THE GEOLOGY
OF
CARMEL BAY, CALIFORNIA

John Page Simpson

NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

THE GEOLOGY
OF
CARMEL BAY, CALIFORNIA

by

John Page Simpson, III

Thesis Advisor: R. S. Andrews

March 1972

Approved for public release; distribution unlimited.

The Geology
of
Carmel Bay, California

by

John Page Simpson, III
Lieutenant, United States Navy
B.A., Colgate University, 1963

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OCEANOGRAPHY

from the

NAVAL POSTGRADUATE SCHOOL

March 1972

[illegible]

ABSTRACT

Data obtained from rock and sediment samples collected in Carmel Bay were coordinated with seismic and bathymetric information to produce the first geologic map of the area showing the terrestrial geology extended into the bay itself. The map shows a large underwater area of possible contact metamorphism which serves as the source rock for the heavy minerals found along the local beaches.

A previously undescribed granodiorite boulder conglomerate was found resting uncomformably on the Paleocene Carmelo Series along the shores of Stillwater Cove. The conglomerate is unlike anything else seen in the area, but it is thought to be associated with the Temblor Formation of Miocene age.

Seismic data assisted in locating sediment pockets within the bay. The sediment pockets, when associated with the geologic map of the bay itself, help to give a greater understanding of the geomorphology and sedimentary processes occuring within the bay.

TABLE OF CONTENTS

I. INTRODUCTION ---------- 9

A. OBJECTIVE ---------- 9

B. DESCRIPTION OF AREA ---------- 9

II. PREVIOUS INVESTIGATIONS ---------- 11

A. LITERATURE REVIEW ---------- 11

B. GEOLOGIC EVOLUTION ---------- 14

III. COLLECTION OF DATA ---------- 17

A. BATHYMETRIC AND SEISMIC SURVEY ---------- 17

B. FIELD WORK ---------- 18

C. DIVING EXPEDITIONS ---------- 19

IV. ANALYSIS OF DATA ---------- 21

A. HEAVY MINERAL ANALYSIS ---------- 21

B. PETROGRAPHIC ANALYSIS ---------- 21

C. FIELD WORK ANALYSIS ---------- 22

D. ANALYSIS OF SEISMIC DATA ---------- 23

V. STATIGRAPHY AND PETROLOGY OF THE AREA ---------- 24

A. INTRODUCTORY REMARKS ---------- 24

B. SANTA LUCIA GRANODIORITE ---------- 24

C. THE CARMELO SERIES ---------- 27

D. THE TEMBLOR FORMATION ---------- 30

E. MIOCENE EXTRUSIVES ---------- 33

F. THE MONTEREY SHALE ---------- 37

G. AROMAS RED SANDS ---------- 38

H. TERRACES AND RECENT SEDIMENTS ---------- 39

VI. DISCUSSION ---------- 41

VII. SUMMARY ---------- 44

VIII. SUGGESTIONS FOR FURTHER STUDIES ---------- 46

REFERENCES CITED -- 69
INITIAL DISTRIBUTION LIST ------------------------------ 71
FORM DD 1473 --- 73

LIST OF TABLES

TABLE — Page

I. Comparative stratigraphic columns from Lawson (1893), Beal (1915), and Bowen (unpublished) -- 47

II. Heavy Mineral Analysis of Carmel Bay and Carmel River Sediment samples ------------------------ 48

III. Sample Numbers and Field Descriptions --------- 49

IV. List of Fossils from the Type Locality of the Monterey Series ------------------------------ 51

V. Chemical Analysis of Area Rocks -------------- 52

VI. Type, Description and Relative Abundance of Carmelo Pebbles ------------------------------ 53

VII. List of Species of Fauna from the Carmelo Series at Point Lobos and Pebble Beach, Monterey, California ------------------------------------ 54

LIST OF FIGURES

Figure Page

1. Location Map of Carmel Bay---------------------------- 55
2. Survey Lines Steamed and Survey Lines Not Completed--- 56
3. Locations of Outcrops Studied ------------------------ 57
4. Carmel Bay Sediment Sample Locations ----------------- 58
5. Carmel River Watershed and Sediment Sample Locations-- 59
6. Geologic Map of Carmel Bay Area ---------------------- 60
7. Bay Sediment Pocket Locations ------------------------ 61
8. Fathometer Record of Carmel Bay Showing Submerged Terraces-- 62
9. Trace of 3.5 kHz Record Showing High Reflectivity and Smoothness of Sediment Portion ----------------------- 63

LIST OF PLATES

Plate Page

1. Aerial Photograph of Carmel Bay ----------------- 64
2. Iddingsite Crystal -------------------------------- 64
3. Iddingsite and Augite Crystals ------------------ 65
4. Previously Undescribed Boulder Conglomerate ----- 65
5. Contact Between Carmelo and Boulder Conglomerate - 66
6. Microphotograph of Pebble Beach Pay Streak ------ 66
7. Pay Streak of Heavy Minerals -------------------- 67
8. Garnet Crystal ---------------------------------- 67
9. Carmelo Outcrop Showing Typical Carmelo Features - 68

ACKNOWLEDGMENTS

The author wishes to express his gratitude to Dr. Robert S. Andrews of the Department of Oceanography, Naval Postgraduate School, Monterey, California, for his assistance and professional advice. Further assistance in the collection of data is gratefully acknowledged from Lt. Ralph A. Zardeskas, USN, Lt. L.S. Carter, USN, Lt. B.F. Howell, USN, Mr. Lawrence Leopold, and the crew of the R/V ACANIA. Mr. Frederick A. Meyer of the California Department of Parks and Recreation, Mr. Earl Smith of the Monterey County Park Department, Mr. T. J. Hudson, and Mr. S. Fish provided land access for the study. Mr. Carl Hooper of George C. Bestor & Associates, Inc., provided a copy of Dr. Oliver Bowen's unpublished geologic charts of the area.

Partial funding for this study was provided to Dr. Andrews by the Naval Postgraduate School Research Foundation under an Office of Naval Research Grant. Funds for the leasing of the seismic research vessel were provided by the Naval Postgraduate School Department of Oceanography. Funds for the operation of the R/V ACANIA are provided through the Oceanographer of the Navy.

I. INTRODUCTION

A. OBJECTIVE

The objective of this study was to create a complete geologic reference of Carmel Bay and the adjacent area to aid in describing recent sedimentation and geomorphology. The information included within the study is a correlation of descriptions by previous investigators with data collected as a result of numerous field trips within the locality. Since previous work excluded descriptions of the outcrops under the bay, this area was given special consideration. The ultimate result of the investigation is a geologic map showing outcrops and structural implications in and around Carmel Bay.

B. DESCRIPTION OF AREA

Carmel Bay is located approximately five miles south of Monterey Bay, California, at the northwestern extremity of the Santa Lucia Mountains (Fig. 1). The principal community of the locality is Carmel, which borders the bay on its northeastern flank.

The bay itself is small, with an area of approximately five square miles, and is bounded by two granodiorite headlands, Pescadero Point to the north and Carmel Point to the south. The length and width of the bay are 3.5 n. miles and 1.5 n. miles, respectively.

Two rivers provide primary drainage into the bay. The largest, Carmel River (entering the bay just south of Carmel), is at or near base level at its mouth and, though it possesses

a flood plane about 0.6 miles wide, water flow is present only a small fraction of the year. The second tributary, San Jose Creek, drains the mountains to the southeast and enters the bay about 1 mile south of the Carmel River.

The most dominating topographic features of the region are south of San Jose Creek. Here, the massive, deeply ravined granodiorite hills that characterize the northwestern limit of the Santa Lucia Mountains protrude 2000 to 3000 feet above the surrounding countryside. To the north of the creek the relief is more gentle and it is more often distinguished by mild undulations and ancient terraces.

The beaches, though sporadically broken by both igneous and sedimentary rock outcrops, appear well supplied with a predominantly quartz sand.

Carmel Submarine Canyon originates approximately one quarter of a mile seaward of the mouth of San Jose Creek and empties into the larger Monterey Submarine Canyon some distance from shore.

II. PREVIOUS INVESTIGATIONS

A. LITERATURE REVIEW

One of the first geologists to study the region was J. B. Trask (1854, 1855) who, while working on the structure of the Coast Mountains, described the primitive rocks of what are now considered the Santa Lucia Mountains as a "granite series." He also considered the beds of the Monterey shale as being of the "infusorial period." The original description of the commonly occuring porphyritic granodiorite was made by Blake (1855). Additionally he portrayed the Monterey shale as being of a diatomaceous character. Whitney (1865) recognized the granodiorite as an intrusive, but felt that it intruded into the overlying Miocene beds. Lawson (1893) noted the error in Whitney's deduction and set about to clearly delineate the existing relationships among the rocks surrounding Carmel Bay. He identified the various lava flows common in the vicinity, describing them as, "submarine extravasations intercalated with Pliocene (?) formations." He recognized that a distinguishing feature of a vast proportion of the lava present was the mineral iddingsite and, using this information along with a chemical analysis of the lava itself, speculated that all of the flows present probably originated from one local magma. He specified only one volcanic plug, however, in the vicinity of what is now called Arrowhead Point. He suspected that the abundant Monterey shale was actually a modified volcanic ash rather than an organic deposit as

previously thought. He complemented his field work with an exhaustive petrographic study of the rocks and minerals predominating in the strata of the area. Beal (1915) gave the first good description of the Monterey sandstone, correlating it with the Temblor Formation and distinguishing it from the Vaqueros sandstone found elsewhere in central California. The Monterey shale, considered to be the source of practically all of the oil in California, was felt to be chiefly organic in origin. Hawley (1917) noted the presence of a basement complex of gneisses, schists, granites, and crystalline limestones to the south of Carmel Bay. P. D. Trask (1926), working to the south, surmised that the result of the injection of the Santa Lucia granite into the overlying strata was still apparent. The effect appears as stages of metamorphism of the Sur Series (primarily sedimentary). The porphyritic variety of granite (granodiorite) appears only in the Carmel-Monterey area and grades into a quartz diorite to the south. Trask assigned the name Santa Lucia to the entire plutonic mass. He proposed a western source for most of the sediments of the area. Taliaferro (1944) regarded the Sur Series as either very early Paleozoic or Pre-Cambrian in age. He proposed a paleogeographic map for the close of the Cretaceous which showed a large land mass (Pacificia) to the west of the present coast of California and a large island (Gabilan) jutting southeast from Monterey Bay. Bowen (1965) indicated that the Santa Lucia intrusion occured in early Cretaceous. He showed evidence of a Temblor formation (he referred to this outcrop as Chamisal Formation) outcropping above the Carmelite

Mission. Nili-Esfahani (1965) concentrated his studies on the Paleocene strata of the Point Lobos area. He gave an excellent description of the Carmelo Series and indicated that the source, for at least the Carmelo sediments, was somewhere to the south of Carmel Bay.

Griffin (1969) conducted an investigation of the heavy mineral content of the beach sands along the shores of Carmel Bay. Carter (1971), in his sediment analysis of the bay, determined it to be a "sedimentary system primarily isolated from adjacent coastal sediment sources, with the major sources of sedimentary deposits being terrigeneous debris from the Carmel River, erosion and weathering of the local coastline and offshore rocks by waves and weather, and the shells and tests of numerous calcareous marine organisms."

The environment and origin of submarine canyons has been studied extensively by Shepard and Emery (1941), Shepard and Dill (1966), Martin (1964), and Martin and Emery (1967). Their findings apply at least in part to the Carmel Submarine Canyon.

Bascom (1964) conducted his study of waves and beaches along the beach in the vicinity of the mouth of the Carmel River. Cooper (1967) discussed the dune sands occuring along Carmel Beach.

B. GEOLOGIC EVOLUTION

The presence of altered sandstones and limestones attest to an environment of warm and shallow waters during the deposition of the Sur Series sometime prior to the Cretaceous Period. Occasional interbedded lava flows are proof of the volcanic activity that was taking place during this time. Over 5000 ft of sediment was deposited in a slowly sinking basin encompassing at least the central region of California. Additional sediments may have been deposited after the close of this period, but no evidence of such deposition presently exists. During the Cretaceous period the great Santa Lucia Pluton intruded the sediments, probably assisting in the initial raising of the Santa Lucia Mountain Range. Curtis, Evernden, and Lipson (1958) dated a sample of Santa Lucia Granodiorite from Carmel Bay using the potassium-argon method giving an age of 81.6 million years. The Sur Series rocks were consequently altered to the metamorphic by-products now seen outcropping to the south, in the Sur Quadrangle (Trask, 1926). Injection gneisses are also quite common. During the late Cretaceous the mountain range was eroded deeply and much of it sank below the sea. The rocks of the Sur Series were completely removed from the granodiorite in the vicinity of Carmel Bay. An additional period of sinking and subsequent uplift gave rise to the Franciscian Formation which is seen to the north and south of Carmel Bay, but not in the immediate area. The rocks of the Carmelo Formation were deposited in an environment similar to that existing around the submarine canyons of today. Slumping and turbidity currents were the

primary modes of deposition (Nili-Esfahani, 1965). The source for the Carmelo is unknown, but it may be speculated that the sediments come from the Sur, Franciscian and granitic rocks existing in the Santa Lucia range to the south. In early Miocene time the land was again uplifted and active erosion of the granitic pluton provided the sediments for the Temblor Formation which was deposited near shore in both continental and marine type environments. This period of uplift and sedimentation was accompanied by volcanic activity resulting in the lava flows located around the bay. A gradual subsidence during Middle Miocene time gave rise to a vast shallow embayment. Volcanic ashes combined with siliceous plant and animal remains to form the great thicknesses of Monterey shale now found throughout central California. The region was again uplifted, exposing the sediments to the destructive processes of the elements and forming the basic coastline whose remnants are present today. Further modification of the area occured as it was split by faults and enroached upon by advancing, then receding seas during the Pleistocene Period. A changing water level combined with occasional subsidence produced the terraces found in local hills and up the Carmel River valley. Sediments from the Monterey Series and other older formations were stripped from the shore areas and deposited as the Aromas Red Sands in Carmel, Point Lobos and elsewhere. The coastal submarine canyons were gouged by eroding currents during periods of heavy glaciation, when much of the earth's water was tied up in ice.

The present coastline is composed of granite and conglomeratic outcrops associated with numerous sandy beaches. The beach sands are derived from the sediments carried by the two rivers present and from the wave-eroded outcrops within the bay.

III. COLLECTION OF DATA

A. BATHYMETRIC AND SEISMIC SURVEY

The survey was conducted during the period 10-12 March 1971 from a chartered oceanographic survey boat, R/V DAWN STAR, owned and operated by General Oceanographics, Inc., of Newport Beach, Ca. The purpose of the survey was to obtain enough bathymetric data to complete a detailed hydrographic chart of the Bay (Zardeskas, 1971) while gathering seismic records to be used in interpreting the geology of the bay.

A 12-kHz hull-mounted fathometer and a 3.5-kHz high resolution reflection profiler towed at a depth of 20 ft were used for the bathymetry. The profiler and a 300-Joule sparker were used to determine seismic information. The braided sparker contacts were towed 30 ft astern of the ship at a depth which varied with ship's speed but averaged 10 ft. The equipment operated with a 1/2-sec sweep rate and a 1-sec firing rate. A 150/75-Hz HI/LO filter was utilized. Line spacings for the survey were dependent on hydrographic rather than seismic requirements. Over 87 n. miles of sounding lines were surveyed. Figure 2 shows the area actually covered in the survey.

A HIREX position system, owned and operated by Offshore Navigation, Inc. (ONI), of New Orleans, La., was used for station keeping. This range-range system used two land-positioned transponders and two shipboard recievers. The transponders were located at C&GS Horizontal Control Point Loma Alta and an offset control point termed Corona, which

was surveyed in utilizing C&GS Horizontal Control Points Fox and Loma Alta (Fig. 2). The offset was required to insure that the line-of-sight type operation necessary for x-band transmissions could be maintained. System accuracy of from 5 to 10 ft was considered more than adequate for the seismic survey. More complete information on navigation, track maintenance, and slope corrections is found in the work done by Zardeskas (1971) on the bathymetry of Carmel Bay.

Dense beds of kelp (Macrocystis pyrifera), shallow water, and shoaling waves prevented completion of the survey in some nearshore areas. Dives were subsequently planned to extend coverage to these areas.

All data was collected simultaneously as the ship tracked. A modified Gifft GRG precision depth recorder using 18-inch wide wet paper was used. Records were marked and annotated at the start and finish of each line and at 3-min intervals coinciding with the navigational system fixes. A cruise log was kept noting equipment settings and meteorological/navigational conditions.

B. FIELD WORK

Fifteen field trips were taken around Carmel Bay. In the city of Carmel and the area surrounding the bay each street was driven to its full usable length in order to locate outcrops. The shoreline was walked where passable from Pescadero Point to Point Lobos. When access to the shoreline was impossible, observations were made from sea. The area south of Carmel River was covered extensively on foot. Eighty samples were

taken throughout the area. Sample and outcrop locations are shown in Fig. 3.

Bay sediment samples analyzed for heavy minerals were collected by Carter (1971) from the R/V ACANIA using a Shipek grab sampler and a 2.75-inch outside diameter, 700-lb total weight gravity corer. Sample locations are plotted on Fig.4. Samples were gathered in plastic bags and refrigerated until analysis could be accomplished. For reference purposes sand samples were taken at five locations up the Carmel River Valley (Fig. 5).

Sample and outcrop locations were plotted to some accuracy using reference points from the U.S. Geological Survey maps of the area. Only rough estimates of dip and strike were made using a Brunton compass.

One cruise was made on R/V ACANIA for the purpose of sampling near-shore rocks in the Pescadero Point to Carmel Beach area. A Smith-MacIntyre grab sampler was used with very limited success. The sampler is unable to break off pieces of parent rock and is useful only in sampling sediments of pebble size and smaller. A second cruise on the R/V ACANIA was conducted for the partial purpose of collecting rock samples from the small islands found in and near Stillwater Cove. Two samples were taken using the ACANIA'S Boston Whaler.

C. DIVING EXPEDITIONS

Three diving expeditions were conducted in the area between Arrowhead Point and Abalone Point. The first of these expeditions identified as lava the large rock visible several hundred

yards off shore north of Ocean Avenue. The second dive was centered in the Abalone Point area, and the third, conducted from the ACANIA'S small boat, covered the area in between that explored on the other two dives. Outcrops were located generally by observing the growth of kelp. In the 20-to 60-ft depth range it was found, without fail, that if a kelp bed existed, so did an outcrop. This was to be expected since the kelp requires a good sized anchor for its holdfast. The samples, though broken from large outcrops, were not always easily identified in the field. They were therefore returned to the laboratory for analysis.

It is interesting to note that numerous golf balls were observed on the final diving expedition. The balls were found concentrated in the southern portion of the area off of Carmel Beach. The source for the balls was obviously the Pebble Beach Golf Course hundreds of yards to the north.

IV. ANALYSIS OF DATA

A. HEAVY MINERAL ANALYSIS

The samples collected in the Carmel Valley river bed were manually sieved and the 3.0 and 4.0 Ø sizes were stored for the study of heavy mineral content. Bay sediment samples were sieved and analyzed by Carter (1971). The 3.0 and 4.0 Ø samples were also retained for heavy mineral analysis.

Separation of the heavy from the light minerals was accomplished by the standard Bromoform method. Separation funnels were half filled with Bromoform (specific gravity of 2.85 gm/cm^3); 15 to 20 g of the sediment sample were poured into the Bromoform and mixed. Separation was permitted to take place, then the heavy minerals were drained off, washed with acetone, dried and stored. The remaining light minerals received the same treatment. The process was repeated until all samples had been completed.

Sediment slides were prepared by dropping 500 to 1000 grains of the minerals onto a blank slide previously heated and coated with warm, liquid 'Lakeside 70'. The slides were removed from the heat, allowed to harden, then studied under the petrographic microscope by R. S. Andrews (Table II).

B. PETROGRAPHIC ANALYSIS

Thin sections of 26 samples were prepared by Cal-Brea, Brea, California. Two slides were made from each sample to insure inclusion of all salient features. Sample numbers and

field descriptions including thin-section identification appear in Table III.

The lava, shale, and granodiorite have previously been described in detail by Lawson (1893), so only cursory examination of these rock types was made. The other sedimentary rocks had not been well described previously, so considerable time and effort were spent studying them. The sandstones were examined for angularity, grain size, matrix type and percentage, and mineral variety. The two primary minerals present were quartz and feldspar. Percentage of these two minerals was determined by grain count using optical interference figures for identification. Other minerals present were identified in a similar manner.

For visual comparison, pictures of the various rock types were taken through the microscope utilizing a Bausch and Lomb Model N Eye-Piece Camera (Plates 2,3,8)

C. FIELD WORK ANALYSIS

All outcrops were plotted on a field map when observed. The information from the field map was then transferred to a smooth chart. When the sample from an outcrop was not easily identifiable a portion of it was sent out for thin sectioning. Rock samples taken from the bay were dried and broken before positive identification was made as they were coated with organisms. Utilizing strike and dip measurements, outcrop locations and topographic features, a geologic map of the area was constructed (Fig. 6).

D. ANALYSIS OF SEISMIC DATA

A thorough examination of all gathered seismic records showed absolutely no sedimentary rock layering visible beneath that portion of the bay covered by the seismic survey. Recent sediment pockets (primarily sand) were located by observing areas of extremely high reflectivity on the 3.5-kHz records. The sparker records were useful in obtaining approximate thickness of these sediment pockets (Fig.9). A maximum sediment thickness of about 22 m was found in the northern part of the bay (thickness calculated assuming a sound speed in sand of 1.7 km/sec).

It had been hoped that the 300-Joule seismic records would be useful in determining the extent of the rock formations under the bay. The deep water records showed no sedimentary layering, indicating a primarily granitic rock mass under the bay. The surficial layering that might be expected in some of the shallow water areas was masked by the high reflectivity of the sand sediments and the lack of resolution in the first 6 fm of the records due to the pulse and bubble pulses. The equipment was in good working order as evidenced by perfect records showing sedimentary layering obtained in Monterey Bay during the time alloted for the Carmel Bay survey.

V. STRATIGRAPHY AND PETROLOGY OF THE AREA

A. INTRODUCTORY REMARKS

Each rock type has been observed macroscopically in the field and microscopically in the lab. The following sections provide a general description of each of the strata, including appearance, structure, thickness, and petrography. Occurrence, conditions of deposition and relative stratigraphic position are also mentioned. A stratigraphic column based on the research done for this study appears in Fig. 6. Some of the petrographic descriptions given below are based on work done by Lawson (1893).

B. SANTA LUCIA GRANODIORITE

The Santa Lucia Granodiorite is a coarse-grained rock characterized by large phenocrysts of orthoclase feldspar (Lawson, 1893). It outcrops in numerous areas around the bay, the largest of these occuring at Point Lobos. It surrounds San Jose Creek and extends to the south and east for some distance. The tract along the coast from Point Cypress to Pescadero Point encompasses the next largest outcrop. Smaller outcrops occur on the north side of Point Lobos and inland to the north of Stillwater Cove. Granodiorite outcrops guard both sides of the Carmel River valley at its mouth. At the intersection of Route 1 and Carmel Valley Road yet another outcrop appears, and just northwest of this an additional exposure may be located. Additional outcrops may be found along the walls of Carmel Submarine Canyon (Shepard and Dill, 1966).

The groundmass of the rock is extremely coarse and granular and consists primarily of quartz, whitish to greenish-white feldspar, and biotite. The quartz is the best developed of the groundmass minerals, ranging in size to as much as 2 cm. in diameter. Next in size are the areas of feldspar. The biotite measures from 1 to 2 mm. The quartz possesses a vitreous luster, mosaic structure and undulatory extinction. The feldspar is primarily oligoclase-andesine with a small proportion of orthoclase. Striations may be observed on the basal sections of some of the feldspar. The biotite is black, lustrous, and contributes significantly to the appearance of the rock. Muscovite is present, but certainly not common. Microlites of apatite are frequently observed as are small interpositions and liquid inclusions in both the feldspar and the quartz.

The phenocrysts, consisting of large crystals of glassy orthoclase, are the most obvious features of the granodiorite. They are usually twinned (Carlsbad Law) and elongated. The average grain diameter is 4 to 5 cm. The large crystals are visible at all outcrops and are commonly observed to show a degree of parallelism in their orientation in the groundmass.

Closer observation of the phenocrysts shows a certain amount of luster mottling due to inclusions of numerous foreign minerals into the orthoclase. Plagioclose, orthoclase, quartz, biotite, muscovite and minute needles of apatite and zircon may be found, the muscovite and apatite more sparingly. The inclusions may constitute up to 20% of the phenocryst and, with the possible exception of the mica, are found in definite

planes. The size of these "small phenocrysts" varies commonly from 0.25 to 1 mm in length. Some of the progress of the original crystallization of the magma may be surmised by the relationships among the large and small phenocrysts and the ground mass of the rock. It appears that at least some mineral inclusions were crystallizing in conjunction with the huge orthoclase phenocrysts. Some time after solidification minute cracks formed throughout the groundmass. Lawson(1893) tentatively attributed these cracks to the unequal tensions caused by differential expansion and contraction in different crystallographic directions. These minute cracks, which make the rock quite susceptible to disintegration, have probably been aggravated by the mechanical stresses associated with more recent orogenies. Much evidence of this physical weathering can be seen in outcrops up the Carmel Valley. Table V presents Lawson's chemical analysis.

Two types of dikes may be observed to cut through the granodiorite. A greyish or slightly flesh-tinted granite traverses the older rock in all directions. This variety of dike averages several inches in width, is relatively fine grained, and is characterized by an absence of mica (causing the dike to to termed an aplite). The minute cracks characteristic of the granodiorite are not present, therefore the dikes are less friable and more resistant to decomposition than the older Santa Lucia rock. There are also numerous narrow dikes of pegmatite present. These dikes are composed of a coarse granular aggregate of orthoclase and quartz with some plates of biotite and a few shreds of muscovite. The

feldspar is commonly flesh-tinted, fresh, and lustrous, but may be kaolinized and bleached white. The relative ages of the dikes has not been determined.

The composition of the granodiorite indicates that it was formed as a deep, slow cooling pluton. Dike formation was subsequent to cooling, and deep erosion occured sometime thereafter. All younger rocks in the area overlay the granodiorite unconformably. In some areas distinct jointing can be observed though no definite orientation pattern is present. This jointing obviously forms many small canyons where the rock outcrops along the bottom of the bay.

C. THE CARMELO SERIES

Rocks of the Carmelo Series outcrop significantly in two areas around Carmel Bay. On Point Lobos, the granodiorite headland is commonly overlain unconformably with a varying thickness of the Carmelo Formation. To the north, surrounding and underlying Stillwater Cove, the second major outcrop occurs. A third, minor occurence of the Carmelo may be observed just north of the Carmel Mission. Total thickness of the formation is somewhere between 600 and 1000 ft (Nili-Esfahani,1965).

The Carmelo formation is composed of four distinct rock types; sandstone, siltstone, conglomerate, and shale (Plate 9). All of these facies are commonly occuring, but the conglomerate is the most representative. The conglomerate consists of igneous pebbles imbedded in a coarse-grained, well-cemented feldspar and quartz matrix. The pebbles, usually 1 to 4 inches in diameter, are well rounded and porphyritic. A description

and an indication of relative abundance are included in Table VI (Nili-Esfahani, 1965). The sandstones may appear as thick beds, may be included as lenses in the comglomerate, or can occur as thin layers alternating with the siltstones and shales. The shale is dark due to an abundance of carbonaceous materials. The siltstones are usually lighter and are commonly found alternating with layers of shale (Plate 9).

Under a microscope the Carmelo sandstone is not easily identified. The rock is as much as 50% feldspar, the rest being quartz with an occasional lense of twisted biotite. Individual fragments are extremely angular and fresh in appearance. The matrix covers 5 to 10% of the total area of the slide and is composed almost entirely of slit and clay. Some samples show slight effervescence when treated with dilute HCL. The characteristic reddish color of the sandstone is due, evidently, to the presence of iron oxide in the matrix material.

The Carmelo rests uncomformably on the basement granodiorite. At Point Lobos it is overlain, also unconformably, by Quaternary rocks. No other contact of Carmelo with younger rocks was observed at Point Lobos, but at Pebble Beach its contact with the Temblor Formation forms an angular unconformity.

Quite possibly the Carmelo rocks were deposited under conditions similar to those existing now around the submarine canyon and tributaries of Carmel Bay (Nili-Esfahani, 1965). Types of evidence appearing for this type of deposition are: slump, erosion and turbidity features, crossbedding, and the presence of displaced fossil fauna associated with turbidity

currents. The sediments were derived primarily from nearby granitic rocks, but the source of the pebbles can only be speculated. Paleocurrent determinations (Nili-Esfahani, 1965) show a southern source for the major part (lower 3/4) of the formation. The source rock for the pebbles was probably Sur Series and was removed from the area during the deep erosion that took place after the intrusion of the Santa Lucia pluton. Portions of the Sur Series still exist in the Santa Lucia Range south of Carmel Bay.

The Carmelo Formation undoubtedly covered a greater area at the close of the Paleocene than it does now, but the spotty, highly disturbed and faulted outcrops which appear now indicate that the strata were originally deposited in semi-isolated pockets in the basement granodiorite. Subsequent faulting and erosion combined with the mechanical pressures of a younger overburden have resulted in the formation as it presently exists.

The Carmelo is noteworthy in its sparcity of recognizable fossils. Table VII (Nili-Esfahani, 1965) lists the species found and the associated age indications. Two types of plant fossils, one of the family Corallinaceae and the other of the order Cryptonemiales have been identified (Nili-Esfahani, 1969). Additionally, various types of trace fossils may be found. The types of fossils present in the Carmelo Formation give evidence for a turbid environment during its deposition. (Nili-Esfahani, 1965). Bowen (1965) and Nili-Esfahani (1965) agree that the probable age of the Carmelo Formation is Paleocene based on the index fossil Turritella pachecoensis and other fossils of similar age but of more extended range.

The Carmelo was originally deposited conformably on granodiorite. Subsequent faulting has, in places, produced a fault contact between the two formations. The most noticeable of this type of contact occurs along a line extending roughly from Pescadero Point to Abalone Point (Fig. 6).

D. THE TEMBLOR FORMATION

The Temblor Formation (Chamisal of Bowen, 1965) of the area is composed of coarse-grained, white to brownish sandstones and conglomerates. The exposures appear to be flat lying, with occasional inclinations of up to 10 degrees. The included boulders and pebbles are primarily granodiorite, but an occasional pebble similar to those of the Carmelo may be found. The sand grains are angular and generally poorly cemented. The boulders are usually slightly rounded. In some areas the boulders comprise 50% of the rock; in other places only an occasional boulder is present.

The formation outcrops only sparsely around Carmel Bay. Three areas may be located, the largest just northeast of the Carmelite Mission. Another outcrop appears about a mile east of Route 1 on the northern extremity of the Fish Ranch. The third outcrop is sandwiched between the volcanics of Arrowhead Point and the Carmelo of Pebble Beach at Stillwater Cove. This final outcrop has generally been considered to be part of the Carmelo (Nili-Esfahani, 1965). The greatest local thickness, found on the northern border of the Fish Ranch, is approximately 200 ft. Greater thicknesses are found to the south and east of San Jose Creek.

Several fossil beds have been observed in the Temblor south of the area considered (Trask, 1926). Among fossils found are:

Ostrea titan Conrad
Turitella ocoyana Conrad
Agasoma barkerianum Anderson
Pectin andersoni Arnold
Cardiom vaqueroensis Arnold
Mytilus expansus Arnold

No fossils were found in the three outcrops around the bay.

The angularity and coarseness of the deposits coupled with the size and subangular shape of the boulders present indicate a continental source for the majority of the Temblor. Trask implied that most of the rocks were deposited as fanglomerates. Obviously, however, there were occasional submersions of the area allowing beds of marine fossils to be interspersed within the sandstones and conglomerates. The angularity of the sediments, freshness of the feldspars, and size of boulders indicate a nearby source. The presence of porphyritic granodiorite boulders and granodiorite-derived sandstone pinpoints the source as the underlying Santa Lucia Granodiorite which must have been actively eroding at the time.

When observed under the microscope the Temblor sandstone and the matrix of the Temblor conglomerate are, at first, difficult to distinguish from the Carmelo sandstones. The composition is almost exactly the same. There are several features, however, which serve to help differentiate between the two. The Temblor has more rounded particles than does

the Carmelo. Occasional sand-sized rock fragments are noted in the Temblor whereas none are found in the Carmelo. The most obvious difference is the presence in the Carmelo of a great number of small angular bits of rock imbedded in the matrix between the larger pieces of feldspar and quartz.

The Temblor rests on both the granodiorite and the Carmelo and is overlain by lava flows and in places the Monterey shale. These relationships indicate a possible age from Paleocene to Middle Miocene. Correlation of the fossils pinpoints a Middle Miocene age (Trask, 1926).

The outcrop just north of Arrowhead Point deserves special consideration since it has not been previously described. It is essentially a boulder conglomerate, the boulders being composed of Santa Lucia Granodiorite. The matrix consists of angular grains of quartz and feldspar sand. The formation shows no bedding so it is impossible to determine its thickness. The outcrop stands as high as 20 ft and extends about 150 yds along the beach. To the north the formation rests on an eroded surface of the Carmelo Series; to the south it is in contact with the Miocene extrusives. The nature of this southern contact is uncertain, but it appears to be a badly weathered zone of contact metamorphism.

Though it may exist elsewhere as the basal member of the Monterey Formation, the Monterey Sandstone does not exist around Carmel as a distinct, separate portion of the Monterey Formation. What has been called Monterey Sandstone in the past is actually a non-conglomeritic extension of the Temblor Formation of the Monterey Group. Microscopic analysis and

fossil comparisons (Beal, 1915; Trask, 1926) lend force to this statement. The Monterey Sandstone has been considered separately from the Temblor because of its position above the lava and because it represents a marine rather than continental origin. Microscopically the sandstone is extremely similar to that described under the Temblor Formation. This member outcrops in the Pebble Beach area and along Route 1 just south of the Carmel River (Fig. 1).

E. MIOCENE EXTRUSIVES

Lawson (1893) did an exhaustive study of the lava flows around Carmel Bay and must be credited with much of the information which follows. Lava outcrops are found in five different places around the bay (Fig. 6). Each area has produced a slightly different type of rock, but enough similarities are noted to give the rock a common name. The most distinguishing feature of the lava is the almost universal presence of the mineral iddingsite. Local variations of the rock show massive structure in one area and vesicular or amygdaloidal appearance elsewhere. The chemical content and specific gravity vary as shown in Table V. In some places flow structure or lamination may be present, while in other areas they are not. Color varies from a dark blueish grey through a yellow rusty tint to a whitish shade, the color being primarily a function of the degree and type of weathering. The variation in different samples is often even more apparent under a microscope. Sometimes glass is present and occasionally the rock is holocrystalline. The percentage of augite and plagioclase found as phenocrysts varies considerably from place to place.

The characteristic mineral iddingsite is soft (Mohr hardness 2.5), has a maximum specific gravity of 2.839g/cm^3 and is usually bronze to brownish in color. Chemically, iddingsite is a hydrous non-aluminous magnesium-iron silicate molecule. Though frequently associated with the mineral olivine, iddingsite was shown by Lawson (1893) to be a little-altered original separation from the magma.

The largest outcrop occurs at Arrowhead Point. There is variation of the composition of the lava at this one location alone, but generally speaking, the rock is blue-grey, has an aphanatic base, and is characterized by numerous small phenocrysts of augite and iddingsite (Plate 3). The ground-mass appears as a fine network of lath-shaped plagioclase with numerous minute needles of magnitite and some pyroxene. Glass is present and in certain portions of the outcrop the surface is highly vesicular. Breccia may be observed in this area, along with calcite veins and amygdules. Columnar jointing is also apparent.

Lawson (1893) described another large outcrop several hundred yards east of Arrowhead Point. Though it now appears these two outcrops are connected, there are several compositional differences between the two areas. In the easterly portion of the outcrop, there is an absence of phenocrysts of augite, an abundance of glass, and an abundance of iddingsite in the groundmass. Macroscopically, however, the rocks at both locations appear quite similar. On the north side of Abalone Point yet another version of the lava is found. The rock is characterized by an absence of all phenocrysts except

iddingsite. Portions of this outcrop are heavily weathered and portions appear as a volcanic breccia. Much of the lava in this area is vesicular and the outcrop itself is faulted down against the granodiorite.

A short distance west of the Carmel Mission there is another small exposure. The rock has a whitish color with an occasional brown stain. Much of the outcrop is characterized by excessive splitting in parallel planes causing the rock to be mistaken for the Monterey shale which occurs nearby. Phenocrysts of iddingsite are, however, abundant, and microscopic examination indicates a volcanic groundmass composed primarily of plagioclase and iddingsite with occasional grains of magnetite and considerable interstitial glass.

In the hills north of San Jose Creek and northeast of the Carmelite Mission the nearly flat-lying lava appears as a crescent shape around the head of a canyon cutting eastward to the mouth of the San Jose Creek. The rock here is generally greenish grey to purple in color, but it is microscopically similar to the rocks of Arrowhead Point.

The relationship of the lavas from the various locations points toward a single age of deposition. In the area above San Jose Creek the lava is seen to rest on the Temblor. Terrace and recent sediments are piled on the lava at this location, but an abundance of pieces of Monterey shale indicate the lava is older than the Monterey or was intruded along the Monterey-Temblor contact. In addition, just east of the lava outcrop on a different hill, numerous exposures of the nearly flat-lying shale are present at significantly higher

elevations than the lava. A comparison of the relative altitudes of the two rock types and the associated dips and strikes clearly shows that the shale is younger than the lava. The Temblor and the Monterey Formations have been established as being Middle Miocene and upper Miocene respectively in age, so the lava must be Middle Miocene or slightly younger.

During the Miocene the land mass including Carmel Bay was in frequent vertical motion. Many of the Miocene deposits are marine and some are continental. This type of environment led to numerous erosional gullies and delta and submarine type deposits. This is the variety of landscape onto which the Miocene lavas flowed. As a consequence, the lava may be observed sitting on granodiorite or more recent formations such as the Temblor. Arrowhead Point, interpreted as a volcanic plug by Lawson (1893), appears to have been the source for several of the outcrops, but it is difficult to say exactly what outcrops came from where. The lava at Arrowhead Point displays typical columnar jointing. The visible lavas were layed down in a non-marine environment, but it is quite conceivable that some magma flowed into the ocean and has since been covered and/or eroded away. Thickness is of course highly variable. Exempting the plug at Arrowhead Point, the thickness of 60 ft just north of San Jośe Creek appears to be fairly representative.

The classification of the lava poses some problems because of the highly variable silica content (52-60%). The predominance of iddingsite and andesine plagioclase feldspar in both

the groundmass and the phenocrysts justify calling the lava iddingsite-andesite (carmelöite).

F. THE MONTEREY SHALE

The Monterey shale does not outcrop along the shores of Carmel Bay, but appears frequently north of Carmel and east of Route 1. The individual outcrops are easily identified and far too numerous to mention. The shale is white or yellowish in color, chalky in texture and soft enough to scratch with a fingernail. It is insoluble in water and thus extremely resistant to decomposition. The shale is found in flat-lying to gently undulating beds and is usually traversed by numerous irregular joints. The beds are occasionally interlayed with thin layers of chert and chalcedony. The rock has a density of 2.018g/cm^3 and contains traces of organic material. Close observation shows the presence of numerous holes, often arranged in planes, throughout the rock. Lawson (1893) speculated that these holes were the casts of foraminifera which were quite probably the source of the carbon compounds found to exist in the rock. The shales are considered to be over 1200 ft thick around Carmel Bay and, because of their abundance and insolubility, have in the past been used as building material.

The porous structure becomes even more obvious when viewed under a microscope, but with the exception of a few occasional bits of bitumen, biotite, orthoclase, plagioclase or quartz, the great proportion of the shale is remarkably homogenous. It is usually finely granular and cloudy. The chemical composition is shown in Table V.

The origin of the white Monterey shales has been open to speculation for more than a hundred years. Lawson (1893) felt that the presence of the numerous foraminifera casts indicated marine origin. The high silica content (87%) might point toward volcanic deposition. Bramlette (1946) believed that the sediments occured as a result of accumulation of silica in diatom tests and redistribution of the silica during diagenesis. Taliaferro (1944) felt that the presence of silica was related in some manner to volcanism. In reality, it is best assumed that the Monterey shale is a result of several processes acting simultaneously with the volcanics probably providing most of sediments to a marine environment. Volcanic eruptions were common during this period, giving additional credence to a primarily volcanic origin.

Occasional fossiliferous beds yield numerous fossils. One of the best examples occurs near the apex of Los Laureles Grade, east of Carmel Bay. The fossils found by Martin (1912) are listed in Table IV.

The age of the Monterey shale has been established as lower-Upper Miocene by the use of index fossils and stratigraphic relationships. It is underlain by the Temblor formation and overlain in the vicinity of Carmel Bay by the Aromas Red Sands.

G. AROMAS RED SANDS

The Aromas Red Sands outcrop in numerous places throughout the village of Carmel. The most noticeable of these outcrops occurs along the beach and extends from Abalone Point to the lava outcrop of Arrowhead Point. The rocks as they exist

in the vicinity of the bay are poorly consolidated, coarse-grained, quartzose and in places massive; cross-bedding is noted north of Ocean Avenue along the beach. Color is generally orange, but may vary from yellow to grey. Massive outcrops occurring at the southern end of Carmel Beach show enough bedding to indicate a northwest dip of up to 5 degrees. Along Ocean Avenue at the eastern edge of Carmel, differential weathering of the poorly cemented sandstone has produced a badlands effect. Deposition was probably the result of wind and wave action in a nearshore or lagoonal environment. Thickness in the area is less than 200 ft, though a maximum of 1000 ft is found elsewhere in the county. No fossils have been discovered, but the age of the rocks has been determined as Pleistocene by its relationship to other formations.

H. TERRACE AND RECENT SEDIMENTS

It is not the intent of this paper to analyze the location and content of the unconsolidated Quaternary sediments around Carmel Bay. Suffice it to say that terrace deposits exist as high as 600 ft above present sea level (Lawson, 1893), indicating a long period of uplift since Pleistocene time. The most obvious terrace bordering the bay occurs at the Pebble Beach Golf Course, where unconsolidated sediments resting on older rock form the foundation for fairways and greens. Bathmetric and seismic records have indicated the presence of submerged terraces at an approximate depth of 35 fm throughout Carmel Bay (Fig. 8).

Most of the area is covered with a thin veneer of recent sediment. The content of the sediment varies from area to area, but it contains, almost universally, bits of Monterey shale and remnants of granodiorite.

Sand is abundant along the coastline and in the river beds. Composition is variable depending on the source region for the particular area involved.

A portion of the town of Carmel is built on a sand dune area (Cooper, 1967). Near the north end of Carmel Beach, around Ocean Avenue, there is still a small area of active sand, derived primarily from the Santa Lucia Granodiorite. Heavy minerals, particularly garnet, biotite, and magnetite are common in the sands of Carmel Bay, but quartz and feldspar predominate. The pay streak analysed from the Pebble Beach area (Fig. 4) was almost entirely made up of magnetite and garnet (Table II). Since this beach is isolated from other parts of the bay, the source of the garnet is assumed to be contact metamorphism between the Miocene lava and pre-existing rocks.

In general, the sediments in Carmel Bay are rich in the ampliboles hornblende and lamprobolite and in biotite. The euhedral zircon crystals containing many inclusions, derived from the granodiorite, are distinctive features of these sediments. Heavy mineral analyses of beach sands in Carmel Bay may be found in reports by Griffin (1969) and Judge (1970).

VI. DISCUSSION

The geology of Carmel Bay was studied extensively by Lawson in 1893. New techniques and improved highway coverage have, however, necessitated a more current study of the area. Bowen completed a more recent but less thorough investigation of the area in 1965. The work of these two men and that of Nili-Esfahani (1965) are integral parts of this paper.

The enclosed map (Fig.6) is a result of a combination of information supplied from past investigations and information gathered in researching this paper. Several new interpretations of the geology of Carmel Bay are proposed below.

The seismic records clearly show a primarily granitic basement complex in direct contact with the bay water. Sediment pockets were occasionally observed, but no underlying strata could be detected from the records. Diving expeditions located a large Carmelo outcrop extending from off Arrowhead Point to a position about 300 yd seaward of Ocean Avenue. The majority of the floor of Stillwater Cove appears to be Carmelo, but the southeastern portion of it shows the Carmelo cut by the lava flow extending out from Arrowhead Point. The same lava flow is found east of the aforementioned Carmelo and extends from Arrowhead Point all the way down to Abalone Point. The rest of the shallow water rock outcrops are granodiorite except in the area north and east of Whalers Cove in Point Lobos State Park. Diving information (Lawrence Leopold,

San Jose State College, personal communication) shows the Carmelo extending a considerable distance northward of the mouth of the cove.

The rapid disappearance of Carmelo off of Ocean Avenue gives further evidence of a fault (Bowen, 1965) running from Pescadero Point through Abalone Point.

The Quaternary rocks outcropping throughout the city of Carmel and along the beach from Arrowhead Point to Abalone Point are tentatively identified as Aromas Red Sandstone. These rocks have been identified as Carmelo or Paso Robles, but they most accurately fit the description of the Aromas appearing in a report by the California State Department of Water Resources (1969).

Two other rock outcrops may have been incorrectly identified in prior work. The sandstone conglomerate beneath the lava on the hill just north of San Jose Creek shows a great similarity to the Temblor in texture, content, and stratigraphic relationship to the lava. It has therefore been categorized as Temblor rather than Chamisal.

The outcrop along the shoreline in Stillwater Cove, just north of Arrowhead Point has also tentatively been classified as Temblor. This formation appears to have been deposited directly on the eroded surface of the Carmelo, which strikes NE/SW and dips NW at 25 degrees. As mentioned previously, this rock shows a greater correlation to the Temblor than to the Carmelo.

Small pay streaks of heavy minerals may be found along the beaches adjoining Carmel Bay. Particularly rich deposits

were found along Carmel Beach several hundred yards north of Ocean Avenue, on Pebble Beach, and south of the Carmel River mouth. The source of these minerals is still highly speculative. The contact metamorphism caused by the local lava flows found under the bay should certainly be considered as the most probable source, but no direct evidence of this metamorphism was found. Garnet schists (Dr. W. C. Thompson, Naval Postgraduate School, personal communication) and garnet hornfels have been found at the mouth and in the riverbed of the Carmel Valley river. A cobble of garnet hornfels was also located high on the hill just north of San Jose Creek. The metamorphic rocks of the Sur Series are exposed extensively throughout the upper watershed of the Carmel River Valley (Fig. 5). These altered rocks are high in heavy mineral content and probably provide a portion of the garnet seen along the Carmel Bay beaches as evidenced by the heavy mineral analyses of Carmel River sediments (Table II).

Only one new fault is speculated. The small valley running east from the Carmelite Mission near Monastery Beach appears to have been created by erosion of a fault scarp. Displacement, however, is not great as lava may be observed on both sides of the valley. The most probable origin of the Carmel Submarine Canyon starting just off Monastery Beach is a fault running down the San Jose Creek Valley. Granodiorite walls line both sides of the valley near the beach but younger rocks may be observed high on the northeastern flank. It is reasonable to assume that a fault occured before or during Pleistocene time and the subsequent erosion of the scarp during the Pleistocene created the valley itself and the submarine canyon.

VII. SUMMARY

Six rock types outcrop in the vicinity of Carmel Bay. The oldest is a basement granodiorite which was intruded into the Paleozoic Sur Series during the Cretaceous period. The Sur Series was removed through erosion, and the Paleocene Carmelo Formation deposited as a turbidite in an environment similar to that existing in the Carmel Submarine Canyon today. The area underwent alternating periods of uplift and erosion resulting in the deposits of Temblor sandstones and Monterey shales of Middle and Upper Miocene time. These Miocene deposits were separated by a lava flow composed of iddingsite andesite.

The effects of the Pleistocene ice ages are shown in the numerous elevated and submerged terraces and the deep submarine canyon found in the area. The Aromas Red Sandstones so obvious around Carmel are another result of Pleistocene enroachment. The predominant feature of the area since Cretaceous time has been the large granitic pluton upon which all younger rocks sit. The pluton has provided both a resting place and a source rock for many of the younger sediments.

A completed geologic map of the area is enclosed as Fig.6. The map is a result of combining data from previous studies with data gathered for this paper. This map should provide the best available guide to the geology of Carmel Bay.

Two types of sources exist for the beach sands. On isolated beaches the primary source may be the nearby rock outcrops and recent sediments. In several areas river run-off provides most of the sand for the beaches.

Zones of contact metamorphism in the bay itself and Sur Series metamorphics in the upper drainage basin of the Carmel River are the only identifiable sources for the large amount of garnet found along the beach.

VIII. SUGGESTIONS FOR FURTHER STUDIES

The following studies are presently being conducted within the bay:

1. methods of sediment transport between the mouth of the Carmel River and the head of the Carmel Submarine Canyon (B. F. Howell, NPS, in progress);
2. sediment transport within Whalers Cove (L. Leopold, San Jose State College, in progress).

Further studies that would be useful in defining the marine and geologic environment of the bay should include:

1. carbon, carbonate and organic nitrogen analysis of the sediments;
2. current and water column structure determinations within the bay;
3. heavy mineral analysis of the Carmel Valley riverbed;
4. seismic refraction measurements along the Carmel Valley flood plain;
5. gravity and magnetic measurements of Carmel Bay;
6. current measurements of the bay.

TABLE I

COMPARATIVE STRATIGRAPHIC COLUMNS FROM LAWSON(1893), BEAL(1915) AND BOWEN (UNPUBLISHED)

	FORMATION	AGE
LAWSON	Alluvium	Quaternary
	Terrace Fms.	Quaternary/Pliocene
	Eruptive Rocks	Miocene
	Monterey Series	Miocene
	Carmelo Series	Eocene, Tejon?
	Santa Lucia Granite	Pre-Cretaceous
BEAL	Alluvium	Quaternary
	Dune and Terrace Sands	Quaternary
	Paso Robles and Santa Margerita Fms.	Pliocene
	Lava	Miocene?
	Monterey Shale	Miocene
	Monterey Sandstone	Miocene
	Carmelo Series	Cretaceous
	Granite	Jurassic
BOWEN	Alluvium	Quaternary
	Landslides	Quaternary
	River Terraces	Quaternary
	Aromas Red Sands	Quaternary
	Monterey Shale	Upper Miocene
	Monterey Sandstone	Upper Miocene
	Olivene Basalt	Middle Miocene
	Chamisal Formation	Middle Miocene
	Carmelo Series	Paleocene
	Porphyritic Biotite Granodiorite	Cretaceous

TABLE II.

HEAVY MINERAL ANALYSIS OF CARMEL BAY AND CARMEL RIVER SEDIMENT SAMPLES (ANALYSES OF THE 3.5 TO 4.0Ø FRACTIONS EXCEPT FOR CARMEL BAY SAMPLE #44; AT LEAST 150 GRAINS OF EACH SAMPLE COUNTED; REPORTED AS PERCENT OF TOTAL HEAVY MINERALS COUNTED)

	Carmel Bay Sediment Samples (Locations Shown on Fig. 4)										Carmel River Sediment Samples (Locations Shown on Fig. 5)				
	Pebble Beach Pay Streak	C-1-A	8	10	13	16	17	25	44*	48	1	2	3	4	5
Pyroxene (Augite)	1	6	16	12	6	10	7	12	-	5	2	14	11	14	12
Amphibole (Hornblende + Lamprobolite)	3	26	53	37	42	56	55	53	41	14	13	38	42	48	43
Clinozoisite	-	4	3	-	Tr	8	4	2	-	1	-	2	1	3	1
Chlorite	Tr	6	-	3	2	-	1	3	-	-	-	-	-	-	-
Zircon	5	6	6	4	2	4	2	7	Tr	13	Tr	6	3	9	5
Biotite	-	37	3	27	39	6	13	7	44	3	82	20	6	13	11
Epidote	-	4	4	5	3	7	8	6	-	9	-	-	3	-	2
Garnet	36	3	7	4	2	4	4	3	2	5	Tr	8	13	3	11
Rutile	-	1	Tr	-	-	-	-	-	-	-	-	-	-	-	-
Sphene	1	1	Tr	Tr	-	1	1	Tr	-	4	-	-	2	1	1
Opaque (Magnetite)	54	6	8	8	4	4	5	7	13	46	3	12	19	9	14

*+2.5 to +3.0Ø Fraction

Tr indicates less that 0.5%

TABLE III

SAMPLE NUMBERS AND FIELD DESCRIPTIONS

*SAMPLE NO.	FIELD DESCRIPTION
1. X	Lava
2. X	Lava
3.	Quaternary Sandstone
4. X	Lava
5. X	Lava
6. X	Lava
7.	Quaternary Sandstone
8.	Quaternary Sandstone
9. X	Lava
10. X	Monterey Shale
11. X	Rhyolite?
12. X	Lava
13. X	Conglomerate(Calcite Cement)
14. X	Granitic Material
15. X	Lava
16. X	Cobble in Conglomerate
17. X	Carmelo Pebbles
18. X	Pebble from Conglomerate.
19.	Conglomerate Matrix
20.	Boulder Conglomerate
21. X	Carmelo?
23. X	Lava
24. X	Sandstone(Miocene)
25.	Monterey Shale
26.	Lava
27.	Granite
28. X	Sandstone(Miocene)
29. X	Carmelo Sandstone
30.	Matrix from Conglomerate
31.	Quaternary Sandstone
32.	Lava
33.	Aromas Red Sands
34.	Aromas Red Sands
35.	Aromas Red Sands
36.	Quaternary Sandstone
42.	Quaternary Sandstone
43.	Monterey Shale
44.	Sandstone below Carmelo
45.	Carmelo Matrix
46.	Lava
49.	Quaternary Sandstone
50.	Monterey Shale

---

* Sample locations on Figure 3.

X Thin Sections Prepared

TABLE III (continued)

54.		Monterey Shale
55.		Lava
56.	X	Carmelo Pebble in Temblor
57.		Lava
58.		Chert from Monterey Shale
59.		Temblor
60.		Temblor
61.		Lava
62.	X	Monterey Shale?
63.	X	Lava
64.		Monterey Shale
65.		Lava
66.		Recent Sediments
67.		Quaternary Sandstone
68.		Carmelo Pebble in Quaternary
69.		Vein in lava
70.	X	Temblor
71.	X	Garnet Hornfels
101.		Granite
102.		Lava
103.		Carmelo
109.		Granite (Out of Place)
110.		Carmelo
111.		Carmelo
112.		Carmelo
113.		Carmelo
114.		Carmelo
115.		Lava
116.		Lava
117.		Granite

TABLE IV

LIST OF FOSSILS FROM THE TYPE LOCALITY OF THE MONTEREY SERIES

(FROM MARTIN, 1912)

PELECYPODA
  Arca obispoano Conrad
  Glycymeris, sp.
  Leda, cf. taphria Dall
  Macoma (Tellina) congesta Conrad
  Marcia oregonensis Conrad
  Modiolus, sp.
  Nucula, sp.
  Pecten peckhami Gabb.
  Venericardis montereyana Arnold
  Sharks teeth

GASTEROPODA

  Ficus kernianus Cooper
  Necerita, sp. indet.
  Trochita, sp.

TABLE V

CHEMICAL ANALYSIS OF AREA ROCKS

(FROM LAWSON, 1893)

	Lava (Arrowhead Point)	Lava (Lagoon Area)	Monterey Shale	Granodiorite
SiO_2	52.83	60.00	86.89	71.63
TiO_2	Tr.	0.00	0.00	Tr.
Al_2O_3	17.67	10.01	2.32	13.86
Fe_2O_3	7.50	3.20	1.28	0.46
FeO	1.68	0.68	0.00	2.67
CaO	7.35	4.10	0.43	3.26
MgO	2.47	1.28	Tr.	Tr.
K_2O	2.52	2.79	1.26	2.65
Na_2O	6.61	6.97	2.32	3.40
P_2O_5	0.00	0.00	0.00	0.20
MnO	0.00	Tr.	0.00	0.00
Ignition	2.32	4.30	4.89	0.89
Total	100.95	102.33	99.39	99.11
Sp. g.	2.80	2.51-2.54	2.018	2.68

TABLE VI

TYPE, DESCRIPTION AND RELATIVE ABUNDANCE OF CARMELO PEBBLES (FROM NILI-ESFAHANI, 1965)

Pebbles & Cobbles (rock name)		
Andesitic tuff	Hard, black, dense, with aphanitic texture. The matrix constitutes 90% of the rock and is chloritic in composition. Phenocrysts of andesine with some quartz.	49%
Meta-andesitic tuff	Dark green, hard, dense, with aphanitic texture. Matrix contains chloritic minerials and quartz (90%). Phenocrysts are of albite.	
Meta-andesitic andesite	Greenish, hard, dense, with porphyritic texture. Phenocrysts consist of plagioclase and augite which have been strongly altered to epidote, calcite, chlorite, spene, apatite and magnetite.	25%
Porphyritic andesite	Light pink, hard, dense and porphyritic. Phenocrysts comprise as much as 30% of the rock. They consist of quartz, sodic plagioclase. They are angular and show some alterations. Chlorite and magnetite form the matrix.	9%
Porphyritic rhyolite	Dark gray-brown, porphyritic, hard, and dense. Up to 20% phenocrysts which consist of orthoclase and quartz. Matrix is very fine mixture of chloritic minerals and fine quartz.	7%
Others:	Granodiorite	3%
	Alkali	2%
	Chert, quartz, and Jasper	
	Rhyolittic tuff	4%

TABLE VII

LIST OF SPECIES OF FAUNA FROM THE CARMELO SERIES AT POINT LOBOS AND PEBBLE BEACH, MONTEREY, CALIFORNIA

(FROM NILI-ESFAHANI, 1965)

Phyla	Genus and species	Age
Gastropod	*Heteroterma* (?) *trochoidea*	Paleocene
	Turritella pachecoensis	Paleocene
Pelecypod	*Lucina* cf. *miltha*	Paleocene
Foraminifera	*Anamalina sp.*	
	Ammobaculites spp.	Carb-Recent
	Ammodiscus sp.	Sil-Recent
	Bathysiphon eocenicus Cushman & C. D. Hanna	Eocene
	Bathysiphon spp.	L. Camb-Recent
	Cribrostomoides cf.C.*trinitatensis* Cushman & Waters	U. Cret-Recent
	Dorthia sp.	L. Camb-Recent
	Haplophrogmoides	
	" cf. *H.excavata* Cushman & Waters	U.K.
	" cf. *H.longifussus* Israelsky	U. Pal. or Eocene
	spp.	Carb-Recent
	Hypermina	L. Ord-Recent
	Silicosigmoilina californica Cushman & Church	U.K.
	Spiroplectammina spp.	U.K. Paleocene
	Spiroplectammina perplexa Israelsky	Paleocene
	Textularia (?) *sp.*	Permian-Recent
	Trochamina cf.*T.trifolia* (Egger)	
	Trochammina sp.	Carb-Recent

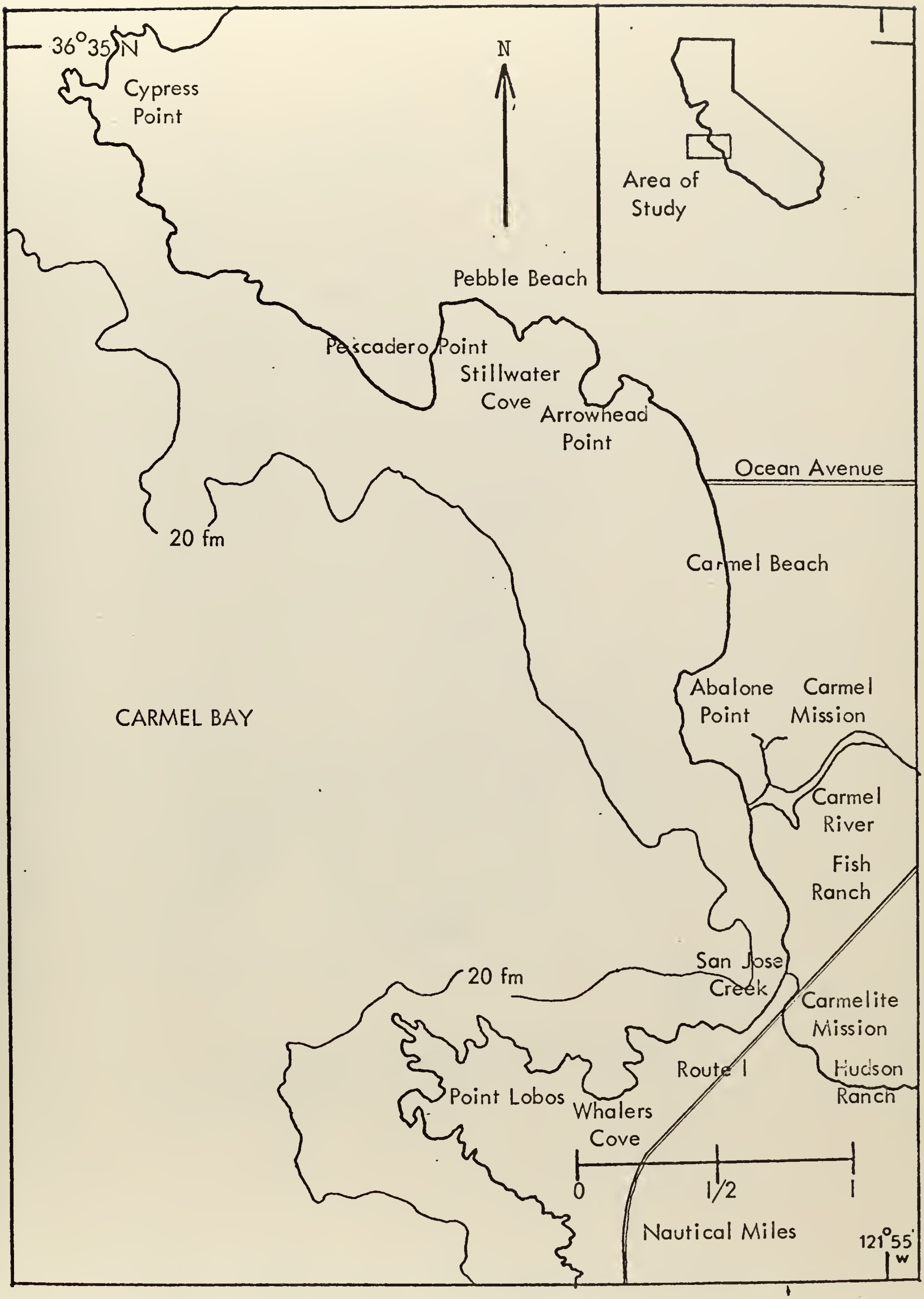


Figure 1. Location Map of Carmel Bay (from C&GS 5476)

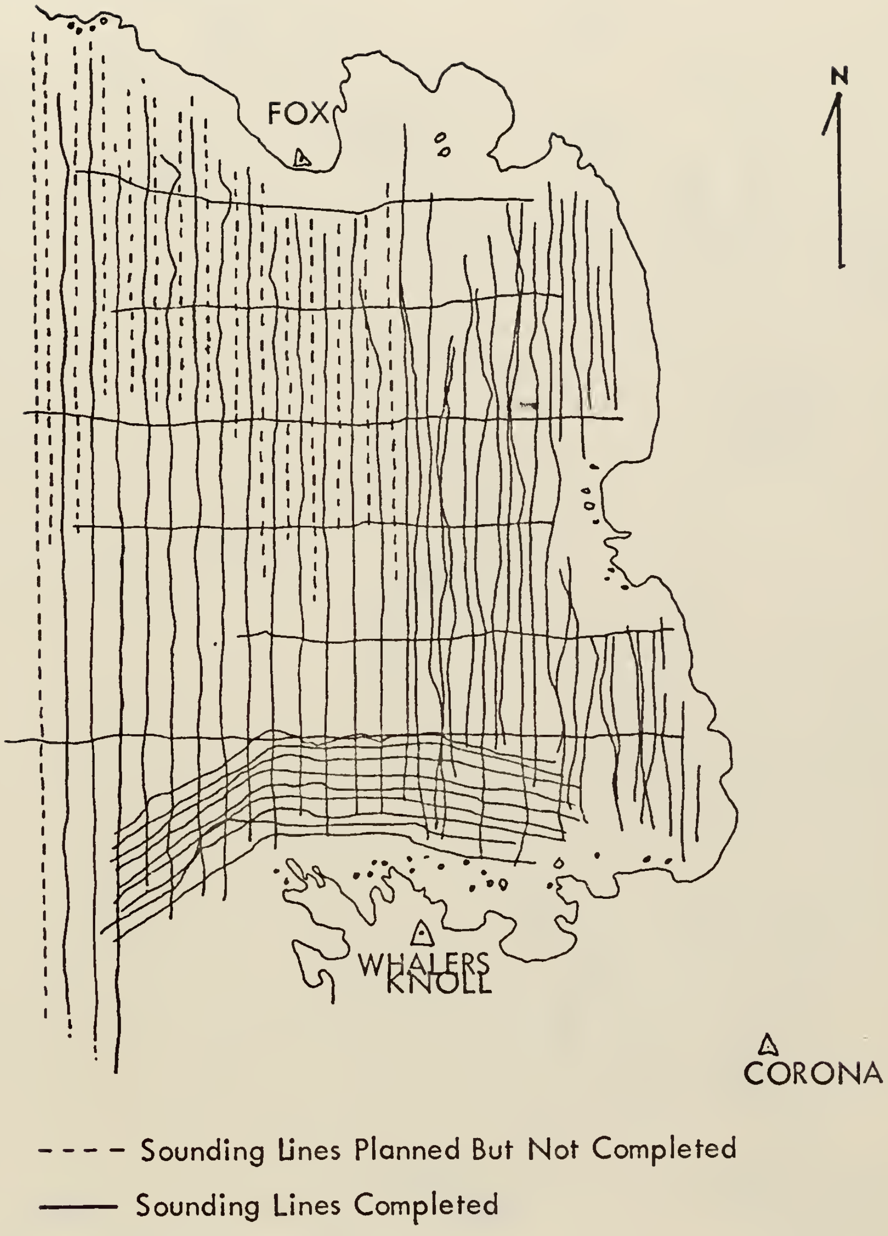


Figure 2. Survey Lines Steamed and Survey Lines Not Completed

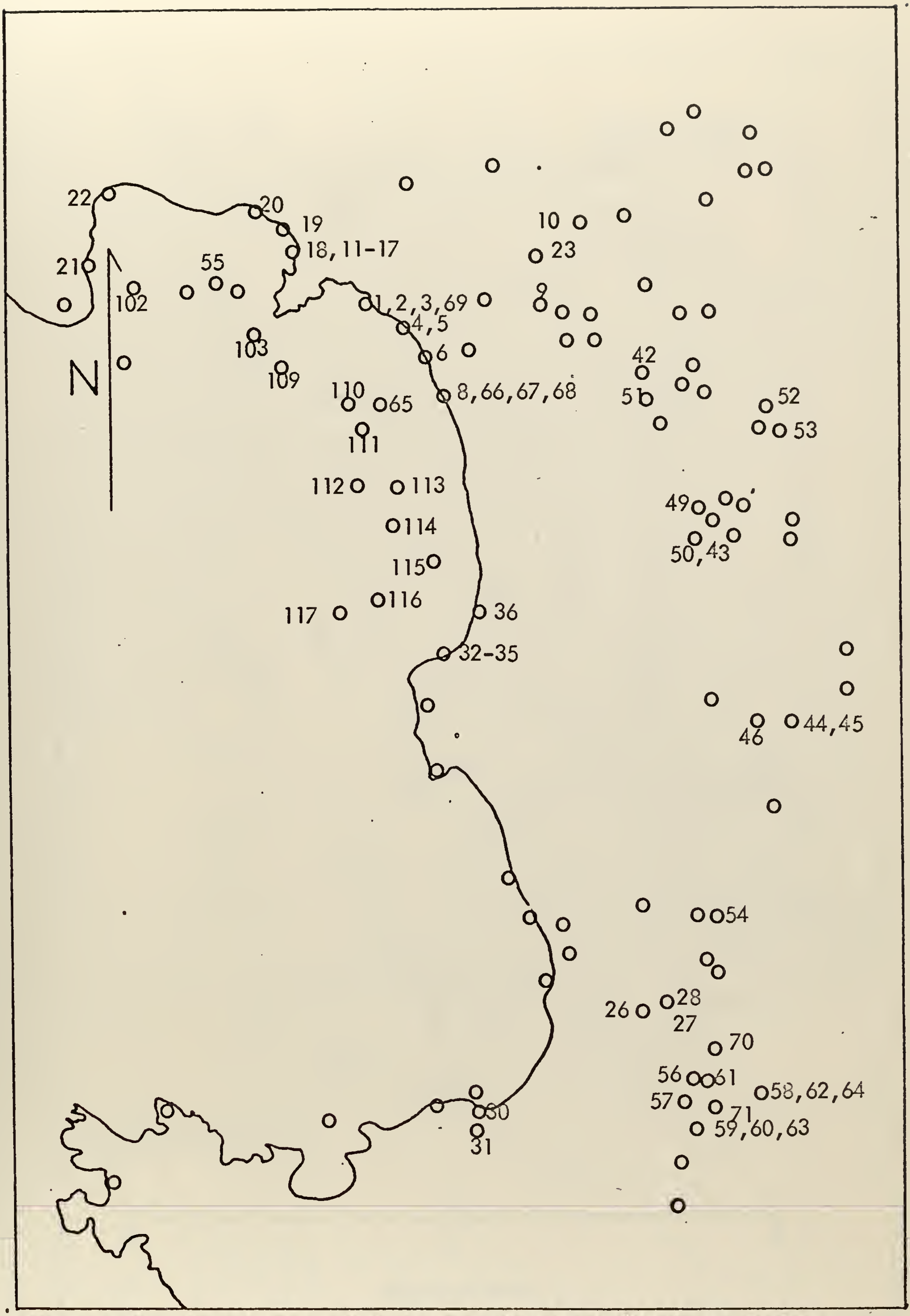


Figure 3. Locations of Outcrops Studied (Numbers Refer to Collected Samples Listed in Table III)

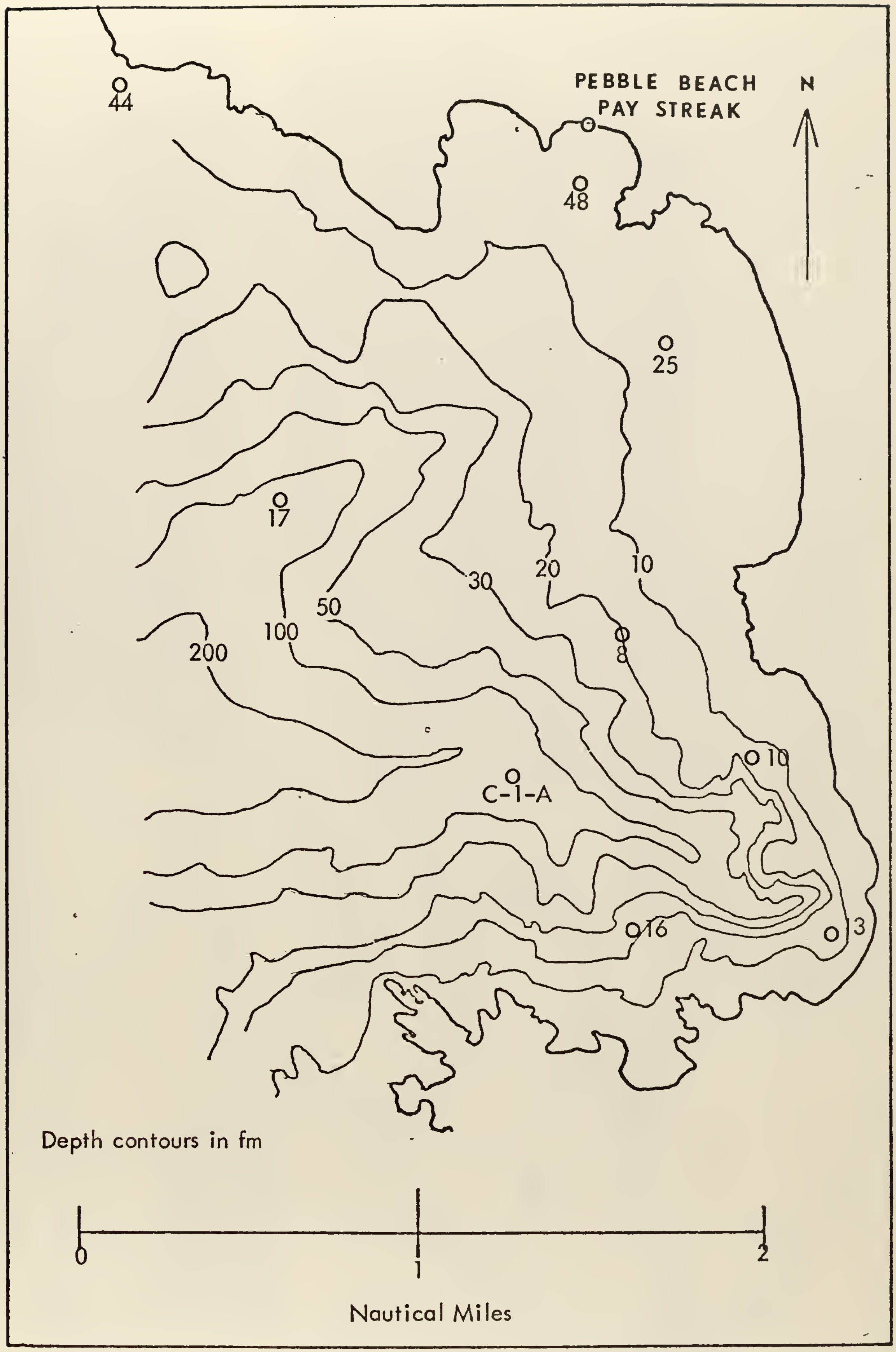
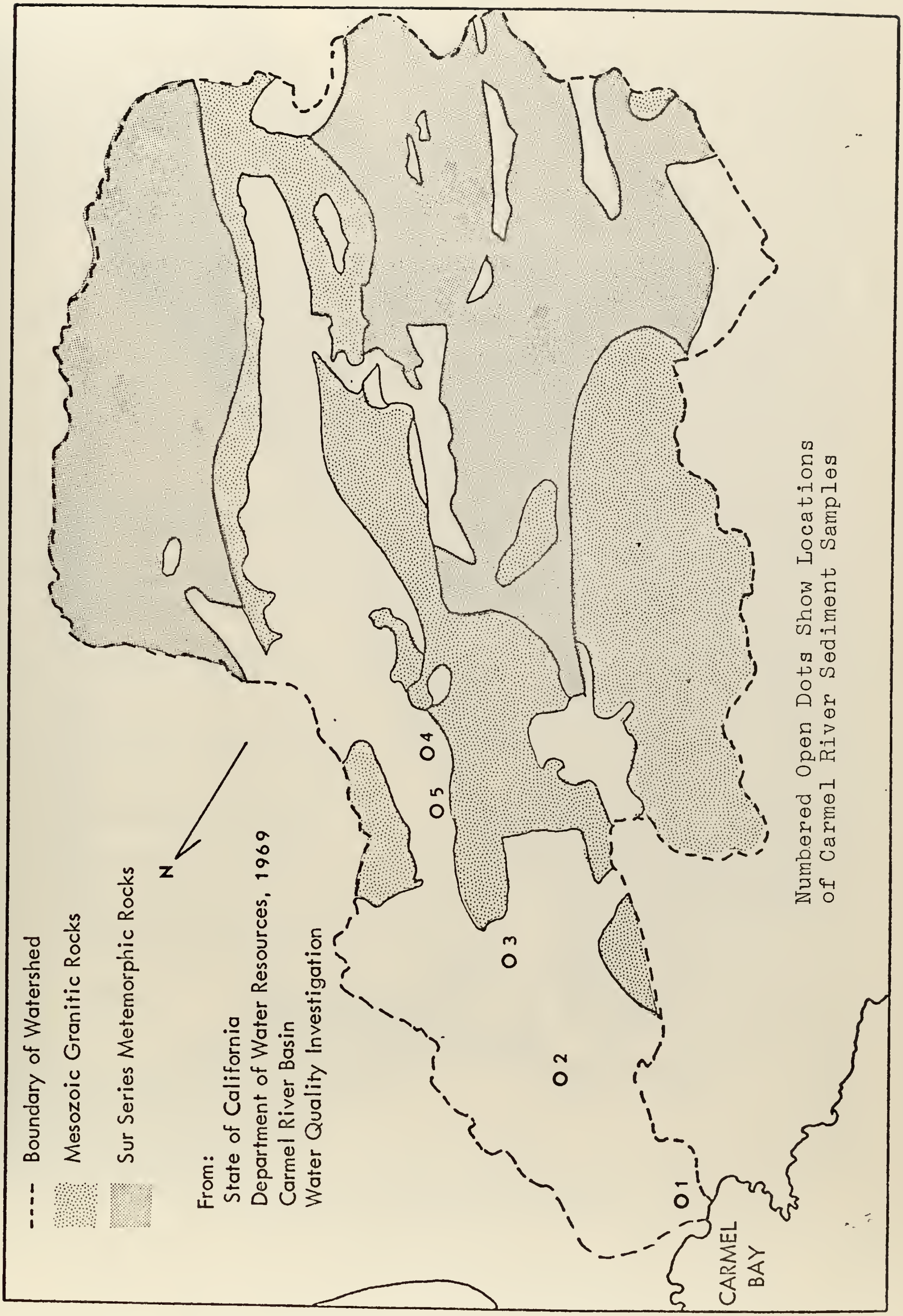


Figure 4. Carmel Bay Sediment Sample Locations (From Carter, 1971)



From:
State of California
Department of Water Resources, 1969
Carmel River Basin
Water Quality Investigation

Numbered Open Dots Show Locations of Carmel River Sediment Samples

Figure 5. Carmel River Watershed and Sediment Sample Locations

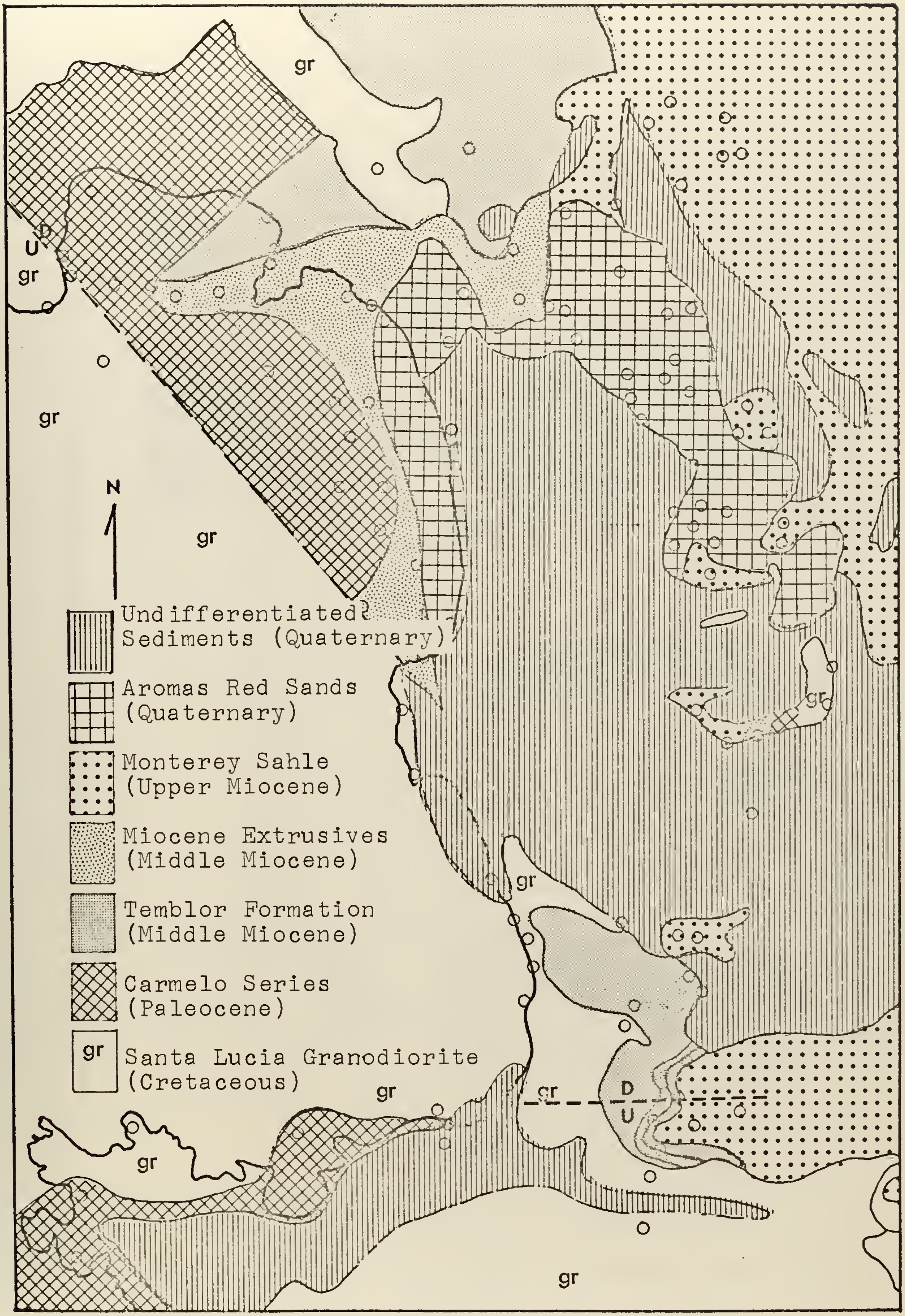


Figure 6. Geologic Map of Carmel Bay Area.

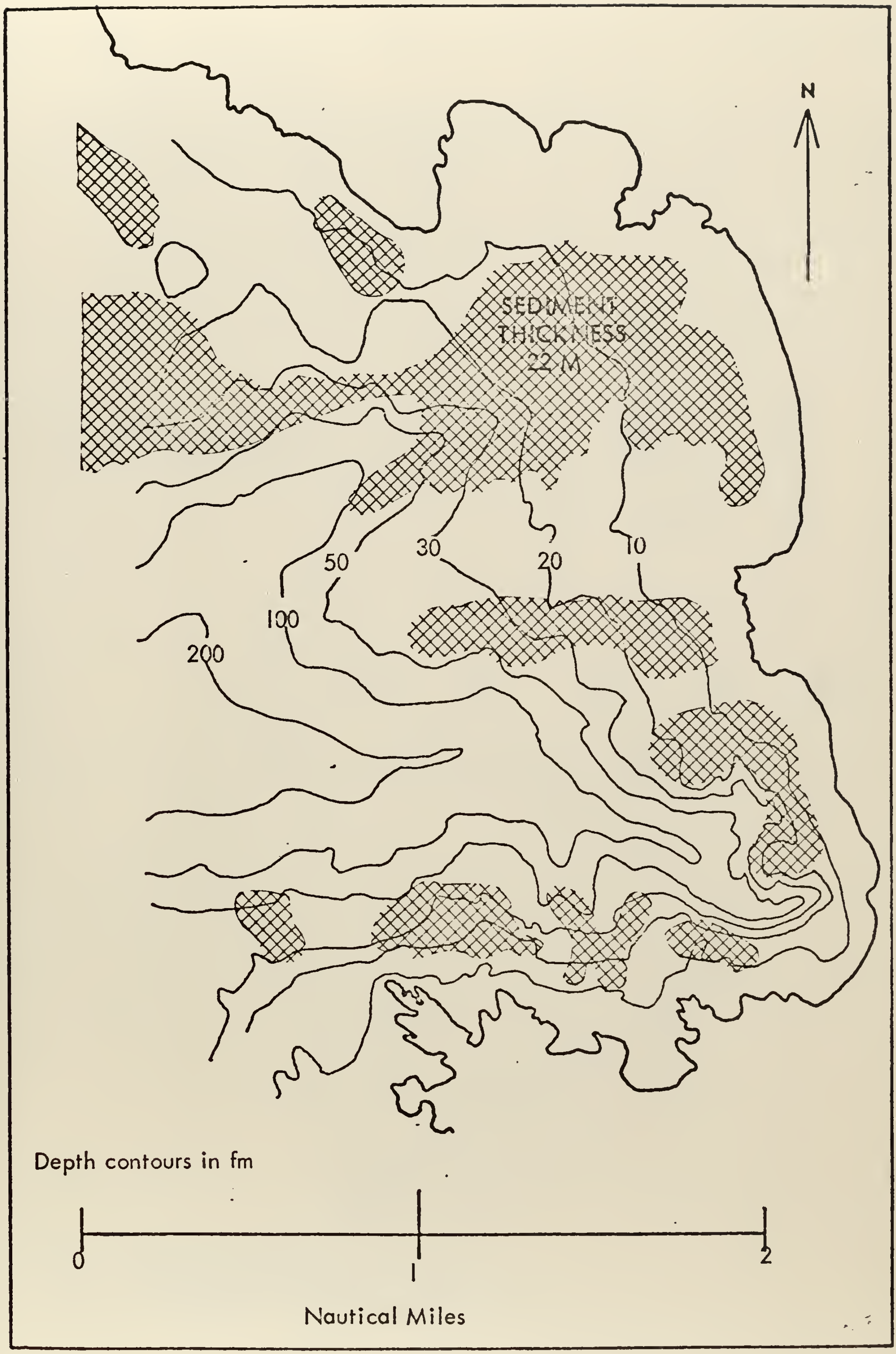


Figure 7. Bay Sediment Pocket Locations

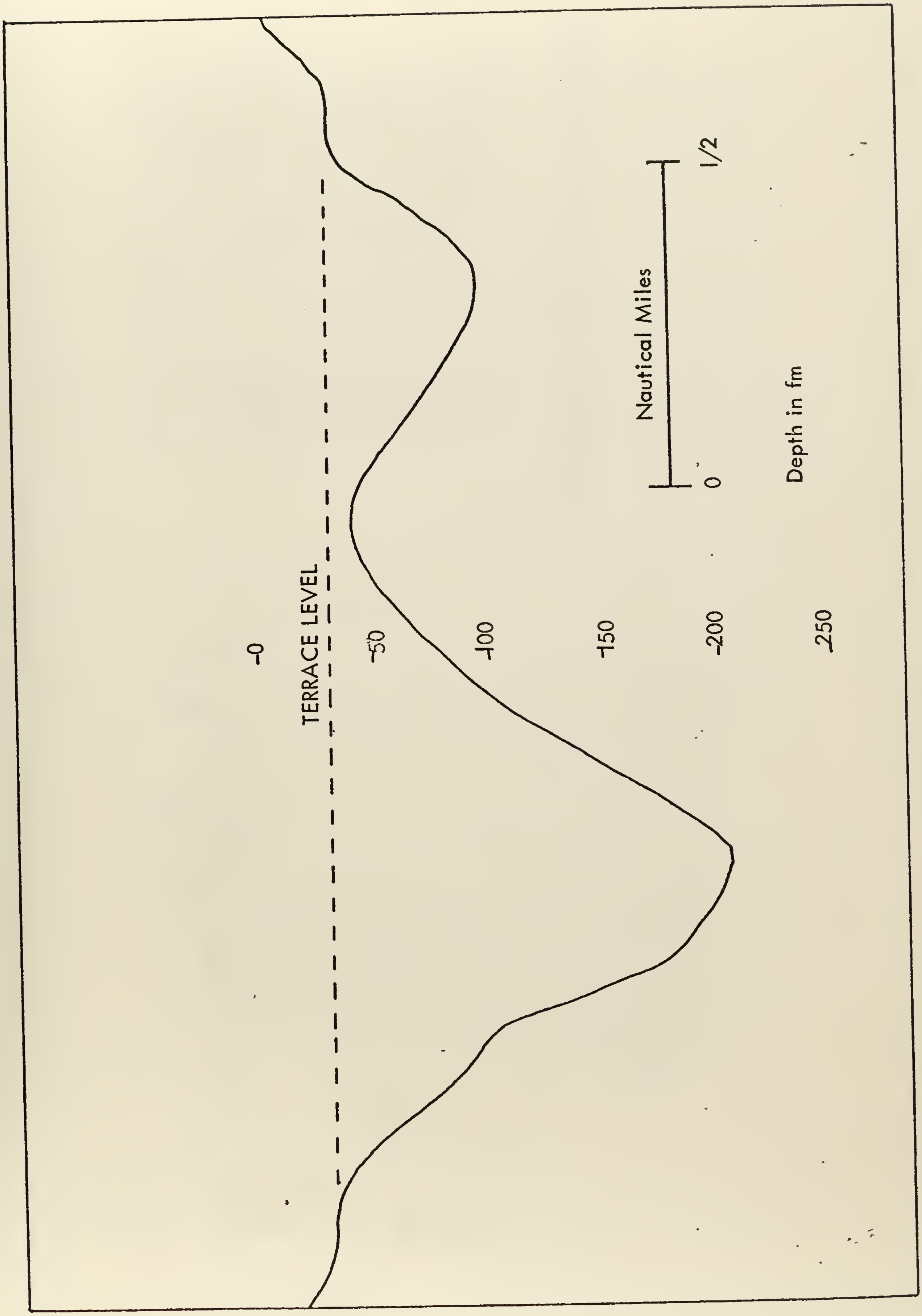


Figure 8. Fathometer Record of Carmel Bay Showing Submerged Terraces

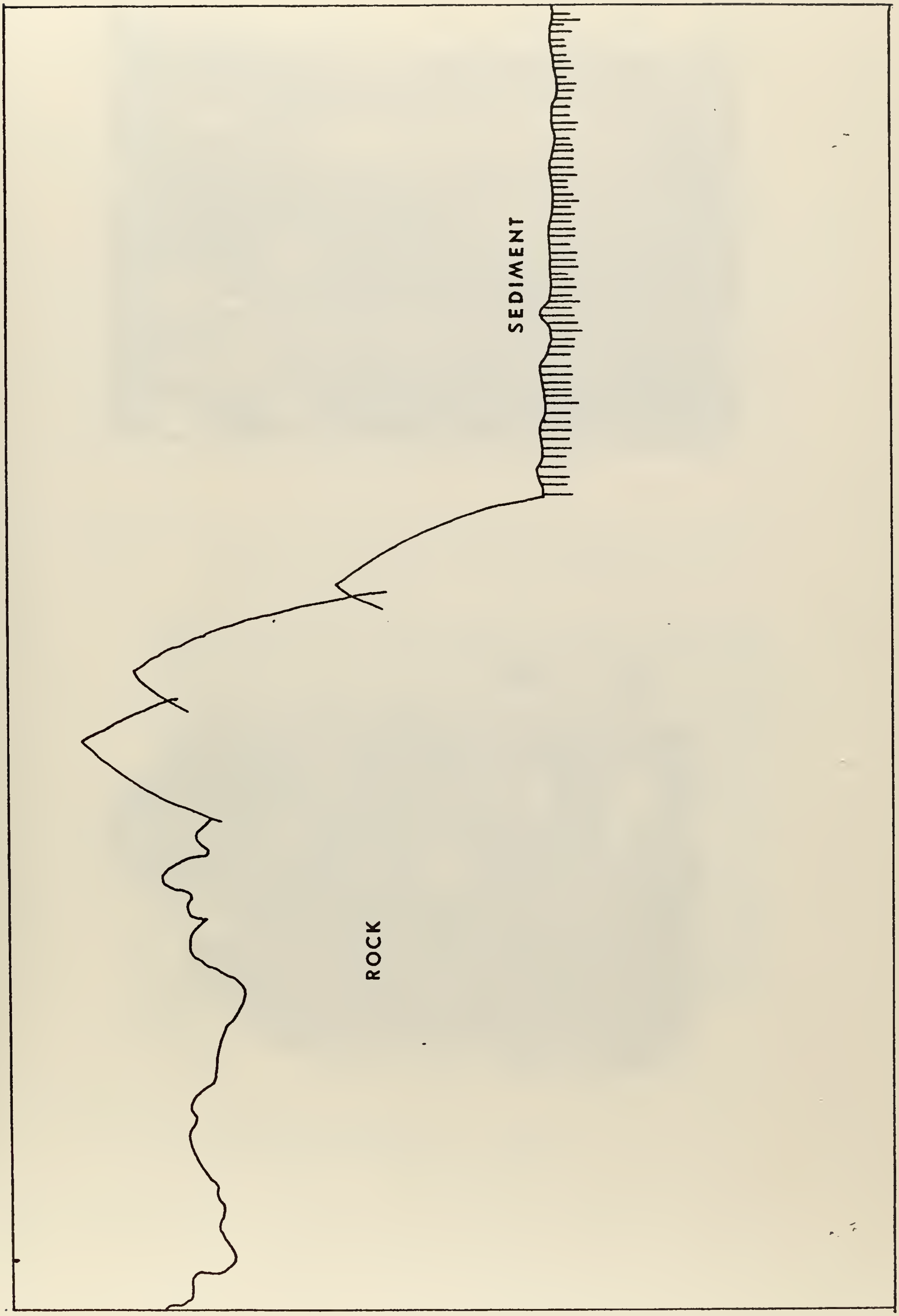


Figure 9. Trace of 3.5 kHz Record Showing High Reflectivity and Smoothness of Sediment Portion

Plate 1. Aerial Photograph of Carmel Bay (Taken from a position south of Point Lobos looking north)

Plate 2. Iddingsite Crystal (X110)

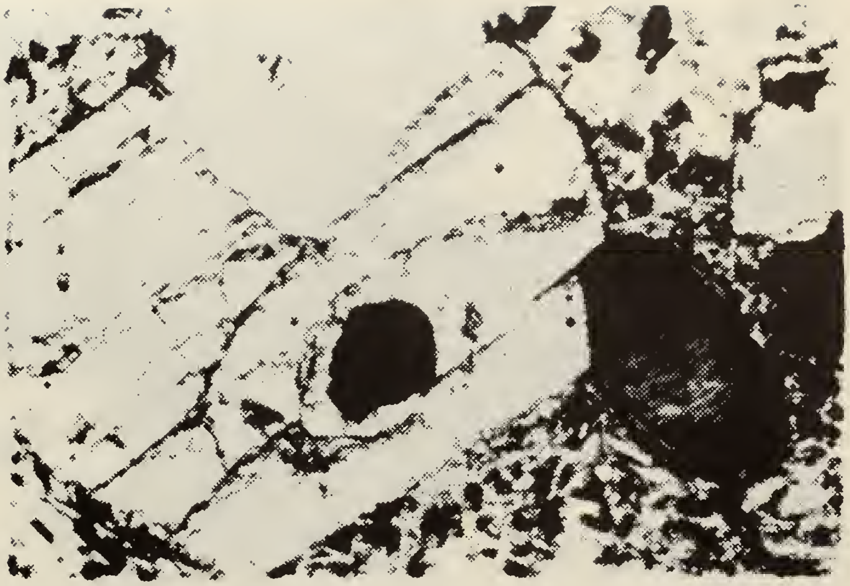


Plate 3. Iddingsite and Augite Crystals (X87)

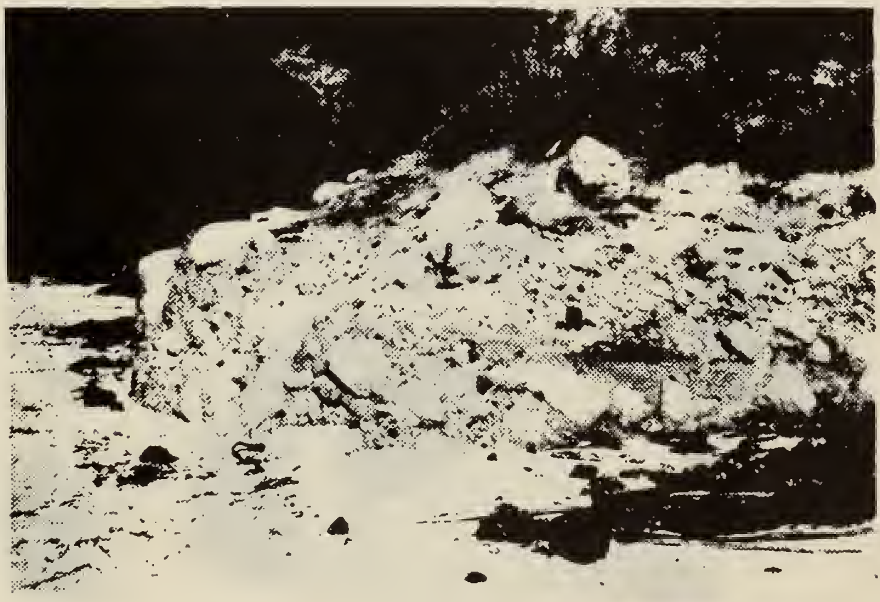


Plate 4. Previously Undescribed Boulder Conglomerate

[illegible]

[illegible]

Plate 5. Contact Between Carmelo and Boulder Conglomerate

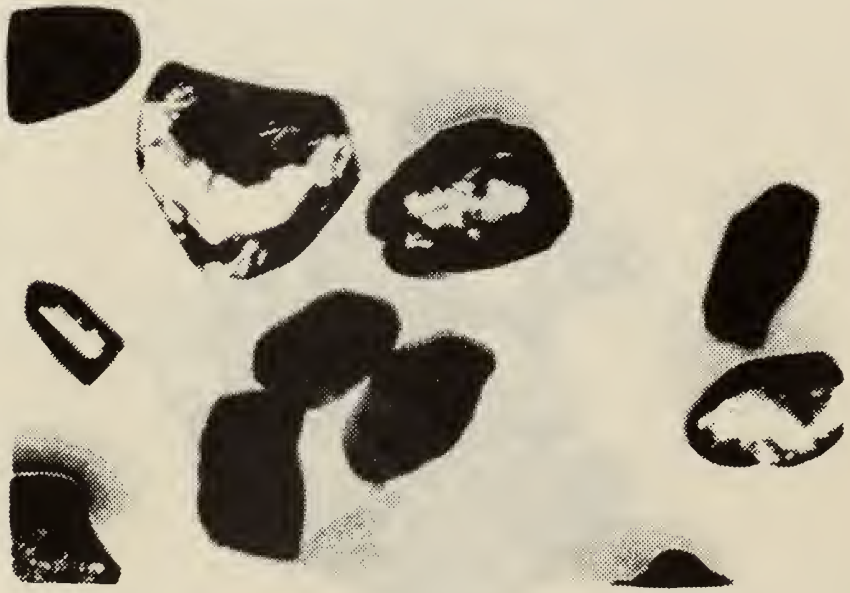


Plate 6. Microphotograph of Pebble Beach Pay Streak (Large Transparent Grains of Garnet; Euhedral Grains of Zircon; Opaque Magnetite Grains) (X310)

Plate 7. Pay Streak of Heavy Minerals
(Photographed at Pebble Beach)

Plate 8. Garnet Crystal (From Garnet Hornfels found North of San Jose Creek) (X83)

[illegible]

[illegible]

Plate 9. Carmelo Outcrop Showing Typical Carmelo Features (Pebble Conglomerate, Sandstone, Siltstone)

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.

Blake, W. P. 1855. Preliminary Geological Report of the U. S. Pacific Railroad Survey, Under the Command of Lieut. R. S. Williamson, Corps of Topographic Engineers, 1853. Am. Jour. Sci. and Arts, 2nd ser: 19:433-434.

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

Brabb, E. E., O. E. Bowen, and E. W. Hart. 1962. Field Trip 2: San Francisco to Monterey Via California Highways 1, 5, 17 and Connecting Routes, p. 381-390. In O. E. Bowen(ed) Geologic Guide to the Gas and Oil Fields of Northern California. Calif. Div. Mines Geol. Bull. 181.

Bramlette, M.N. 1946. The Monterey Formation of California and The Origin of its Siliceous Rocks. U. S. Geol. Survey Prof. Paper 212. 57 p.

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

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

Cooper, W. S. 1967. Coastal Dunes of California. The Geological Society of America, Inc., Boulder, Colo. 131p.

Curtis, C. H., J. F. Evernden, and J. Lipson. 1958. Age Determination of Some Granitic Rocks in California by The Potassium-Argon Method. Calif. Dept. Natural Resources Div. Mines Sp. Rpt. 54. 16 p.

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

Hawley, H. J. 1917. Stratigraphy and Paleontology of the Salinas and Monterey Quadrangles, California. Bull. Geol. Soc. Amer. 28:225. (Abstract).

Judge, C. W. 1970. Heavy Minerals in Beach and Stream Sediments as Indicators of Shore Processes between Monterey and Los Angeles, California. U.S. Army Coastal Engr. Research Center, Tech. Memo. No. 33, Washington, D. C. 44 p.

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

Martin, B. 1912. Fauna from the Type Locality of the Monterey Series in California. Bull. Dept. Geol., Univ. of Calif. Berkeley 7:143-150.

Martin, B. D. 1964. Monterey Submarine Canyon, California: Genesis and Relationship to Continental Geology. PhD Dissertation, Univ. of S. Calif., Los Angeles. 249 p.

Martin, B. D., and K. O. Emery. 1967. Geology of Monterey Canyon, California. Bull. Amer. Assoc. Petrol. Geologists. 51(11):2281-2304.

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

Shepard, R. P., and R. F. Dill. 1966 Submarine Canyons and Other Sea Valleys. Rand McNalley & Co., Chicago. 381 p.

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

Taliaferro, N. S. 1933 The Relation of Volcanism to Diatomaceous and Associated Siliceous Sediments. Calif. Univ. Dept. Geol. Sci. Bull. 46(7):1079-1100.

Taliaferro, N. S. 1944. Cretaceous and Paleocene of Santa Lucia Range, California. Bull. Amer. Assoc. Petrol. Geologists. 28(4):450-465.

Trask, J. B. 1854. Report of the Geology of the Coast Mountains and Particularly of the Sierra Nevada. Assembly Journal, Appendix doc. 9, 5th Session, State Legislature, Calif. 21, 22, 36

Trask, J. B. 1855. Report of the Geology of the Coast Mountains. Assembly Journal, Appendix doc. 14, 6th Session State Legislature, Calif. 28.

Trask, P. D. 1926. Geology of Point Sur Quadrangle, California Bull. Dept. Geol., Univ. of Calif. 16:119-186.

Whitney, J. D. 1865. Geological Survey of California. Geology, Volume I. Caxton Press, Philadelphia. 498 p.

Zardeskas, R. A. 1971. A Bathymetric Chart of Carmel Bay, California. 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 58Ad Department of Oceanography Naval Postgraduate School Monterey, California 93940	10
4.	Department of Oceanography, Code 58 Naval Postgraduate School Monterey, California 93940	3
5.	LCDR C.K. Roberts, USN Department of Oceanography, Code 58 Rb Naval Postgraduate School Monterey, California 93940	1
6.	LT R.A. Zardeskas, USN Tactical Electronic Warfare Squadron 129 NAS Whidbey Island Oak Harbor, Washington 98277	1
7.	LT L.S. Carter, USN COMFAIRADAK Staff U.S. Naval Station F.P.O. Seattle, Washington 98791	1
8.	Mr. Thompson J. Hudson Pt. Lobos Carmel, California 93921	1
9.	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

		No. Copies
10.	Office of Naval Research Code 480D Arlington, Virginia 22217	1
11.	Point Lobos State Reserve Carmel, California 93921	1
	Attn: Mr. D. Rich	1
12.	Dr. Francis P. Shepard Scripps Institute of Oceanography University of California at San Diego La Jolla, California 92038	
13.	LT J.P. Simpson, USN ASW Group III Staff FPO, San Francisco 96601	3
14.	Mr. Earl Smith Director, Monterey County Park Dept. P. O. Box 367 Salinas, California 93901	1
15.	Professor W. C. Thompson, Code 58th Department of Oceanography Naval Postgraduate School Monterey, California 93940	1
16.	Mr. Lawrence Leopold Department of Geology San Jose State College San Jose, California	1
17.	Oceanographer of the Navy The Madison Building 732 N. Washington Alexandria, Virginia 22314	1
18.	LT B. F. Howell Naval Postgraduate School, SMC #1028 Monterey, California 93940	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

The Geology of Carmel Bay, California

4. DESCRIPTIVE NOTES (Type of report and, inclusive dates)
Master's Thesis; March, 1972

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

John P. Simpson, III

6. REPORT DATE March 1972	7a. TOTAL NO. OF PAGES 74	7b. NO. OF REFS 27
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

Approved for public release; distribution unlimited.

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

13. ABSTRACT

Data obtained from rock and sediment samples collected in Carmel Bay were coordinated with seismic and bathymetric information to produce the first geologic map of the area showing the terrestrial geology extended into the bay itself. The map shows a large underwater area of possible contact metamorphism which serves as the source rock for the heavy minerals found along the local beaches.

A previously undescribed granodiorite boulder conglomerate was found resting unconformably on the Paleocene Carmelo Series along the shores of Stillwater Cove. The conglomerate is unlike anything else seen in the area, but it is thought to be associated with the Temblor Formation of Miocene age.

Seismic data assisted in locating sediment pockets within the bay. The sediment pockets, when associated with the geologic map of the bay itself, help to give a greater understanding of the geomorphology and sedimentary processes occuring within the bay.

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Carmel Bay Geology						
Marine Geology						

Thesis
S512
c.1
133921
Simpson
The geology of the
Carmel Bay, California.

25 JUL 72 20887
31 AUG 73 22337
21 OCT 76 23661
5 Aug' 80 INTERLIBRARY LOAN
3 MAR 81 S12428
8 AUG 83 S10109

Thesis
S512
c.1
133921
Simpson
The geology of the
Carmel Bay, California.

thesS512
The geology of the Carmel Bay, Californi
3 2768 001 91425 2
DUDLEY KNOX LIBRARY