/0/,MED/0/,KSM/0/
      NINOT=1
  902 N2=1
      NA=1
      NZ=1
      NL=1
      NB=1
      M=0
      PAWT=0.
      DO 903 K=1,100
      T(K)=4.09
      ACPC(K)=999.99
      FRWT(K)=0.0
  903 PHI(K)=99.99
      MA=0
      MB=0
      MBT=0
      MC=0
      MED=0
      SUMWT=0.0
      SUMPC=0.0
      ACPC(1)=0.0
      READ(5,20) TITLE
   20 FORMAT(20A4)
      READ(5,21) TATLE
   21 FORMAT(20A4)
    1 NK=1
    2 READ(5,26)CRUZR,MCR,STATR,SMPLR,EXID,MO,DA,YR,LATA,
     *DEGLT,LNGA,DEGLN,PHIR,SIGN,BFWT,DEPTHR,CRLN,IQUD,NE
   26 FORMAT(A7,A2,A3,A6,3A2,A4,I2,F4.2,I2,2F4.2,A1,4X,F7.4,
     *2F5.0,12X,2I1)
      TIMES=1.
      IF(SIGN.EQ.NEG) TIMES=-1.
      PHIR=(TIMES*PHIR)
    3 IF(PHIR.LT.3.9) GO TO 29
      IF(NZ.EQ.1) GO TC 48
      IF(PHIR.LE.4.1) GO TO 46
      NZ=2
      GO TO 29
   46 NZ=1
      GO TO 44
   48 IF(NL.EQ.2) GO TO 44
      NL=2
      NZ=2
   29 FRWTR=BFWT
      IF(FRWTR.GE.0.) GO TO 52
      IF((FRWTR+.01).GE.0.) GC TO 25
      WRITE(6,51) FRWTR
   25 FRWTR=0.0
   52 PAWT=PAWT+FRWTR
      SUMWT=PAWT
      GC TO 49
   44 IF(NK.EQ.2) GO TO 59
      NK=2
      FWT1=BFWT*50.
      GO TO 2
   59 FWT2=BFWT*50.
```

```
      FRWTR=FWT1-FWT2
      IF(FRWTR.GE.0.) GO TO 53
      IF((FRWTR+0.01).GE.0.) GO TO 55
   60 WRITE(6,51) FRWTR
   51 FORMAT(25X, 'WEIGHING ERROR. FRACTION WEIGHT WAS ',
     *F10.4,' BEFORE BEING SET TO ZERO')
   55 FRWTR=0.0
   53 FWT1=FWT2
      NINCT=2
      IF(NE.LT.8) GO TO 52
   54 PAWT=PAWT+FRWTR+FWT2
      SUMWT=PAWT
      K=K+1
      M=M+1
      KK=KK+1
      PHI(K)=PHIR
      FRWT(K)=FRWTR
      K=K+1
      M=M+1
      KK=KK+1
      FRWT(K)=FWT2
      PHI(K)=12.
      IF(PHIR.LE.11.) PHI(K)=PHIR+1.
      GO TO 100
   49 IF(NA.EQ.2) GO TO 50
      NA=2
C     DETERMINE OCTANT FROM FIRST CARD OF SAMPLE
      DK=WEST
      IDH=LNGA
      IF(IQUD-2) 8,9,11
    8 IDH=IDH+100
    9 DG=ANORTH
      GO TO 23
   11 IF(IQUD-4) 12,13,15
   12 IDH=IDH+100
   13 DG=SOUTH
      GO TO 23
   15 DK=EAST
      IF(IQUD-6) 17,16,19
   17 IDH=IDH+100
   16 DG=ANORTH
      GO TO 23
   19 IF(IQUD.GE.8) IDH=IDH+100
      DG=SOUTH
   23 CRUZ=CRUZR
      NCR=MCR
      STAT=STATR
      EXC=EXID
      DPTH=DEPTHR
      WRITE (6,799) TITLE
  799 FORMAT('1',26X,20A4)
      WRITE(6,800)TATLE
  800 FORMAT('0',26X,20A4//)
      WRITE (6,801) CRUZ,NCR,STAT,EXC,SMPLR,MO,DA,YR,LATA,
     *DEGLT,DG,IDH,DEGLN,DK,DEPTHR,CRLM
  801 FORMAT(/36X,'CRUISE ',A7,A2,' SAMPLE NUMBER ',A3,
     *' DEPTH ',A2//25X,' SAMPLER TYPE ',A6,' DATE ',A2,'/',
     *A2,'/',A4,' LAT. ',I2,'-',F5.2,A1,' LONG. ',I3.
     *'-',F5.2,A1/26X,'DEPTH FROM TOP OF CORE ',F7.0,
     *' MM.    LENGTH OF CORE ',F7.0,' MM.')
      NB=2
      KK=0
      K=0
      IF(FRWTR.NE.0.) N2=3
      PHIA=-12.0
      GO TO 1
C     SAVE PHI & FRACTION WT. FROM EACH DETAIL CARD
   50 KK=KK+1
```

```
      K=K+1
      PHI(K)=PHIR
      FRWT(K)=FRWTR
      IF(NE.GE.8) GO TO 100
C     SET FLAG (N2=2) IF NEW PHI LESS THAN LAST PHI
      IF(PHIA.GE.PHIR) N2=2
      PHIA=PHIR
      M=M+1
      IF(NINOT-1) 1,1,2
  100 M=K
C     DETERMINE FRACTION PERCENTS AND ACCUMULATED %
      DO 67 K=1,M
      PRCT(K)=(FRWT(K)/PAWT)*100.
      SUMPC=SUMPC+PRCT(K)
      ACPC(K)=SUMPC
   67 CONTINUE
      CALL TVAL(T,ACPC,M)
      IF(SUMPC.LT.99.94.OR.SUMPC.GT.100.06) GO TO 1500
      IF(N2-2) 103,1666,1990
  103 WRITE(6,802) (PHI(J),FRWT(J),PRCT(J),ACPC(J),J=1,KK)
  802 FORMAT('0',40X,'PHI    SAMPLE  FRACTION  ACCUMULATED',
     */41X,'SIZE   WEIGHT  PERCENT      PERCENT'/(40X,F6.2,
     *F8.4,F8.2,F12.2))
      KJK=KK
      WRITE (6,79) PAWT
   79 FORMAT( /40X,'POST-ANALYTICAL WEIGHT IS',F9.4)
      SUMNL=ACPC(KK)
      NSSC=2
      NTRSK=1
      NINM=1
      NFAW=1
      JJ=0
      DO 77 I=1,KK
      IF(FRWT(I).EQ.0.) GO TO 77
      JJ=JJ+1
      T(JJ)=T(I)
      ACPC(JJ)=ACPC(I)
      PHI(JJ)=PHI(I)
   77 CONTINUE
      KK=JJ
      KJK=JJ
      IF(SUMNL.GE.72.0) GO TO 105
      NSSC=1
      WRITE(6,809) PHI(KK)
  809 FORMAT('0',29X,'DID NOT INTERPOLATE ANY PHI SIZES',
     *' BECAUSE'/29X,'ACCUMULATED PERCENT AT ',F5.2,
     *' DID NOT EXCEED'/29X,'72 PERCENT')
      GO TO 160
  105 IF(4.LT.KK) GO TO 111
      WRITE(6,815) KK
  815 FORMAT(' ',28X,' ONLY ',I3,' DETAIL CARDS SO ONLY',
     *' SAND.'/30X,'SILT, CLAY RELATIONSHIPS CALCULATED.')
      GO TO 901
C     COMPUTE T-VALUES
  111 CALL INTRP(ACPC,PHI,T,KK)
  160 CALL SNSTCL(PHI,ACPC,SUMPC,KJK)
      CALL CTIFW
C     INCREMENT COUNTERS AND GO TO NEXT SAMPLE
  901 KKK=KKK+KK+1
      KSM=KSM+1
      I=I+1
      NINOT=2
      IF(NE.NE.9) GO TO 902
```

```
C       PRINT RESULTS AND MESSAGES
  950 WRITE(6,860) KSM,KKK
  860 FORMAT('1',30X,'THIS BATCH OF CARDS CONTAINED DATA',
     *' FROM ',I4,' SAMPLES'/30X,' FOR A TOTAL OF ',I4,
     *' CARDS.')
      IF(MBT.GT.0) WRITE(6,863) (CRMB(L),ICR(L),STMB(L),
     *EXMB(L),L=1,MBT)
  863 FORMAT('0',29X,'CARDS OUT OF ORDER ON THE FOLLOWING',
     1' SAMPLES'/31X,'CRUISE',5X,'SAMPLE ',5X,'DEPTH'//,
     2(33X,A7,A2,A3,A2))
      IF(MC.GT.0) WRITE(6,864) (CRMC(L) ,JCR(L),STMC(L),
     1EXMC(L),L=1,MC)
  864 FORMAT('0',29X,'NO ZERO PERCENT CARDS ON THE',
     1' FOLLOWING STATIONS'/31X,'CRUISE,5X,'SAMPLE ',5X,
     2'DEPTH'//(33X,A7,A2,A3,A2))
      MTT=MBT+MC+MED
      IF(MTT.GT.0) GO TO 959
      WRITE(6,861)
  861 FORMAT('0',30X,'CONGRATULATIONS    NO ERRORS WERE',
     1' FOUND IN THIS BATCH OF CARDS')
      GO TO 960
  959 WRITE (6,865) MTT
  865 FORMAT('0',29X,'SORRY OLD CHAP, BUT YOU MADE ',I3,
     1' ERRORS ON THE DATA'/30X,FOR THIS RUN. NEXT TIME BE '
     2' MORE CAREFUL')
  960 RETURN
 1666 WRITE(6,8666)
 8666 FORMAT('0',29X,'CARDS OUT OF ORDER. CHECK VALUES',
     1'BELOW')
      MBT=MBT+1
      CRMB(MBT)=CRUZ
      ICR(MBT)=NCR
      STMB(MBT)=STAT
      EXMB(MBT)=EXC
      GO TO 1501
 1990 WRITE(6,8990)
 8990 FORMAT('0',28X,'NO ZERO PERCENT CARD.'/30X,'CHECK',
     1' VALUES BELOW.')
      MC=MC+1
      CRMC(MC)=CRUZ
      JCR(MC)=NCR
      STMC(MC)=STAT
      EXMC(MC)=EXC
      GO TO 1501
 1500 WRITE(6,830) PAWT
  830 FORMAT('0',32X,'SUM OF FRACTION WEIGHTS DID NOT ',
     1'EQUAL POST ANALYTICAL WEIGHT '/32X,'WHICH WAS ',
     2F8.3,' . CHECK THE VALUES BELOW FOR ERRORS.')
 1501 WRITE(6,831)
  831 FORMAT('0',40X,' PHI   FRACTION   FRACTION   ACCUM.   T-',
     1/41X,' SIZE  WEIGHT    PERCENT    PRCT   VALUE')
      WRITE(6,833) (PHI(J),FRWT(J),PRCT(J),ACPC(J),T(J),
     1J=1,KK)
  833 FORMAT('0',40X,F5.2,F9.3,F9.2,F8.2,F7.3)
      WRITE(6,8333) SUMWT
 8333 FORMAT('0',29X,'SUM FRACTION WEIGHTS = ',F8.3,' GRAMS'
     1)
      MED=MED+1
      GO TO 901
  999 RETURN
      END
C
```

```
C*****************************************************************
C
C       INTERPOLATION SUBPROGRAM
C
C*****************************************************************


      SUBROUTINE INTRP(ACPC,PHI,T,KK)
      DIMENSION ACPC(1),PHI(1),T(1)
      COMMON /BLK1/PHIS(8,2),NINM,NFAW,NSSC,SUMNL,NTRSK
      REAL   PC(8)/1.,5.,16.,25.,50.,75.,84.,95./,
     1XTT(8)/-2.325,-1.645,-.995,-.674,0.0,.674..995,1.645/
      PHIS(6,1)=99.99
      PHIS(6,2)=99.99
      PHIS(7,1)=99.99
      PHIS(7,2)=99.99
      PHIS(8,1)=99.99
      PHIS(8,2)=99.99
      NINT=0
 1101 IF(NINT.EQ.0) GO TO 1102
      PHIS(NINT,1)=YYA
      PHIS(NINT,2)=YYL
 1102 NINT=NINT+1
      XPC=PC(NINT)
      XT=XTT(NINT)
      DO 151 L=1,KK
      IF(ACPC(L)-XPC) 151,152,153
  151 CONTINUE
  152 YYA=PHI(L)
      YYL=PHI(L)
      GO TO 210
  153 IF(XPC-75.0) 154,155,157
  155 IF(SUMNL.GE.75.0) GO TO 156
      NINT=9
      GO TO 1197
  157 IF(XPC.GT.84.0) GO TO 159
      IF(SUMNL.LT.84.) GO TO 168
  156 IF(L-KK) 195,197,197
  159 IF(SUMNL-95.0) 169,156,156
  168 IF(SUMNL.LT.81.0) GO TO 1475
      NINT=10
      GO TO 1197
  169 IF(SUMNL.LT.92.0) GO TO 1476
      NINT=11
 1197 XT=XTT(NINT-3)
      GO TO 197
  154 IF(L.LE.2) GO TO 196
  195 LA=2
      GO TO 199
  196 LA=1
      GO TO 199
  197 LA=3
  199 LS=L-LA
      X=XT
      X1=T(LS)
      X2=T(LS+1)
      X3=T(LS+2)
      X4=T(LS+3)
      Y1=PHI(LS)
      Y2=PHI(LS+1)
      Y3=PHI(LS+2)
      Y4=PHI(LS+3)
C
C     AITKENS FOUR POINT INTERPOLATION
C
      P12=((Y1*(X2-X))-(Y2*(X1-X)))/(X2-X1)
      P13=((Y1*(X3-X))-(Y3*(X1-X)))/(X3-X1)
      P14=((Y1*(X4-X))-(Y4*(X1-X)))/(X4-X1)
      P123=((P12*(X3-X))-(P13*(X2-X)))/(X3-X2)
      P124=((P12*(X4-X))-(P14*(X2-X)))/(X4-X2)
      YYA=((P123*(X4-X))-(P124*(X3-X)))/(X4-X3)
```

```
C       LINEAR INTERPOLATION
        X11=T(L-1)
        X22=T(L)
        Y11=PHI(L-1)
        Y22=PHI(L)
        YYL=(X-X11)*(Y22-Y11)/(X22-X11)+Y11
        IF(L.LE.2) YYA=YYL
  210   IF(NINT.LT.8) GO TO 1101
        INI=NINT-7
        PHIS(NINT,1)=YYA
        PHIS(NINT,2)=YYL
        WRITE(6,803) ((PHIS(II,K),II=1,8),K=1,2)
  803   FORMAT('0',29X,'PHI SIZES AT PERCENT LEVEL OF    '
      1  /32X,'1 (C)       5          16',7X,'25',7X,'50 (M)     75'
      2,7X,'84',7X,'95'/27X,8F9.2,' 4 PT.
      3' LINEAR')
        RETURN
 1275   NM3=NINT-3
        PHIS(NM3,1)=YYA
        PHIS(NM3,2)=YYL
        IPH=NM3
        IPER=PC(NM3)
        IF(NINT.EQ.11) NFAW=2
 1300   WRITE (6,1301) IPER,((PHIS(II,K),II=1,8  ),K=1,2)
 1301   FORMAT('0',29X,'PHI SIZES AT PERCENT LEVEL OF    (',I2,
      1' LEVEL EXTRAPOLATED)'/32X,1(C)',6X,'5',7X,'16',7X,
      2'25',7X,'50(M)   75',7X,'84'/30X,F5.2,7F9.2,' 4 PT.'/,
      330X,F5.2,7F9.2,' LINEAR')
        RETURN
 1475   IPER=84
        NINM=2
        GO TO 1400
 1476   NFAW=2
        IPER=95
        GO TO 1400
 1400   WRITE (6,1401) IPER,((PHIS(II,K),II=1,8  ),K=1,2)
 1401   FORMAT('0',29X,'PHI SIZES AT PERCENT LEVEL OF (',I2,
      1' LEVEL EXTRAPOLATED)'/32X,1(C)',6X,'5',7X,'16',7X,
      2'25',7X,'50(M)   75',7X,'84'/30X,F5.2,7F9.2,' 4 PT.'/,
      330X,F5.2,7F9.2,' LINEAR')
        RETURN
        END
C
C**************************************************************
C
C       SUBPROGRAM WHICH IS THE EQUIVALENT OF PLOTTING, BY
C       HAND, THE GRAIN SIZE AGAINST THE ACCUMULATED
C       PERCENTAGE.

C**************************************************************

        SUBROUTINE TVAL(T,ACPC,M)
        DIMENSION T(1),ACPC(1)
        REAL TBLPC(87)/0.0,01.20,03.59,04.78,05.96,07.14,08.32
      *  ,09.48,
      1  10.64,11.79,12.93,14.06,15.17,16.28,17.36,18.44,19.50
      *  20.54,
      2  21.57,22.57,23.57,24.54,25.49,26.42,27.34,28.23,29.10
      *  ,29.95,
      3  30.78,31.59,32.38,33.15,33.89,34.61,35.31,35.99,36.65
      *  ,37.29,
      4  37.90,38.49,39.07,39.62,40.15,40.66,41.15,41.62,42.07
      *  ,42.51,
      5  42.92,43.32,43.70,44.06,44.41,44.74,45.05,45.35,45.64
      *  ,45.91,
      6  46.16,46.41,46.64,46.86,47.06,47.26,47.44,47.61,47.78
      *  ,47.93,
      7  48.08,48.21,48.34,48.46,48.57,48.68,48.78,48.87,48.96
      *  ,49.04,
      8  49.11,49.20,49.31,49.40,49.60,49.70,49.80,49.90,50.0/
```

```
      REAL TBLT(87)/0.00,0.03,0.09,0.12,0.15,0.18,0.21,0.24,
     *     0.27,0.30,
     1     0.33,0.36,0.39,0.42,0.45,0.48,0.51,0.54,0.57,0.60,
     *     0.63,0.66,
     2     0.69,0.72,0.75,0.78,0.81,0.84,0.87,0.90,0.93,0.96,
     *     0.99,1.02,
     3     1.05,1.08,1.11,1.14,1.17,1.20,1.23,1.26,1.29,1.32,
     *     1.35,1.38,
     4     1.41,1.44,1.47,1.50,1.53,1.56,1.59,1.62,1.65,1.68,
     *     1.71,1.74,
     5     1.77,1.80,1.83,1.86,1.89,1.92,1.95,1.98,2.01,2.04,
     *     2.07,2.10,
     6     2.13,2.16,2.19,2.22,2.25,2.28,2.31,2.34,2.37,2.41,
     *     2.46,2.51,
     7     2.65,2.75,2.88,3.08,4.09/
C     CALCULATE T-VALUE
      DO 68 K=1,M
      IF(ACPC(K).LT.100.0) GO TO 62
   61 T(K)=4.09
      GO TO 68
   62 DLPC=ACPC(K)-50.
      IF(DLPC) 64,63,65
   63 T(K)=0.0
      GO TO 68
   64 GMPC=-DLPC
      GO TO 66
   65 GMPC=DLPC
   66 DO 69 L=1,87
      IF(TBLPC(L)-GMPC) 69,70,71
   69 CONTINUE
   70 TCALC=TBLT(L)
      GO TO 72
   71 TCALC=(GMPC-TBLPC(L-1))*(TBLT(L)-TBLT(L-1))/
     * TBLPC(L)-TBLPC(L-1))+TBLT(L-1)
      IF(TCALC.GT.4.09) GO TO 61
   72 IF(DLPC.GE.0.0) GO TO 74
      TCALC=-TCALC
   74 T(K)=TCALC
   68 CONTINUE
      RETURN
      END
C
C*************************************************************
C
C     SUBPROGRAM FOR COMPUTING SAND-SILT-CLAY RELATIONSHIPS
C
C*************************************************************

      SUBROUTINE SNSTCL(PHI,ACPC,SUMPC,KJK)
      DIMENSION PHI(1),T(1),ACPC(1)
      REAL*8 CLASS(9)/' SAND     SILT     CLAY     SANDY   '
     1,'SILTY  CLAYEY        -SILT    -CLAY    '/
      INTEGER SUBS(33)/1,7,7,2,7,7,3,7,7,1,8,9,5,1,7,4,2,7,6
     *,1,7,6,2,7,
     14,3,7,5,3,7,7,7,7/
      NI=0
      RATIO=9999.99
      GRSN=0.0
      SAND=0.0
      SILT=0.0
      CLAY=0.0
      SANDP=0.0
      IF(PHI(KJK).LT.-1.0) GO TO 380
      DO 302 KG=1,KJK
      IF(ABS(PHI(KG)+1.0).LE..0001) GO TO 303
      IF(PHI(KG)+1.0) 302,303,307
  302 CONTINUE
  303 GRSN=ACPC(KG)
  307 IF(PHI(KJK).LT.4.0) GO TO 312
```

```
      DO 309 KS=1,KJK
      IF(ABS(PHI(KS)-4.0).LE..0001) GO TO 310
      IF(PHI(KS)-4.0) 309,310,313
  309 CONTINUE
  310 SAND=ACPC(KS)
      SANDP=SAND-GRSN
      FMUD=SUMPC-SAND
      IF(FMUD.NE.0.) RATIO=SAND/FMUD
      GO TO 313
  312 SAND=SUMPC-GRSN
      SANDP=SAND
      GO TO 380
  313 IF(ABS(PHI(KJK)-8.0).LE..0001) GO TO 314
      IF(PHI(KJK).LT.8.0) GO TO 317
  314 DO 315 KSL=1,KJK
      IF(ABS(PHI(KSL)-8.0).LE..0001) GO TO 316
      IF(PHI(KSL).GE.8.0) GO TO 316
  315 CONTINUE
  316 SILT=ACPC(KSL)-SAND
      CLAY=SUMPC-SAND-SILT
      GO TO 320
  317 SILT=SUMPC-SAND
  320 NI=1
      IF(SAND.GE.75.0) GO TO 380
      NI=2
      IF(SILT.GE.75.0) GO TO 380
      NI=3
      IF(CLAY.GE.75.0) GO TO 380
      NI=4
      IF(SAND.GE.20.0.OR.SILT.GE.20.0.OR.CLAY.GE.20.0)
     *   GO TO 380
      N4=1
      IF(CLAY/SILT.LT.1.) N4=2
      IF(SAND/SILT.LT.1.) GO TO (341,334),N4
      GO TO (334,336),N4
  334 IF(CLAY/SAND.LT.1.) GO TO (338,337),N4
      GO TO (340,339),N4
  336 NI=5
      GO TO 380
  337 NI=6
      GO TO 380
  338 NI=7
      GO TO 380
  339 NI=8
      GO TO 380
  340 NI=9
      GO TO 380
  341 NI=10
  380 WRITE(6,804)
  804 FORMAT('0',28X,' SAND, SILT, CLAY, RELATIONSHIPS'/30X,
     1'  GRAVEL      SAND      SILT      CLAY      TOTAL    '
     2,'SAND/MUD    TYPE')
      NN=3*(NI-1)+1
      N1=SUBS(NN)
      N2=SUBS(NN+1)
      N3=SUBS(NN+2)
      WRITE(6,87) GRSN,SANDP,SILT,CLAY,SUMPC,RATIO,CLASS(N1)
     * CLASS(M2),
     1 CLASS(N3)
   87 FORMAT(' ',29X,F8.2,5F9.2,3X,3A6)
      RETURN
      END
C
```

```
C*************************************************************************
C
C      SUBPRCGRAM FCR CCMPUTING TRASK, INMAN, AND FOLK AND
C      WARD STATISTICS.
C
C*************************************************************************

      SUBROUTINE CTIFW
      CCMMCN /BLK1/PHIS(8,2),NINM,NFAW,NSSC,SUMNL,NTRSK
      REAL*8 ZMEN(20)/'VERY COARSE SANDCCARSE SAND      MEDIU
     1M SAND        FINE SAND          VERY FINE SAND   COARSE SILT
     2       MEDIUM SILT       FINE SILT          VERY FINE SILT
     3CLAY              '/
      REAL*8 DEVI(18)/'VERY WELL SORTED           WELL SORTED
     *           MODERATELY SORTED          POORLY SCRTED
     *    VERY POORLY SCRTED        EXTREMELY POORLY SCRTED'/
      REAL*8 SKEW(15)/'VERY NEGATIVELY SKEWED  NEGATIVELY SK
     1EWED          NEARLY SYMMETRICAL        POSITIVELY SKEWED
     2        VERY POSITIVELY SKEWED   '/
      REAL*8 KURT(15)/'PLAYTKURTIC                   MESOKURTIC
     1              LEPTOKURTIC               VERY LEPTCKURTIC
     2       EXTREMELY LEPTOKURTIC    '/
      REAL TLFC(7)/0.0,0.35,0.50,1.,2.,4.,99.99/,TLFS(6)/-3.
     *,-.3,-.1,
     1.3,9.99/,TLFK(6)/0.,.9,1.11,1.5,3.,99.99/
      REAL HEAD(6)/'4 PT. PHIS  LINEAR PHIS '/
      INTEGER ITLFSC(6)/2*1,2,3,4,5/
      DC 1000 LL=1,2
      IF(NSSC.EQ.1) GC TC 400
C     CALCULATE TRASK VALUES
      PHI5=PHIS(2,LL)
      PHI16=PHIS(3,LL)
      PHI25=PHIS(4,LL)
      PHI50=PHIS(5,LL)
      PHI75=PHIS(6,LL)
      PHI84=PHIS(7,LL)
      PHI95=PHIS(8,LL)
      Q1=2.**(-PHI25)
      Q2=2.**(-PHI50)
      Q3=2.**(-PHI75)
      SO=SQRT(Q1/Q3)
      FLGSO=ALOG10(SO)
      SKG=SQRT((Q1*Q3)/(Q2*Q2))
      LLL=3*(LL-1)+1
      LLT=LLL+2
      WRITE(6,805)(HEAD(LLK),LLK=LLL,LLT),Q1,Q2,Q3,SO,FLGSO,
     *29X,'    Q1          Q2          Q3          SO        LOG SO
     *SKG'/30X,F6.3,4F9.3,F8.2)
      IF(NTRSK.GT.1) GC TC 1000
C     CALCULATE INMAN VALUES
      IF(NINM.GT.1) GO TO 505
      FIMD=(PHI16+PHI84)/2.0
      FIDV=(PHI84-PHI16)/2.0
      FISK=(FIMD-PHI50)/FIDV
      IF(PHI95.EQ. 99.99) GO TO 504
      F2SK=(((PHI95+PHI5)/2.)-PHI50)/FIDV
      FIKU=(((PHI95-PHI5)/2.)-FIDV )/FIDV
      WRITE(6,806) PHI50,FIMD,FIDV,FISK,F2SK,FIKU
  806 FORMAT('0',29X,'INMAN VALUES'/32X,'MEDIAN     MEAN',5X,
     1'DEV.      SKEWED.    2ND SKEW.      KURT.'/32X,
     2F5.2,3F9.2,2F11.2)
      GO TO 600
  504 WRITE(6,92) PHI50,FIMD,FIDV,FISK
     1'ND SKEWNESS AND KURTOSIS)'/30X,'MEDIAN     MEAN        '
     1,'DEV.      SKEW.'/30X,F5.2,3F9.2)
      GO TO 600
  505 WRITE(6,93)
```

```
   93 FORMAT('0',28X,' INMAN PLUS FOLK AND WARD VALUES NOT '
     1'CALCULATED BECAUSE'/29X, ' NEXT TO LAST ACCUMULATED '
     2PERCENT WAS LESS THAN 84')
      GO TO 1000
  400 WRITE(6,91)
   91 FORMAT('0',28X,' NCT ABLE TO CALCULATE TRASK, INMAN, '
     *,' OR FCLK AND WARD'/29X,
     *' VALUES BECAUSE NEXT TO LAST ACCUMULATED PERCENT DID'
     *,' NOT'/29X,' EXCEED 72')
      GO TO 1000
C     CALCULATE FOLK AND WARD VALUES
  600 IF(NFAW.EQ.1) GO TC 601
      WRITE (6,94)
   94 FORMAT('0',29X,'COULD NOT CALCULATE FOLK AND WARD'
     *' VALUES BECAUSE NEXT'/30X,'TO LAST ACCUMULATED PERCEN
     *,'NT DID NOT EXCEED 92.')
C     CCMPUTE MEAN AND DETERMINE CATEGORY
  601 FMZ=(PHI16+PHI50+PHI84)/3.0
      DC 300 I=1,10
      ZVAL=I-1
      IF(FMZ.LT.ZVAL) GO TO 301
  300 CONTINUE
      I=10
  301 I1=2*(I-1)+1
      I2=I1+1
      WRITE (6,8C7) FMZ,(ZMEN(II),II=I1,I2)
  807 FORMAT('0',29X,'FOLK AND WARD VALUE'/31X,'MEAN',F12.2,
     14X,2A8)
C     COMPUTE DEVIATION AND DETERMINE CATEGORY
      FDEV=(PHI84-PHI16)/4.+(PHI95-PHI5)/6.6
      DO 604 L=1,7
      IF(TLFD(L).GE.FDEV) GC TC 605
  604 CONTINUE
  605 IFCTL=L-1
      IF(IFDTL.EQ.0) IFDTL=1
      I1=3*(IFDTL-1)+1
      I2=I1+2
      WRITE (6,131) FDEV,(CEVI(II),II=I1,I2)
  131 FORMAT(31X,'DEVIATION',F7.2,4X,3A8)
C     COMPUTE SKEWNESS AND DETERMINE CATEGORY
      FSK=(PHI16+PHI84-2.0*PHI50)/(2.*(PHI84-PHI16))+
     1 ((PHI 5+PHI95)-(2.*PHI50))/(2.*(PHI95-PHI5))
      DO 608 L=1,6
      IF(TLFS(L).GE.FSK) GO TO 609
  6C8 CONTINUE
  609 IFSKTL=ITLFSC(L)
      I1=3*(IFSKTL-1)+1
      I2=I1+2
      WRITE(6,142) FSK,(SKEW(II),II=I1,I2)
  142 FCRMAT(31X,'SKEWNESS',F8.2,4X,3A8)
C     COMPUTE KURTOSIS AND DETERMINE CATEGORY
      FKG=(PHI95-PHI5)/(2.44*(PHI75-PHI25))
      DO 612 L=1,6
      IF(TLFK(L).GE.FKG) GO TO 613
  612 CONTINUE
  613 IFKTL=L-1
      IF(IFKTL.EQ.0) IFKTL=1
      I1=3*(IFKTL-1)+1
      I2=I1+2
      WRITE(6,162) FKG,(KURT(II),II=I1,I2)
  162 FORMAT(31X,'KURTOSIS',F8.2,4X,3A8)
 1000 CCNTINUE
```

```
RETURN
END
```

REFERENCES CITED

Bascom, W. 1964. Waves and Beaches. Doubleday & Company, Garden City, New York. 267 p.

Beal, C. H. 1915. The Geology of the Monterey Quadrangle. M.A. Thesis, Leland Stanford Junior University, Palo Alto, Calif. 88 p.

Bowen, A. J., and D. L. Inman. 1966. Budget of Littoral Sands in the Vicinity of Point Arguello, Calif. U.S. Army CERC Tech. Contrib. No. 19. 41 p.

Bowen, O. E. 1965. Point Lobos, a Geologic Guide. Cal. Div. Mines and Geology Mineral Inf. Service 18(4):60-67.

California State Department of Water Resources. 1969. Carmel River Basin Water Quality Investigation. Central Coastal Regional Water Quality Control Board, San Luis Obisbo, Calif. 46 p.

Carter, L. S. 1971. Recent Marine Sediments of Carmel Bay, Calif., M.S. Thesis, Naval Postgraduate School, Monterey, Calif. 61 p.

Cherry, J. 1965. Sand Movement Along a Portion of the Northern California Coast. U.S. Army CERC Tech. Memo. No. 14 125 p.

Dinger, C. 1970. Computer Program in Oceanography. Publication C-5 (2nd Revision). National Oceanographic Data Center, Washington, D.C. 143 p.

Folk, R. L., and W. C. Ward. 1957. Brazos River Bar: A Study in the Significance of Grain Size Parameters. J. Sediment. Petrol. 27(a): 3-26

Griffin, P. A. 1969. Heavy Mineral Investigation of Carmel Bay Beach Sands. M.S. Thesis, Naval Postgraduate School, Monterey, Calif. 50 p.

Krumbein, W. C., and F. J. Pettijohn. 1938. Manual of Sedimentary Petrography. Appleton-Century-Crofts., Inc., New York. 549 p.

Krumbein, W. C., and L. L. Sloss. 1963. Stratigraphy and Sedimentation, 2d ed. W. H. Freeman and Co., San Francisco, Calif. 660 p.

Lawson, A. C. 1893. The Geology of Carmelo Bay. Bull. Dept. Geol., Univ. of Calif., Berkeley. 1:1-59

McLean, J. H., and V. O. Peckham. 1961. Biological Exploration at the Head of Carmel Submarine Canyon (Abstract). Annual Report of the American Malacological Union. 48 p.

Moritz, C. A., Jr. 1968. A Descriptive Survey of the Head of the Carmel Submarine Canyon. M.S. Thesis, Naval Postgraduate School, Monterey, Calif. 82 p.

National Marine Consultants. 1960. Wave Statistics for Seven Deep Water Stations Along the California Coast. Prepared for the Los Angeles and San Francisco Districts, U.S. Army, Corps of Engineers.

Nili-Esfahani, A. 1965. Investigation of Paleocene Strata, Point Lobos, Monterey County, Calif. M.A. Thesis, Univ. of Calif., Los Angeles. 228 p.

Shepard, F. P., and K. O. Emery. 1941. Submarine Topography Off the California Coast: Canyons and Tectonic Interpretation. Geol. Soc. Amer. Spec. Paper 31. 171 p.

Shepard, F. P., and R. F. Dill. 1966. Submarine Canyons and Other Sea Valleys. Rand McNally and Company, Chicago. 381 p.

Simpson, J. P. 1972. The Geology of Carmel Bay, Calif. M.S. Thesis, Naval Postgraduate School, Monterey, Calif. 74 p.

U.S. Army Coastal Engineering Research Center. 1966. Shore Protection, Planning and Design. Tech. Report No. 4. 401 p.

U.S. Coast and Geodetic Survey. 1971. Tide Tables, High and Low Water Predictions, 1971, West Coast North and South America including the Hawaiian Islands. U.S. Government Printing Office, Washington, D.C. 226 p.

U.S. Naval Hydrographic Office. 1958. H. O. 234: Breakers and Surf; Principles of Forecasting. U.S. Navy Hydrographic Office, Washington, D.C. 54 p.

Wallin, S. R. 1968. The Sediments in the Head of the Carmel Submarine Canyon. M.S. Thesis, Naval Postgraduate School, Monterey, Calif. 98 p.

Zardeskas, R. A. 1971. A Bathymetric Chart of Carmel Bay, Calif. M.S. Thesis, Naval Postgraduate School, Monterey, Calif. 108 p.

INITIAL DISTRIBUTION LIST

		NO. COPIES
1.	Defense Documentation Center Cameron Station Alexandria, Virginia 22214	2
2.	Library, Code 0212 Naval Postgraduate School Monterey, California 93940	2
3.	Professor R. S. Andrews, Code 58 Ad Department of Oceanography Naval Postgraduate School Monterey, California 93940	10
4.	Department of Oceanography, Code 58 Naval Postgraduate School Monterey, California 93940	3
5.	Lt. B. F. Howell, USN U.S. Naval Destroyer School Newport, Rhode Island 02840	3
6.	Mr. Frederick A. Meyer Environmental Resources Section Supervisor, Dept. of Parks and Recreation State of California - Resources Agency P. O. Box 2390 Sacramento, California 95811	4
7.	Office of Naval Research Code 480D Arlington, Virginia 22217	1
8.	Mr. Don Rich California Department of Parks and Recreation District 4 Headquarters 2211 Garden Road Monterey, California 93940	1
9.	Mr. J. C. Mellor, Code 58 Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
10.	Professor W. C. Thompson, Code 58th Department of Oceanography Naval Postgraduate School Monterey, California 93940	1

		NO. COPIES
11.	Oceanographer of the Navy The Madison Building 732 N. Washington Alexandria, Virginia 22314	1
12.	Hopkins Marine Station Cabrillo Point Pacific Grove, California 93950 Attn: Mr. Tony Weaver	1

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 93940	2a. REPORT SECURITY CLASSIFICATION Unclassified
	2b. GROUP

3. REPORT TITLE

Sand Movement Along Carmel River State Beach, Carmel, California

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)

Master's Thesis; September 1972

5. AUTHOR(S) (First name, middle initial, last name)

Buford F. Howell; Lieutenant, United States Navy

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
September 1972	71	24
8a. CONTRACT OR GRANT NO.	9a. ORIGINATOR'S REPORT NUMBER(S)	
b. PROJECT NO.		
c.	9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report)	
d.		

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY
	Naval Postgraduate School Monterey, California 93940

13. ABSTRACT

The direction of sand movement along the Carmel River State Beach was qualitatively determined by diving observations, a bathymetric survey, wave refraction diagrams and a sediment size analysis of 18 samples.

The primary source of sediments for the beach appears to be the Carmel River which flows only seasonally. Sedimentary material is introduced into the bay after winter precipitation provides a sufficient amount of run-off to warrant the opening of the river mouth by bulldozer.

The fine sedimentary material is lost offshore and the coarser material is either redeposited on the beach or is carried south with the littoral drift and deposited at a nodal point in the sand transport pattern. This node is located on the northern edge of the head of the Carmel Submarine Canyon.

Winter storms probably induce slumping or gravity sliding and much of the material is carried to deeper water by the canyon.