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C.W. Judge

TECHNICAL MEMORANDUM NO. 33

NOVEMBER 1970

U. S. ARMY, CORPS OF ENGINEERS

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ABSTRACT

A study of heavy minerals along the California Coast was made at the Coastal Engineering Research Center (CERC) as an adjunct to the Radioisotopic Sand Tracer (RIST) and the Littoral Environmental Observation (LEO) programs of the Center. Sand samples taken at the waterline during various times of the year were supplemented by samples from the offshore zone and the rivers. Heavy minerals in the 63-125 micron fraction of the samples were identified by optical techniques.

Five heavy-mineral provinces were identified: 1) a northern Hornblende province from north of Monterey Bay to Piedras Blancas Point; 2) a northern Augite Province from Piedras Blancas Point to Avila Beach; 3) an Epidote province from Avila Beach to Ventura; 4) a southern Augite Province from Ventura to Palos Verdes Point; and 5) a southern Hornblende Province from Point Fermin south.

The ratios of the less stable augite and hornblende to the more stable garnet and zircon indicated a definite southward littoral transport north of Point Conception. The increase in grain sizes and in augite and hornblende content south of the input from the Ventura and Santa Clara Rivers indicated a southward net littoral transport there. Similar trends could not be found between Point Conception and Ventura. Because of possible multiple sources for augite and because of reversals in the littoral transport, heavy minerals are not definitive indicators of littoral drift along beaches from Point Conception to Ventura. However, coupled with other evidence from radioisotopic tracer surveys, historical surveys, and dredging projects, it is reasonable to conclude that, although Point Conception-Point Arguello may act as a partial barrier, some sand moves south and east around them.

FOREWORD

Since July 1966, CERC has directed a multiagency program to develop a sand-tracing system using radioactive isotopes. A part of this RIST program is directed to studying sand movement along the California Coast, and was the basis for this study and the source of many samples. The CERC Littoral Environmental Observation (LEO) program - established in 1968 in cooperation with the State of California to monitor beach changes along the California Coast - was the source of additional samples. This report summarizes the results of a study of heavy minerals along the California Coast made in conjunction with both the RIST and LEO studies.

Charles W. Judge, Geologist on the CERC staff, prepared this report under the general supervision of G. M. Watts, Chief, Engineering Development Division and D. B. Duane, Chief, Geology Branch. W. R. James developed the dendrograms used in this study. It is part of a cooperative program of the Atomic Energy Commission (AEC) and CERC. Work of the AEC is provided through the Oak Ridge National Laboratory (ORNL). Other participants in the present West Coast studies are: U. S. Army Engineer District, Los Angeles; U. S. Army Mobility Equipment (Research and Development) Command; First Strategic Aerospace Division, USAF; U. S. Navy Pacific Missile Range; Nuclear Systems and Space Power Division, National Aeronautics and Space Administration (NASA); and the Department of Water Resources, State of California.

The assistance of Dr. D. S. Gorsline, University of Southern California, in providing several heavy-mineral samples from streams and beaches, is sincerely appreciated.

At the time of publication, Lieutenant Colonel Edward M. Willis was Director of the Coastal Engineering Research Center; Joseph M. Caldwell was Technical Director.

NOTE: Comments on this publication are invited. Discussion will be published in the next issue of the CERC Bulletin.

This report is published under authority of Public Law 166, 79th Congress, approved July 31, 1945, as supplemented by Public Law 172, 88th Congress, approved November 7, 1963.

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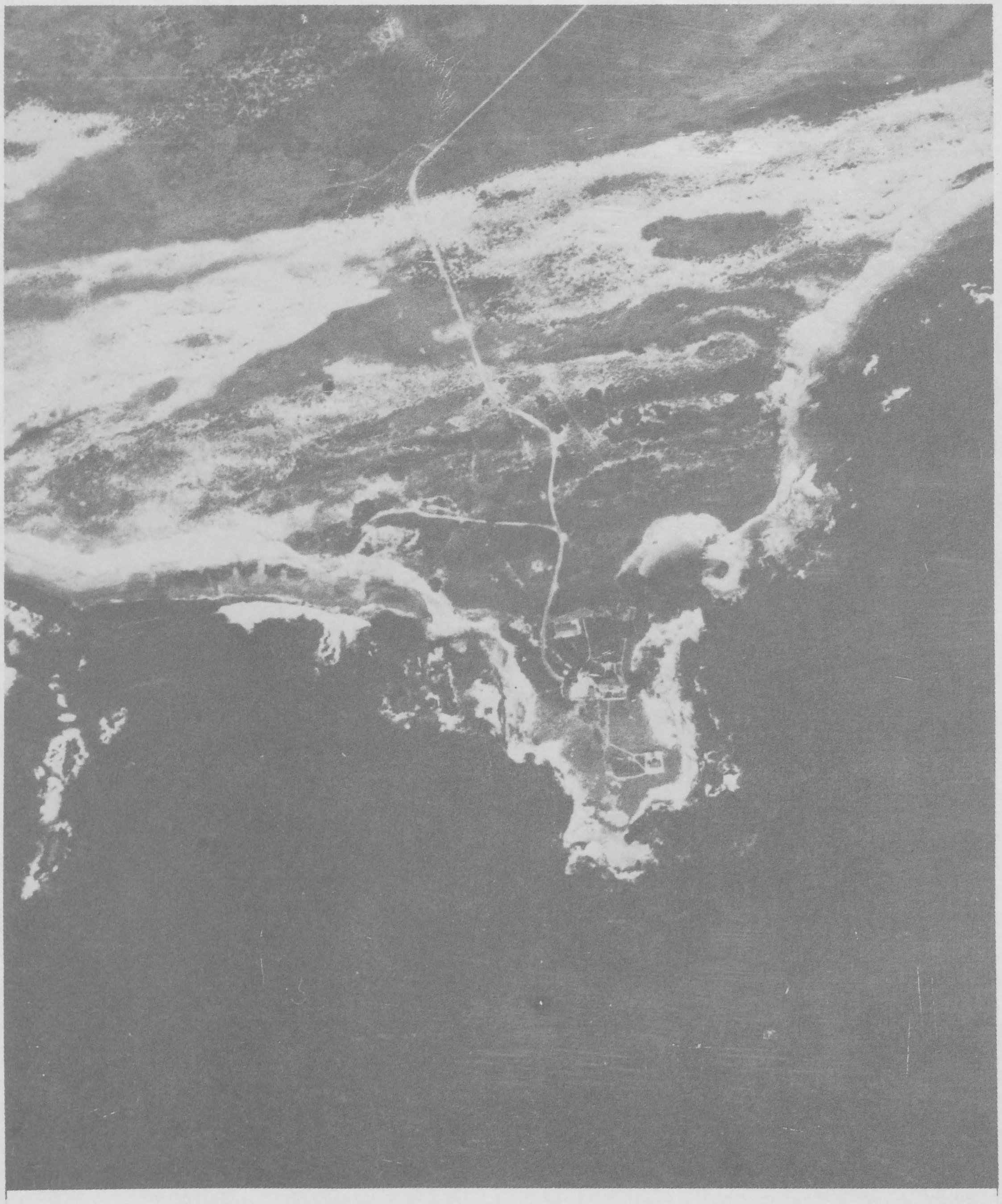
ILLUSTRATIONS



Point Conception, California. Vertical aerial view from 10,000 feet.

Section I. INTRODUCTION

1. Nature and Purpose of the Study

This study was initiated by the U. S. Army Coastal Engineering Research Center (CERC) to determine heavy-mineral provinces along a segment of the California Coast, and if possible, to identify source areas and determine long-term littoral movement.

The net littoral drift along the Southern California Coast moves southward. However, this north-to-south transport is complicated by frequent reversals, by submarine canyons which may remove sediment from the littoral stream, and by numerous headlands which project seaward and may act as natural barriers. At the Point Conception-Government Point complex the situation is further complicated by the fact that the shoreline changes from a north-south orientation to an east-west orientation. Here, pocket beaches are separated by rocky projections where no sand beaches exist above MLLW. While net littoral drift east of Point Conception is to the southeast, periods of northward littoral drift along southern California beaches are known from measurements of dye movement, current drogue studies, and studies of the movement of radioactive nuclide tagged sand.

This study of heavy minerals was undertaken to delineate the net long-term littoral movement along the California Coast between Pismo Beach and Los Angeles and in particular to test Trask's (1952) conclusion that sediment moves around Point Conception. The study was originally conceived as an adjunct to the Radioisotopic Sand Tracer (RIST) study which was initiated in 1966 to develop and use radioactive tracer methods for research in sand-movement and littoral processes, and which is explained in CERC Miscellaneous Paper 2-69 (Duane and Judge, 1969). Concurrent with the research and development objectives of the RIST program, studies were conducted to determine whether sediment was transported around Point Conception or whether the Point acted as a barrier to littoral transport.

In addition to samples taken for the RIST program, beach samples have been collected monthly at various beaches along the California coast as part of the CERC Littoral Environmental Observation (LEO) program, established in 1968 (Berg, 1968 and Szuwalski, 1970). Selected samples from this program were analyzed in addition to the RIST samples in order to expand the area of the study. As a result, beach samples from Carmel River Beach (at the southern end of Monterey Bay) to Bolsa Chica Beach (south of Los Angeles), offshore samples around Point Conception, and selected river samples were analyzed (Figure 1). In addition, samples were selected at different times of the year to determine the importance, if any, of seasonal variations.

2. Previous Research

Considerable research has been done on heavy minerals and on rates of littoral transport along the beaches of southern California. However, most of this research was concerned with localized areas.

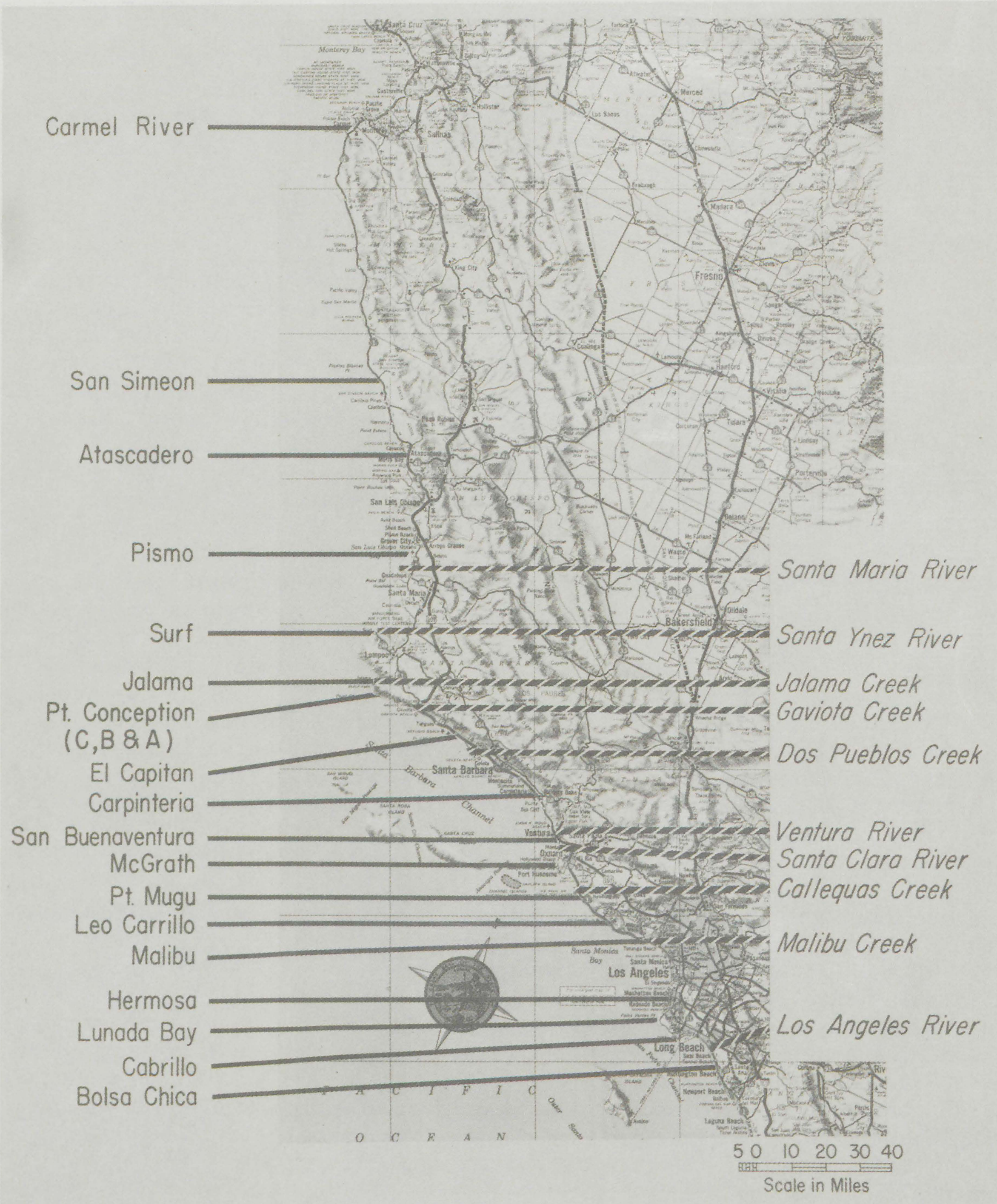


Figure 1. Map of California showing the locations of heavy-mineral samples utilized in this study. Beach and offshore samples are to the left; stream samples are to the right.

The region north of San Francisco Bay was studied by Minard (1964), Cherry (1965), and Moore (1965). Cherry's investigation established that Point Reyes and Bodega Head are barriers to longshore transport. A study of heavy minerals by Sayles (1965) concluded that the sands in Halfmoon Bay were locally derived and that there was no net, long-term littoral transport around Pillar Point. Krumbein (1944) concluded that sands along beaches in Halfmoon Bay have a net northward movement toward Pillar Point.

Hutton (1952 and 1959) examined the heavy minerals along beaches from Halfmoon Bay to Monterey Bay. Sayles (1966) and Yancey (1968) report on heavy minerals in the vicinity of Monterey Bay.

Trask (1952) examined the heavy minerals of beaches and streams between Monterey Bay and Santa Barbara. He found that augite was supplied by streams north of Point Conception, particularly in an Augite Province from Piedras Blancas to Avila Beach, but was not present in streams south of Point Conception. Because augite was found in sediments east of Point Conception and because it could not have been supplied by the local streams, he concluded that sediments move south and east around the Point Conception complex. Studying heavy mineral assemblages in beach and offshore samples between Surf, California (north of Point Conception) and the Mexican border, Azmon (1960, page 40) concluded that Point Conception acts as at least a partial barrier to sediment movement.

Handin (1951) examined the heavy-mineral content of beach samples between Santa Barbara and Point Fermin at Los Angeles. He identified an Augite Province between Ventura and Palos Verdes (Bluff Cove.). Handin concluded that the net littoral drift was southeasterly. However, periods of northward littoral movement are known from LEO (Szuwalski, 1970), and from RIST studies recently conducted at Point Mugu Naval Air Station. Therefore, the Augite Province between Ventura and Palos Verdes exists as a possible alternative source of augite in the beach sands immediately south and east of Point Conception.

Inman (1953) and Emery, et al., (1952) studied the heavy-mineral assemblages at La Jolla and San Diego, respectively. Dill (1952) and Wright (1967) studied the marine geology off Point Arguello and Point Conception. Gorsline (1968), reporting on first-year results of a comprehensive program to study the marine geology of Southern California, includes preliminary results of studies of light and heavy minerals in beach and river samples; these results indicate a southward net littoral drift.

Bowen and Inman (1966) report on the rates of littoral transport around the Point Arguello-Point Conception complex. Handin (1961) discusses net littoral drift rates at Santa Barbara and around Santa Monica Bay; and Herron (1960) reports on net littoral drift rates in the vicinity of Port Hueneme. Duane and Judge (1969) and Duane (1970) report on various studies of littoral drift using radioactive tagged tracer sand.

Lampietti (1964) reports on the Ocean Science and Engineering, Inc. study of beach configuration from Pismo Beach to Saint Augustin, California. Emery (1960) gives an excellent summary of various studies on the coastal and offshore areas along southern California.

Section II. GEOLOGY AND OCEANOGRAPHY OF THE REGION

1. Coastal Geomorphology and Oceanography

North of Point Conception the coastline trends NNW to Monterey Bay; at Point Conception the coastline turns abruptly eastward and then gradually changes to a southeastward direction. North of Point Conception, the coastline is generally rocky with high cliffs and numerous rocky promontories. Flat beaches with associated dunes are locally important in basin areas, as at the mouths of the Santa Maria and Santa Ynez Rivers. Cliffs also occur east and south of Point Conception; however, long, flat beaches are more common.

The dominant geological feature between Monterey Bay and Pismo Beach is the Santa Lucia Mountain Range of the Coastal Range Province (Figure 2). Source rocks in the area from Monterey Bay to just north of Cape San Martin are primarily pre-Cretaceous metamorphics intruded by Mesozoic granites which in some areas are overlain by Miocene marine beds (State of California, 1959a). Source rocks in the southern part of the Santa Lucia Range (Cape San Martin to Pismo Beach) consist principally of the Mesozoic Franciscan series (State of California, 1959b). At Point Buchon, Miocene marine deposits are locally important.

The Santa Lucia Mountain Range is separated from the more inland coastal ranges by the Salinas River which drains northward into Monterey Bay. Between Carmel River at the northern end of the Santa Lucia Range to Pismo Beach at the southern end, numerous small streams drain from the mountains, but there are no major river systems entering the ocean. South of Pismo Beach, the broad drainage valley of the Santa Maria River separates the coast ranges from the Santa Ynez Mountains (Transverse Ranges).

From Point Sal southward around Point Conception and east to the Ventura River, the Santa Ynez Mountains, composed of sedimentary rocks of Eocene, Oligocene, Miocene, and Pliocene age, are the major geologic feature (USGS, 1966, and State of California, 1959c). Basement rocks are exposed only in a few small areas and consist of slightly metamorphosed members of the Franciscan group. Primary drainage of the northern slopes of the Santa Ynez Mountains is provided by the Santa Ynez River system which drains westward and empties into the Pacific Ocean at Surf, north of Point Conception. Drainage of the southern slopes is provided by numerous small streams which empty directly into the Santa Barbara Channel with no major drainage systems developed.

The Ventura Basin is situated between the Santa Ynez Mountains to the north and the Santa Monica Mountains to the south. Rocks exposed in the Ventura Basin are primarily Tertiary sediments which are a lateral extension of the Tertiary strata of the Santa Ynez Mountains. Quaternary sediments are abundant. Basement granodiorite and related plutonic rocks of Jurassic or Cretaceous age are exposed in the Topatopa Mountains immediately north of the Ventura Basin (USGS, 1966, and State of California, 1955). The Ventura Basin area is drained by the Ventura River and the Santa Clara River systems.

The Santa Monica Mountains extend from Calleguas Creek on the southeast edge of the Ventura Basin to Santa Monica where they turn inland to form the northern edge of the Los Angeles Basin. These mountains are composed primarily of Tertiary (Eocene, Oligocene, and predominately Miocene) sediments derived from crystalline basement rocks (USGS, 1966, and State of California, 1955). Tertiary basaltic and andesitic volcanic flows are frequent. Inland from the coast, Cretaceous sediments crop out along with the Tertiary rocks. The core of the Santa Monica Mountains is comprised of the metamorphic Santa Monica Slate, which grades in places into mica and chlorite schists, and of numerous intrusive masses of granite and granodiorite of Jurassic (?) age (Azmon, 1960). Many small streams drain from the Santa Monica Mountains directly into the Pacific Ocean.

The Los Angeles Basin extends along the coast from Santa Monica south to the Santa Ana Mountains. Immediately south of Newport Beach, Quaternary sediments cover most of the coastal area (State of California, 1962 and 1966). Further inland Tertiary and Cretaceous sediments are exposed (USGS, 1966). These Quaternary, Tertiary, and Cretaceous sediments were primarily derived from the basement bedrock complexes which consist chiefly of plutonic and metamorphic rock (Azmon, 1960). The one notable exception to Quaternary sediments along the coast is the area of the Palos Verdes Hills from Malaga Cove to Point Fermin. Rocks in the vicinity of the Palos Verdes Hills consist of marine Miocene sediments intruded by Tertiary basalts (State of California, 1962). Drainage of the Los Angeles Basin is provided by Ballona Creek on the north, the Los Angeles River system and the San Gabriel River in the central portion, and the Santa Ana River (which extends into the Santa Ana Mountains) along the southern border.

South of the Los Angeles Basin is the Southern California Batholith which extends southward to the southern tip of Baja California, Mexico. It is a composite of late Mesozoic plutonic rocks composed of 7 percent gabbro, 91 percent tonalite and granodiorite, and 2 percent granite and associated metamorphic rocks (Larsen, 1948).

Drainage areas and discharge of the major streams between Monterey Bay and Los Angeles are summarized in Table I. These streams drain the above-mentioned coastal geomorphic provinces, and are the primary source of beach sediments.

TABLE I

RIVER DISCHARGE AND DRAINAGE AREA

Data from topographic maps and U. S. Geological Survey Water Supply Paper 1735.

Discharges are averages of available years at every station, but more than five years as a minimum. Areas are by planimetric determinations to nearest 10 square miles.

Stream	Average Discharge (Acre-feet per year)	Drainage Area (Square miles)
Salinas River	320,000	4156
Big Sur River	69,570	47
Arroyo de la Cruz	36,560	41
Arroyo Grande	15,570	106
Santa Maria River	26,790	1763
San Antonio Creek	4,720	134
Santa Ynez River	37,070	900
Atascadero Creek	1,720	-
Carpinteria Creek	1,240	15
Ventura River	43,220	210
Santa Clara River	132,630	1700
Calleguas Creek	1,090	250
Malibu Creek	13,250	100
Topanga Creek	3,710	20
Ballona Creek	25,480	89
Los Angeles River	100,600	1190
San Gabriel River	23,560	540
Santa Ana River	11,000	2490

Submarine canyons are a prominent feature of the California Continental Shelf. As shown by Shepard (1965), these canyons may trap sand and thus remove it from the littoral stream. In the vicinity of Monterey Bay, the Monterey Canyon, and associated Soquel and Carmel Canyons, extend nearly to the coastline. Sur Canyon and Partington Canyon lie to the south off Point Sur and Partington Point. Several small unnamed canyons lie off the Point Arguello complex just north of Point Conception. At the southeastern end of the Santa Barbara Channel, Hueneme Canyon and Mugu Canyon extend close to shore at Port Hueneme and Point Mugu. Dume Canyon and Santa Monica Canyon are well offshore from the Santa Monica Mountains; but Redondo Canyon extends close inshore at Redondo Beach, just north of the Palos Verdes Hills. Newport Canyon lies off Newport Beach at the southern end of the Los Angeles Basin; and La Jolla Canyon lies off La Jolla just north of San Diego.

Offshore oceanic water circulation along the California Coast shows a seasonal change or reversal. In the spring and summer, brisk north and northwest winds serve to drive the southward-flowing California current close inshore along the coast. During the fall and winter, a north-directed surface current, the Davidson Current or California Counter-current, develops inshore off Baja California, Mexico, and may extend to 45° N (Wright, 1967). The currents through the Santa Barbara Channel are predominantly from east to west throughout the year (Dill, 1952 and Wright, 1967).

Waves on the California Coast generally approach from the northwest and west with a period of 10 to 13 seconds (Galvin, et al, 1969, and Szuwalski, 1970) and presumably cause a southerly littoral drift. However, during the summer, when swells from the southern hemisphere are important, part of the southern California Coast has northerly longshore currents (Emery, 1960). Data from LEO (Szuwalski, 1970) indicate that a northward littoral drift is pronounced during the summer months on the beaches south of San Buenaventura. Galvin, et al. (1969) indicates that the mean monthly wave height along the California Coast varies from about 2 feet during the summer to about 3 feet during the winter months. Additionally, during the winter months short-period (4-5 seconds) waves develop from the southeast along the Santa Barbara Channel east of Point Conception (National Marine Consultants, 1960).

2. California Heavy-Mineral Provinces

The various coastal heavy-mineral provinces of California defined by previous researchers are summarized in Figure 2 on page 8.

North of Point Arena, there are no significant data to define heavy-mineral provinces. Studies by Minard (1964) and Cherry (1965) define a province from Bodega Head north to Russian River (limit of their studies) where the predominant characteristic minerals are augite and claucophane. Corps of Engineers report (1965) indicates that this province probably extends north to Point Arena. As indicated by Minard (1964) and Cherry (1965), south of Bodega Head the predominant heavy mineral is hornblende. Some localized deposits with garnet-augite predominance are noted in the vicinity of Point Reyes. Work by Moore (1965) indicates that the southern boundary of this hornblende province occurs at Duxbury Reef, Bolinas Bay. Moore (1965) also indicates a more or less localized Aragonite-Augite Province from Duxbury Reef, around Bolinas Bay, and south to Muir Beach.

Hornblende is the chief heavy mineral from Muir Beach southward around Halfmoon Bay to just south of Miramontes Point (Sayles, 1965 and Moore, 1965). Hutton (1952 and 1959) indicates localized zircon concentrations within this Hornblende Province between Princeton Beach and Tuntas Creek in Halfmoon Bay. Similarly he notes a localized concentration of augite at Butano Creek north of Miramontes Point.

As shown by Hutton (1952 and 1959), zircon is predominant from Gazos Creek (just south of Miramontes Point) into the northern end of Monterey

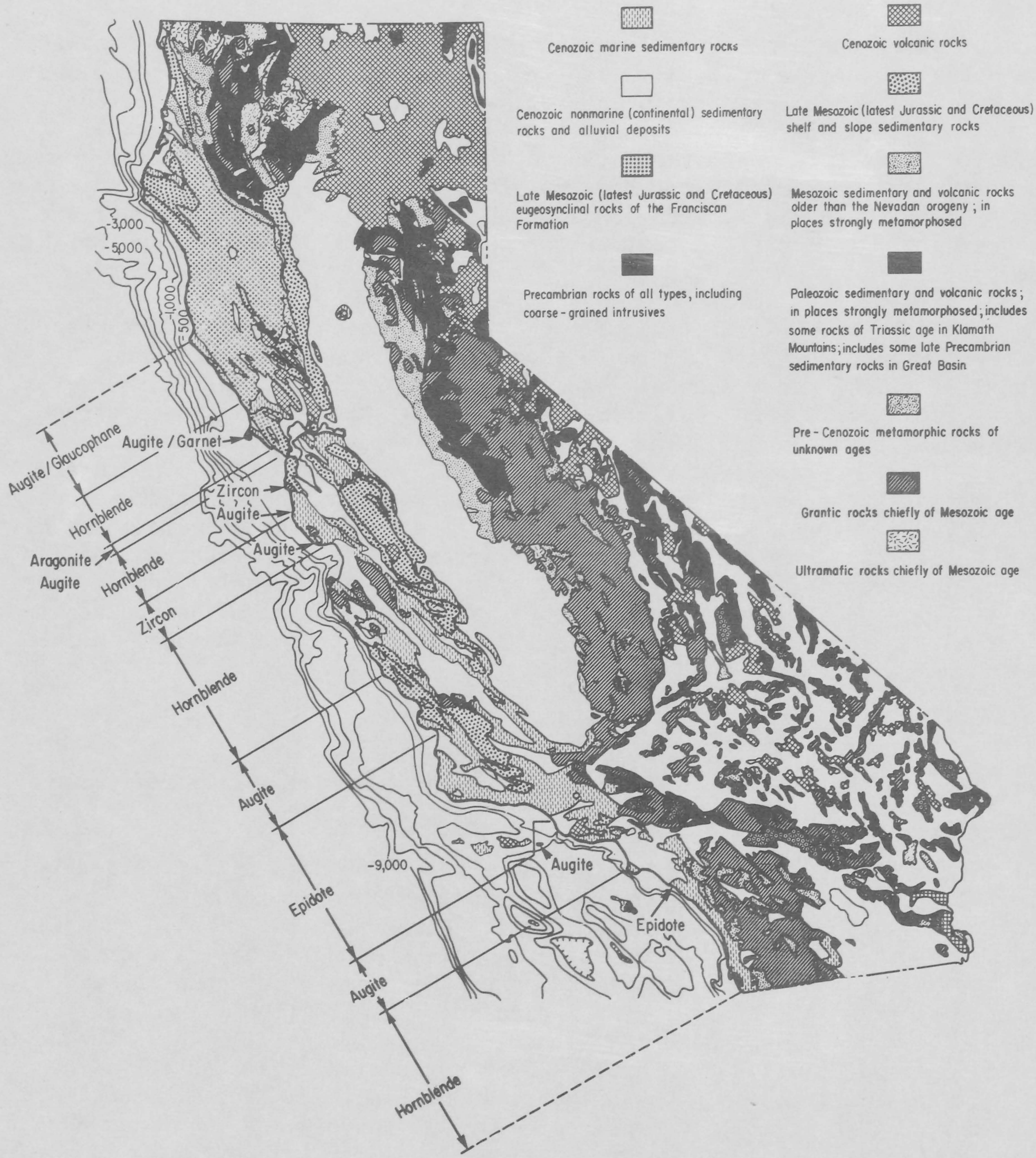


Figure 2. Geologic Map of California showing heavy-mineral provinces of beach and nearshore sediments. Heavy mineral information was compiled from various sources indicated in the text; Geology was taken from USGS Map I-512.

Bay between the Aptos Creek and Pajaro River. Yancey (1968) found a localized concentration of augite in beach sands to the north of Santa Cruz.

Hornblende is the principal heavy mineral from the northern end of Monterey Bay south to Piedras Blancas. The work of Sayles (1966) in the vicinity of Monterey Bay indicates that hornblende is predominant from Aptos southward. Trask (1952) extends the Hornblende Province from Monterey Bay south to Piedras Blancas. The sands in the Hornblende Province contain much hornblende, moderate amounts of titanite and epidote, and minor quantities of other minerals.

An Augite Province extending from Piedras Blancas south to Avila Beach was defined by Trask (1952). The sands of the Augite Province are variable in composition but in general are characterized by abundant augite, moderate amounts of titanite and epidote, and minor quantities of other minerals.

An Epidote Province extends from Avila Beach south and east around Point Conception to Ventura. Trask's (1952) work defined epidote as the major heavy mineral from Avila Beach south to Santa Barbara, the limits of his study. Gorsline (1968) substantiated this work. Handin's (1951) and Azmon's (1960) studies indicate that the Epidote Province extends southeast as far as Ventura. The sand in the Epidote Province contains abundant epidote, moderate quantities of titanite (sphene), ilmenite, and leucoxene, minor but definite amounts of garnet, augite, and zircon, and small quantities of magnetite, apatite, and other minerals. Because the streams east of Point Conception did not contribute augite, and since minor but definite amounts of augite are found in beach sediments east of Point Conception to Santa Barbara, Trask (1952) concluded that some sand moved south and east around Point Conception. Azmon (1960) found greater amounts of augite north of Point Conception than east of it and concluded that the Point acted as at least a partial barrier.

Handin (1951) examined the heavy-mineral content of beach samples collected between Santa Barbara and Point Fermin (Long Beach) and found that in the central part of this span the characteristic mineral is augite. From his work it is apparent that the Augite Province extends from Ventura to Palos Verdes (Bluff Cove). This span corresponds to the position of the Santa Monica Mountains, whose streams carry large percentages of augite. Sands in the Augite Province contain moderate to abundant augite, as well as moderate amounts of titanite, epidote, and opaques, and minor but definite quantities of garnet, hornblende, zircon, and apatite. Handin (1951, page 24) states that "--- the heavy mineral suite occurring in stream and beach samples along the coast from Point Mugu to Santa Monica is quite different from that found upcoast from Point Mugu, particularly for the presence of titaniferous augite east of the Point. It is clear that sand does not pass around Point Mugu in a westerly direction, but there is no direct evidence that it does not pass around the Point in an easterly direction".

The Channel Islands represent a westward extension of the Transverse Ranges (Santa Monica Mountains). Scholl (1960) found that augite was the predominant heavy mineral in beach sands around Anacapa Island. On the other hand, Azmon (1960) found that epidote and opaques were the principal heavy minerals, and that only very minor amounts of other heavy minerals were present in the beach and offshore samples he examined from the vicinity of the Channel Islands, particularly Santa Rosa and Santa Cruz Islands.

Handin (1951) found that the chief heavy mineral around Point Fermin is hornblende. Gorsline (1968) found that hornblende is the predominant heavy mineral from Seal Beach south to Oceanside with a local concentration of epidote at Laguna. Inman (1953) and Emery et al. (1952) found that at La Jolla and at San Diego, hornblende constituted 60 percent of the heavy mineral assemblage. Based on these studies, it is reasonable to extend the Hornblende Province from Palos Verdes south to some undefined point below the Mexican Border. The sand in the Hornblende Province contains abundant hornblende (which increases southward toward San Diego), moderate amounts of epidote, and minor but definite amounts of zircon, titanite (sphene), garnet, augite, and magnetic minerals.

The general geology of California along with heavy-mineral provinces is illustrated by Figure 2. In general, the following relationships of heavy-mineral provinces to the geology apply:

1) Hornblende and zircon heavy-mineral provinces are associated with granitic and highly metamorphic source areas, notably the preCretaceous metamorphic rocks and Mesozoic granitic intrusions of the Coast Ranges (Santa Lucia Mountains) and with the granitic intrusions of the Southern California Batholith.

2) Augite is associated with Franciscan (Mesozoic) sedimentary rocks along the southern part of the Santa Lucia Mountains between Point Piedras Blancas and Pismo Beach. Augite is also associated with the Tertiary sediments and valcanics of the Santa Monica Mountains.

3) Epidote is ubiquitous in the recent sediments along the southern California Coast. However, the area of greatest concentration of epidote (i.e., the Epidote Province) is associated with Quaternary and Tertiary sedimentary rocks (particularly those of Miocene age) where metamorphic and volcanic rocks are not prevalent.

Exceptions to the above relationships may be locally significant.

Section III. FIELD AND LABORATORY PROCEDURES

Beach samples are routinely taken each month along the California Coast in conjunction with the CERC LEO program. These are hand grab samples collected in the wetted zone as near to the waterline as possible. Grab samples were also taken as a part of various RIST studies at Surf and Point Conception. Beach samples were grab samples taken by hand. Offshore grab samples were collected by scuba divers from depths of about 30 feet. Additionally, four cores were taken at Surf (depth -13 feet). Samples utilized in this study were selected from the LEO and RIST samples to represent as many different beaches as possible. In addition, samples were selected at different times of the year to determine whether seasonal variations were important. A few supplemental beach and river grab samples were also collected by hand. Other beach and river samples were made available by D. S. Gorsline, University of Southern California; these were originally utilized in his studies of the California Coast (Gorsline, 1968). Figure 1 illustrates the locations of all the samples utilized in the present study.

Upon receipt in the laboratory, a general field description of the samples was made. The samples were then air or oven dried (<90°C), disaggregated if necessary, and an 8-10-gram portion was split out for size analysis. The samples were then washed to remove salts.

Size analysis of the samples was conducted using a Rapid Sediment Analyzer (RSA) similar to that described by Schlee (1966). By measuring pressure variations in the water column, the RSA is used to determine the size characteristics of sediment as they settle through a 1-meter column of water. By means of a computer program which relates actual pressure and time decay to equivalent fall diameter, statistical parameters descriptive of the sediment size distribution curve were calculated.

The part of the sample not used in the RSA analysis was weighed and the 63-125 micron size fraction was sieved out, weighed, and a part split out for heavy mineral separation. Using a weighed part (about 10-20 grams, or less when insufficient material was available) of the 63-125 micron size fraction, the heavy minerals were separated in a funnel filled with bromoform (specific gravity = 2.867).

The heavy minerals and the light minerals were collected on separate pieces of filter paper, washed with acetone, dried, and weighed. Each fraction was then microsplit to approximately 1,000 grains and mounted on a slide with Canada balsam.

A study of only the 63-125 micron size fraction is not necessarily representative of the whole sample. A better method might be to count the heavy minerals in each size fraction, calculate the hydraulic ratios, and assign grains to the appropriate equivalent size of quartz in a manner similar to that used by McMaster (1954). However, this is a very time-consuming practice. Because most of the important heavy minerals in the present study have similar densities, the study of one size fraction should permit a relative comparison between samples. Accordingly, the 63-125 micron size fraction was selected as one which would permit easy petrographic study and would give the greatest concentration of heavy minerals. Study of the 63-125 micron size fraction also permitted comparison with the work of Trask (1952) who studied heavy minerals in the 63-125 micron size fraction around Point Conception.

Minerals were identified by optical techniques with a petrographic microscope which permits examination of individual grains in polarized light. Light minerals were not counted, but the slides were scanned to determine minerals present. Heavy minerals were counted by the "ribbon method" in which successive paths are traversed across the slide, and all grains within the microscope field are counted. Traverses were made to represent the entire slide (as for example: top, 1/4, midway, 3/4, and bottom). A minimum of 500 grains were counted. If this produced a count of less than 300 nonopaque grains, counting was continued until at least 300 nonopaque grains were recorded. The abundance of a mineral species was calculated as a percent by number and recorded.

Dendrograms showing the relationships between individual samples were produced by methods similar to those of McCammon and Wenninger (1970).

Distance, i.e. the measure of the degree of similarity between samples, was computed as a scaled Euclidian distance as follows:

$$D_{ij} = \sum_{k=1}^{r} \left(\frac{P_{ik} - P_{jk}}{\sqrt{n\overline{P}_k \; (1-\overline{P}_k)}}\right)$$

where:

D_{ij} = distance between the ith and jth sample

r = number of mineral species considered

P_{ik} = observed proportion of the kth mineral species in the ith specimen.

P_{jk} = observed proportion of the kth mineral species in the jth specimen

n = number of counts per sample

$\overline{P}_k$ = computed mean proportion of the kth mineral species in all specimens.

Section IV. PETROGRAPHY OF THE BEACH AND RIVER SANDS

1. General Description of the Beach Sands

Beach and nearshore sediments in the areas studied (Figure 1) consist generally of fine to medium grained, light brownish-grey, subangular quartz sand. Although quartz is the principal mineral, feldspar frequently comprises a substantial part of the total sample (often as much as 30 percent). Heavy minerals generally make up less than 10 percent of the total sample. However, the heavy minerals tend to be concentrated in the finer fractions. Frequently the 63-125 micron size class contains 10-30 percent (by weight) of heavy minerals.

A summary of mean phi (Ø) grain sizes is plotted in Figure 3; and individual values are given in Appendix A. Mean grain sizes of the beach samples range from 0.5 Ø to 2.5 Ø. For beaches north of Point Conception, the grain size gradually decreases from Carmel River (0.5 Ø) southward. An increase in grain size, resulting from the input of the Santa Maria and Santa Ynez Rivers, is noted at Surf, California (1.65 Ø). From Surf southward to Point Conception (2.1 Ø), the grain size again decreases. East of Point Conception, the grain size remains stable (2.1 Ø) to Carpinteria. A sharp increase in grain size is noted between Carpinteria and McGrath Beaches, corresponding to the input of the Ventura and Santa Clara Rivers. Grain size then remains relatively constant (1 to 1.5 Ø) southward to the Palos Verdes Hills. The increase in grain size between Cabrillo and Bolsa Chica Beaches corresponds to the input of the Los Angeles River.

Heavy and light minerals were separated for the 63-125 micron size fraction. While no detailed analysis was made of the light minerals, the samples were given a cursory examination. Although quartz was the predominant mineral, feldspar often made up a substantial (40 to 45 percent) part of the 63-125 micron light-mineral fraction.

The percentage of heavy minerals in the 63-125 micron size fraction varied widely (from less than 1 percent to more than 99 percent), and no significant trend could be found. However, as shown in Figure 3, the percentage of opaque minerals in the heavy-mineral fraction appears to be closely related to the percentage of heavy minerals in the 63-125 micron size fraction. This suggests that fluctuations in the heavy-mineral concentration may be dependent to a large extent on the concentrations of the opaque minerals.

2. Heavy Mineral Composition of the Beach Sands

In general, the heavy mineral species identified in samples examined in this study agree with those of previous workers. Amphibole (in the form of hornblende) and pyroxene (in the form of augite) are important in their provinces, and elsewhere they form minor but significant constituents. Epidote is found throughout the study area but is particularly

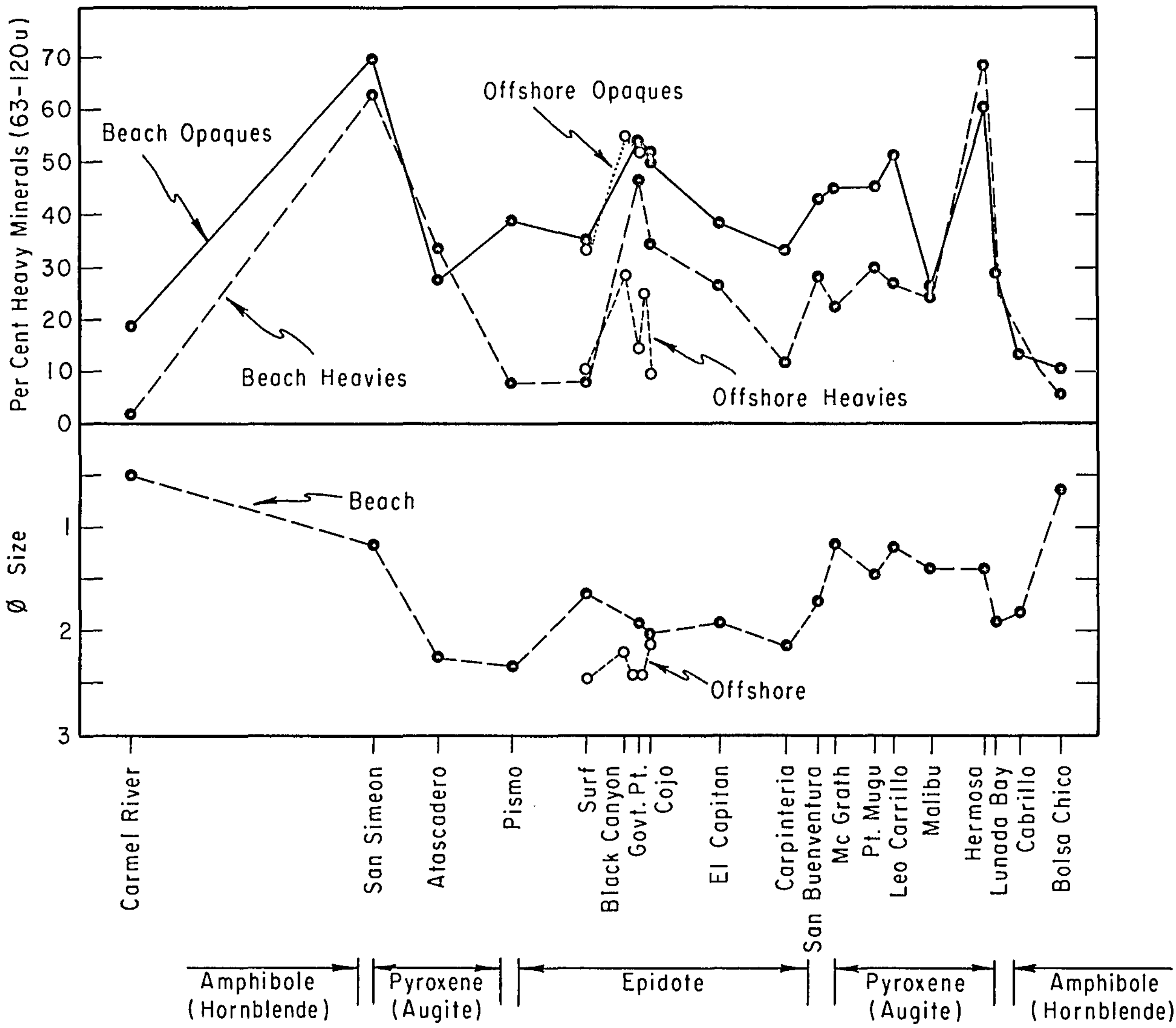


Figure 3. Characteristics of beach and offshore samples. Bottom graph shows the longshore variations in grain size. Top graph illustrates the relationship between the percentage of heavy minerals in the 63-125 micron size fraction and the percentage of opaques in the 63-125 micron heavy-mineral component. All samples from an individual location were averaged.

important in the central span (i.e. the Epidote Province, extending from north of Pismo Beach south around Point Conception to San Buenaventura) where epidote comprises 20-35 percent of the heavy mineral fraction. Titanite is present in moderate amounts, and garnet and zircon in minor but significant amounts throughout the study area. Micaceous minerals (muscovite, sericite, biotite and chlorite) generally appear to be the result of weathering and alteration of other minerals. Opaque minerals consist primarily of magnetite, ilmenite, and leucoxene. They comprise a substantial portion of the 63-125 micron heavy-mineral fraction. They generally form small well-rounded particles, have a higher specific gravity than the other minerals, and hence tend to concentrate in the finer fractions. Calcite, apatite, monazite, and hypersthene form minor constituents. Rutile, tourmaline, glaucophane, anatase, andalusite, and staurolite are rare occurrences.

Heavy mineral data for the 63-125 micron size fraction are tabulated in the Appendix. Figures 4 and 5 are graphic summaries of the heavy minerals for beach (swash zone) and offshore (-30 feet) samples, respectively. Because the percentage of opaques and the percentage of heavy minerals were closely dependent on each other, and since they do not represent one individual species, a plot of the percentage of heavy minerals exclusive of the opaque minerals was also made (Figure 6).

A northern Hornblende Province extends from the Aptos River south to Piedras Blancas. Only one sample (Carmel River) from this province was available for study. This sample contains substantial amounts of hornblende (23 percent) and micaceous minerals and moderate amounts of opaques, titanite, and augite. Minor but significant amounts of garnet, epidote, and zircon are also present.

A northern Augite Province extends from Piedras Blancas south to Avila Beach. Samples from San Simeon (located at the northern edge of this province) are dominated by opaque minerals. Only one other sample from this province (Atascadero) was available. In this sample, epidote was unusually abundant. Opaques, augite and titanite were present in moderate amounts. In general, sands in the northern Augite Province contain substantial quantities of opaque minerals; moderate quantities of augite, epidote, and titanite; and minor but significant quantities of garnet, zircon, hornblende, micaceous minerals, and calcite.

The Epidote Province spans the central portion of this study and extends from Avila Beach south around Point Conception and east to Ventura. The heavy mineral content of beach sands in this province is summarized in Table II. The sand in the Epidote Province contains abundant epidote and opaque minerals, moderate quantities of titanite, and minor but definite amounts of garnet, augite, zircon, and hornblende. Table II shows less augite and hornblende east of Point Conception than north of it.

The Augite Province (southern) extends from Ventura to Palos Verdes (Point Fermin). Sands in the Augite Province contain moderate amounts of

TABLE II

Summary of Beach Heavy Minerals in the Epidote, Southern Augite, and Southern Hornblende Provinces

Mineral	Epidote Province (N. of Pt. Conception)	Epidote Province (E. of Pt. Conception)	Epidote Province (entire)	Southern Augite Province	Southern Hornblende Province (Northern Section)
	%	%	%	%	%
Epidote	22.9	26.5	24.7	8.8	7.5
Titanite	10.1	10.7	10.4	11.7	9.9
Garnet	4.4	5.4	4.9	3.6	1.7
Zircon	3.8	4.5	4.1	3.4	0.9
Augite	3.7	1.9	2.8	9.1	9.1
Hornblende	2.7	1.0	1.9	4.6	32.4
Opaque	40.6	39.9	40.3	45.8	11.3
Chlorite	3.8	3.7	3.7	6.2	16.4
Mica	3.0	4.2	3.6	5.4	7.3
Miscellaneous	4.9	2.3	3.6	1.4	3.5
Number of Samples	11	11	22	12	2

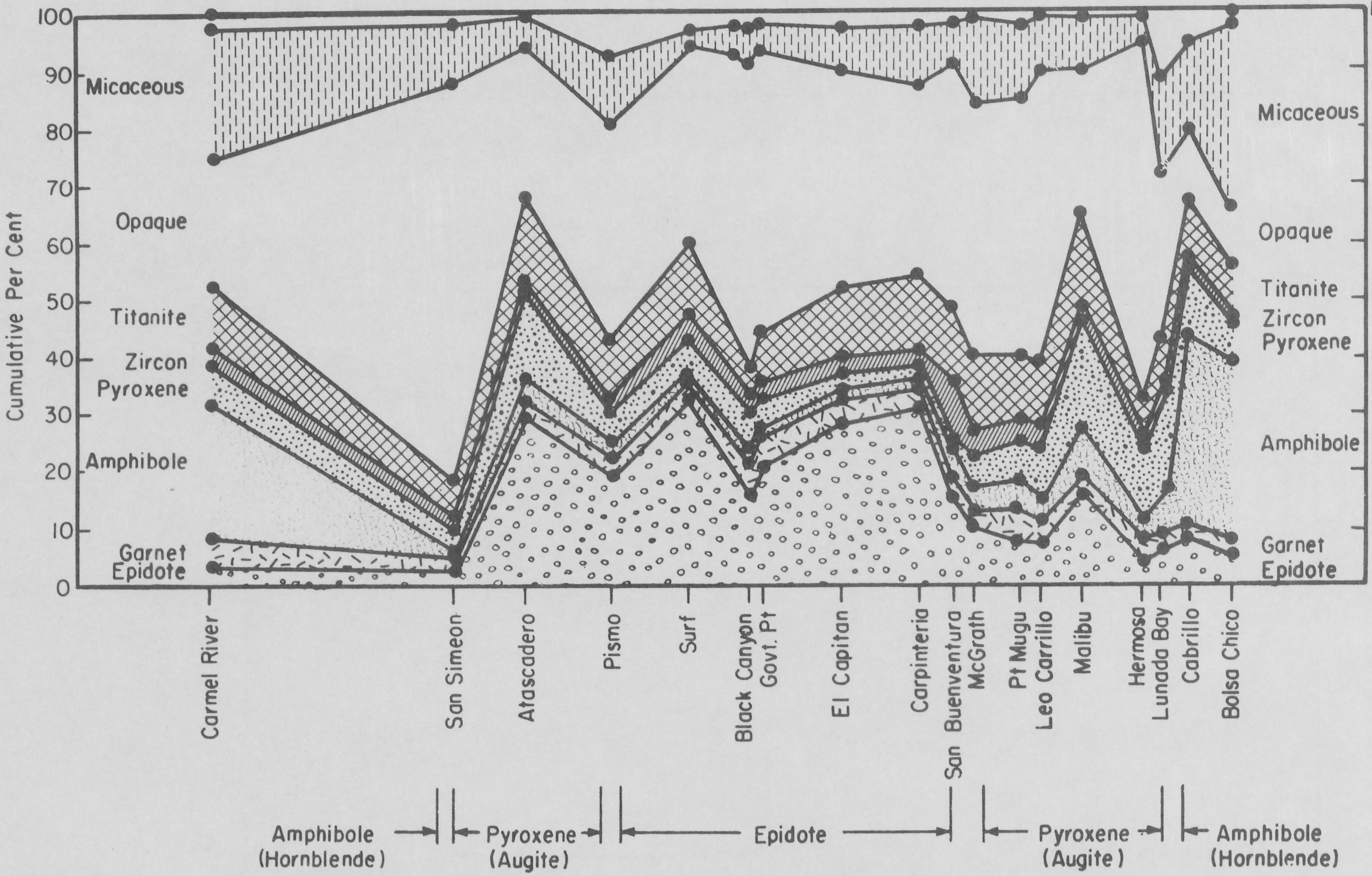


Figure 4. Heavy-mineral composition of beach samples. Samples from an individual location were averaged.

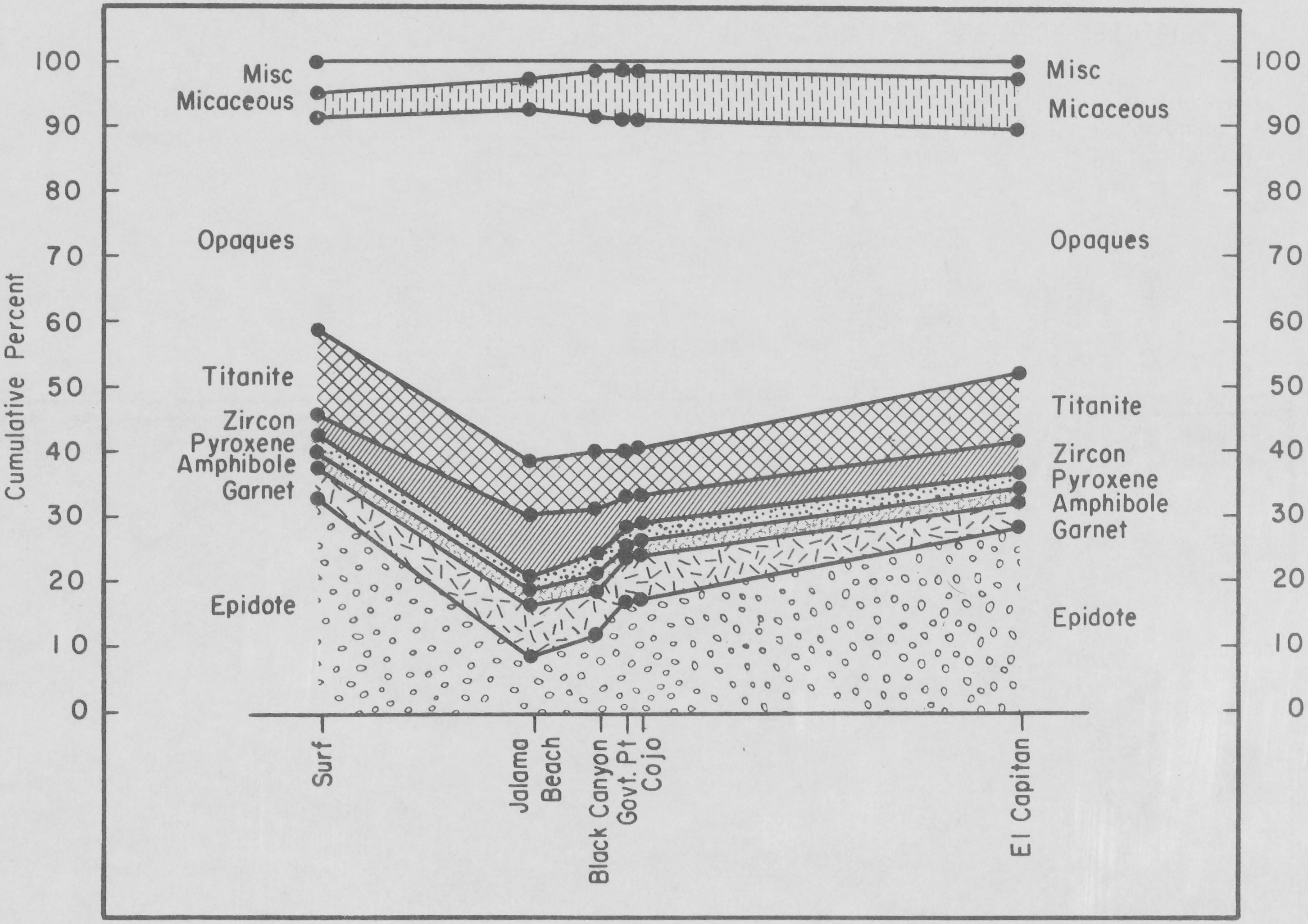


Figure 5. Heavy-mineral composition of offshore samples taken from depth of about 30 feet. Samples from an individual location were averaged.

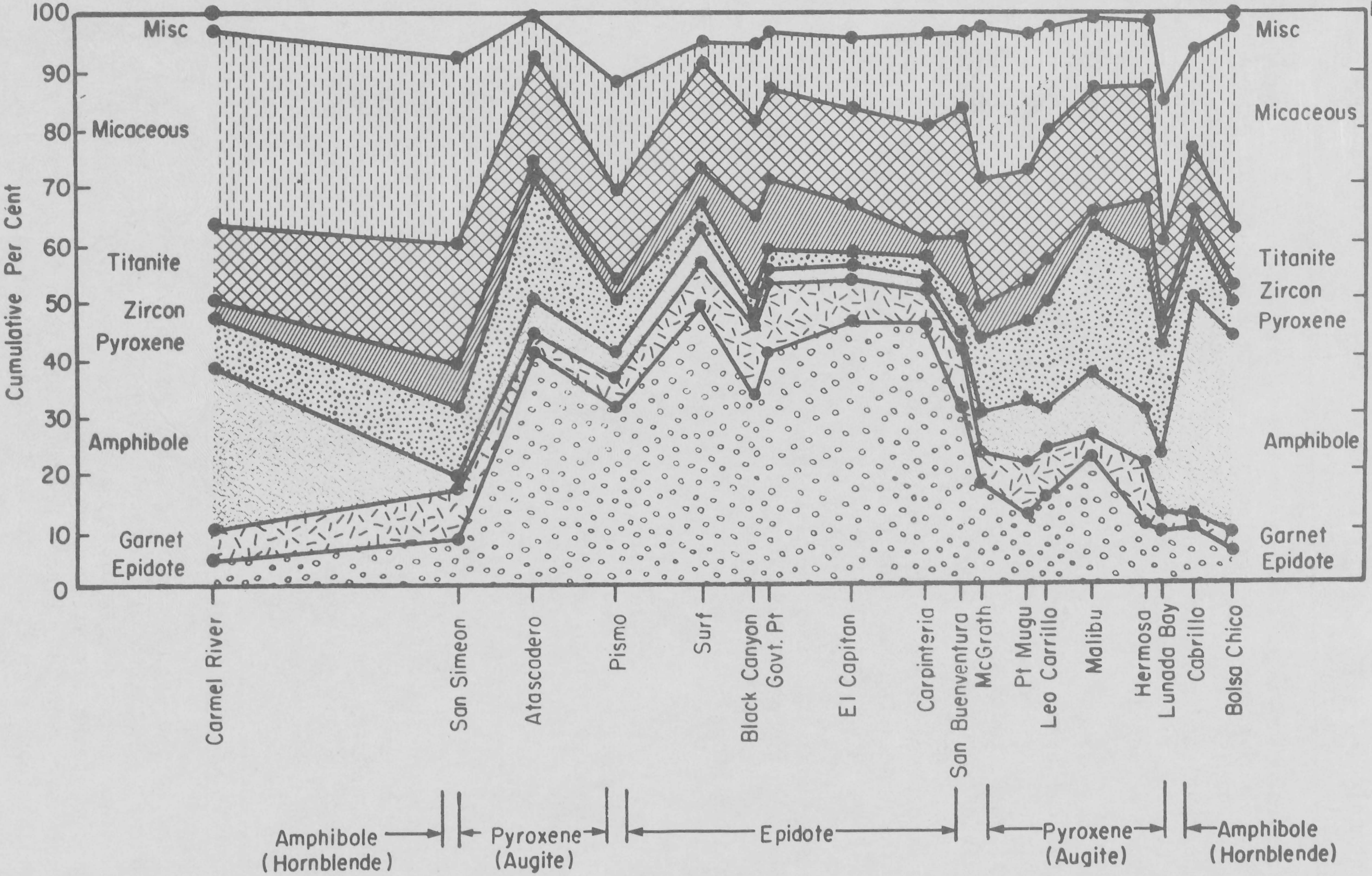


Figure 6. Heavy-mineral composition of beach samples, recomputed to omit opaque minerals. Samples from an individual location were averaged.

augite, epidote, titanite, and opaques, and minor but definite amounts of garnet, hornblende, zircon, and micaceous minerals (Table II). Few grains of titaniferous augite were recognized.

The Hornblende Province (southern) extends from Palos Verdes southward below the study area. Only two samples (both from the northern end of this province) were studied. These samples contained abundant hornblende (32 percent) and micaceous minerals (24 percent), moderate amounts of epidote, augite, titanite and opaque minerals, and minor but definite amounts of garnet and zircon.

The dendrogram shown in Figure 7 illustrates the relationships between individual beach samples excluding opaque minerals. Although samples within a province show a general relationship to each other, not all samples from an individual location relate most closely to each other. The variations between samples from an individual location may be caused by seasonal and climatic factors. For example, during the winter months the California beaches are generally subjected to greater wave energy than during the summer months. Additionally, most small streams and many rivers are blocked off by a stream-mouth spit which is breached only occasionally by short periods of strong flow. During each period of flooding, a new supply of minerals is brought to the beach. Because of variations alongshore, not all samples of a given date are closely related to each other. Consequently (and because only 3 to 4 samples were studied from an individual location), no statistical study of seasonal variation could be undertaken.

Longshore variations are in part caused by changes in source supplies and in part by changes which occur during transport. North of Point Conception, grain size gradually decreases southward to Point Conception and remains stable east of Point Conception to Ventura. Within the Epidote Province a similar trend is found in the percentages of augite and hornblende (which have sources principally outside of the Epidote Province). As shown in Figure 8, north of Government Point, augite and hornblende decrease southward; east of Government Point, the percentages of augite and hornblende remain stable. Within the Epidote Province, opaques decrease away from Point Conception on either side (Figure 3). At San Buenaventura and McGrath Beaches, the percentage of augite (and to some extent, hornblende) shows a marked increase. This increase corresponds to the respective input of the Ventura River and the Santa Clara River, which marks the start of the Augite Province.

3. <u>Heavy-Mineral Composition of the River Sands</u>

The streams in the Epidote Province carry abundant epidote and opaque minerals, moderate quantities of titanite, garnet, zircon, and micaceous minerals, and minor amounts of apatite, augite, and hornblende. Trask (1952) reported that the streams between Point Conception and Santa Barbara did not carry augite. Minute traces (less than 0.5 percent) of augite in these streams were found during the present study; however,

TABLE III

Summary of Heavy Minerals in the River Samples

+ Mineral	N. of Pt. Conception	E. of Pt. Conception	Ventura Basin Area	Santa Monica Mts. (Malibu Creek)	Los Angeles River
	%	%	%	%	%
Epidote	16.2	27.6	21.7	17.4	9.2
Titanite	7.3	9.2	10.5	14.6	10.8
Garnet	7.1	3.4	1.5	1.6	0.6
Zircon	6.9	3.4	0.9	1.6	1.4
Augite	3.5	0.2	7.9	20.4	5.4
Hornblende	0.8	2.1	13.1	3.6	22.8
Opaque	52.9	36.8	26.9	31.0	32.6
Chlorite	1.1	5.1	9.3	3.0	11.6
Mica	1.3	10.5	5.7	3.8	4.2
Apatite	1.3	1.1	1.5	0.4	1.4
Miscellaneous	1.6	0.6	1.0	2.6	0.0
Number of Samples	3	3	3	1	1

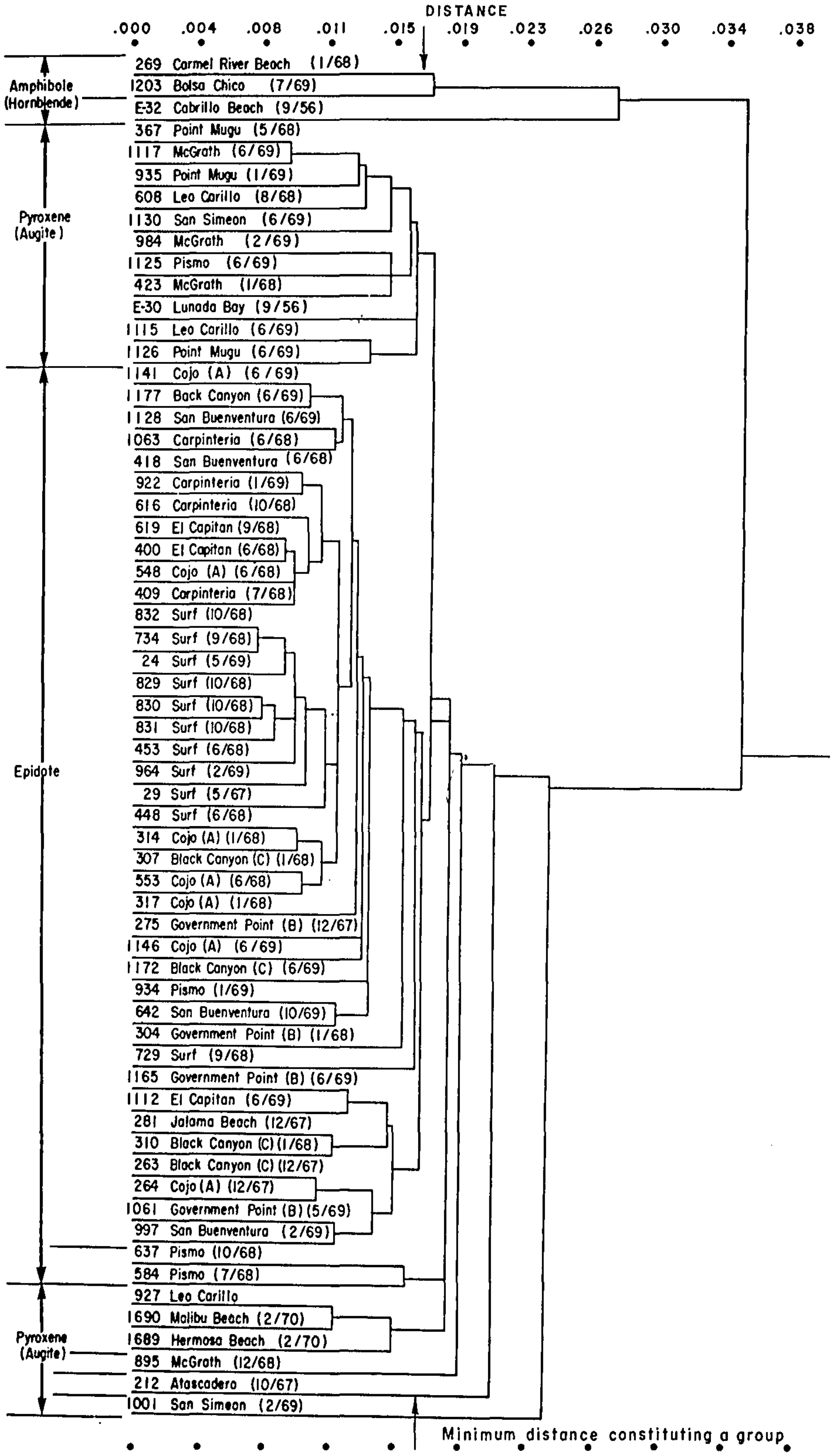


Figure 7. Dendrogram showing relationships between individual beach and offshore samples based on heavy-mineral composition exclusive of opaque minerals. (See page 11 for explanation of distance measure.)

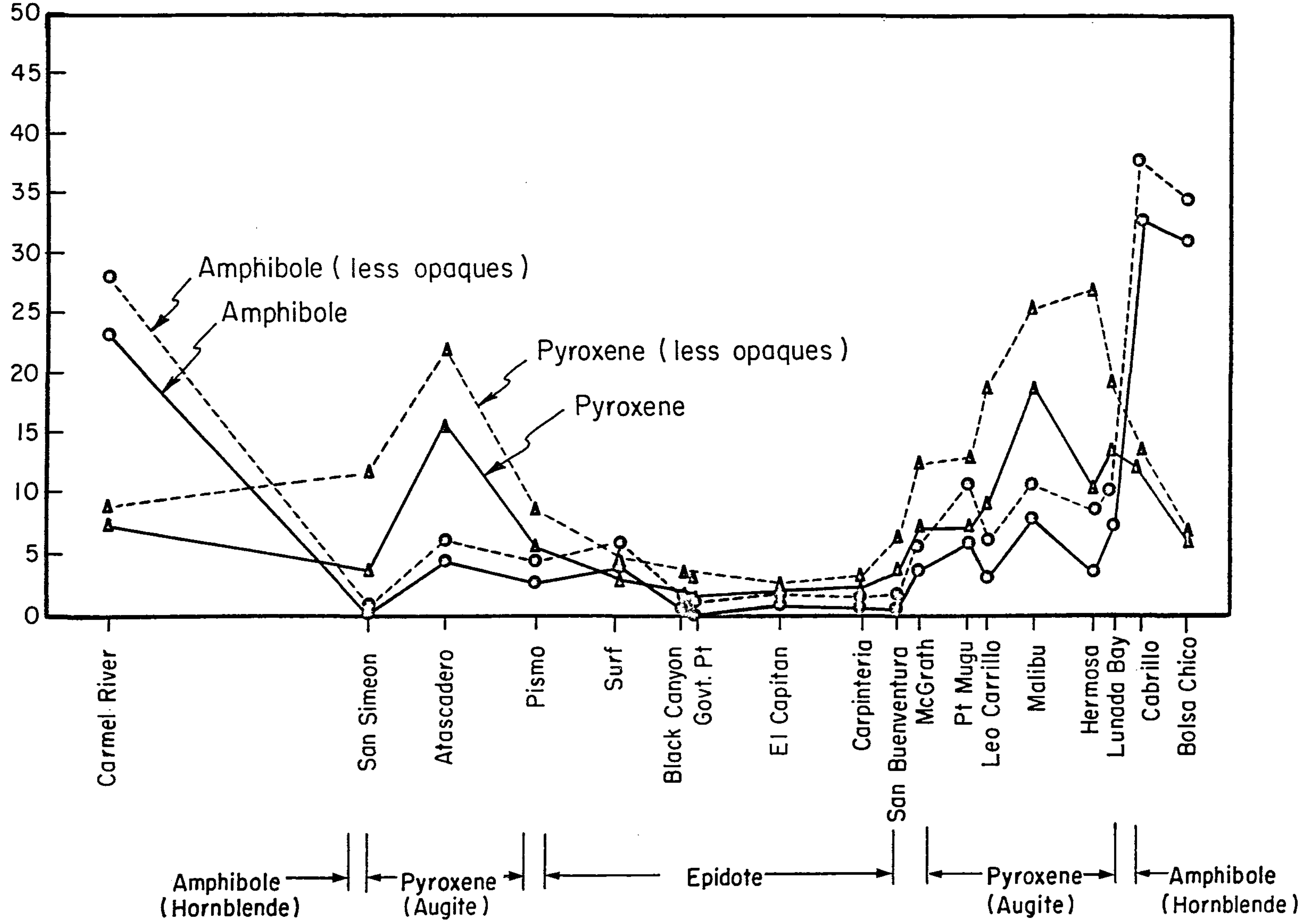


Figure 8. Longshore variations in the percent of pyroxene and amphibole in the 63-125 micron heavy-mineral component of beach samples.

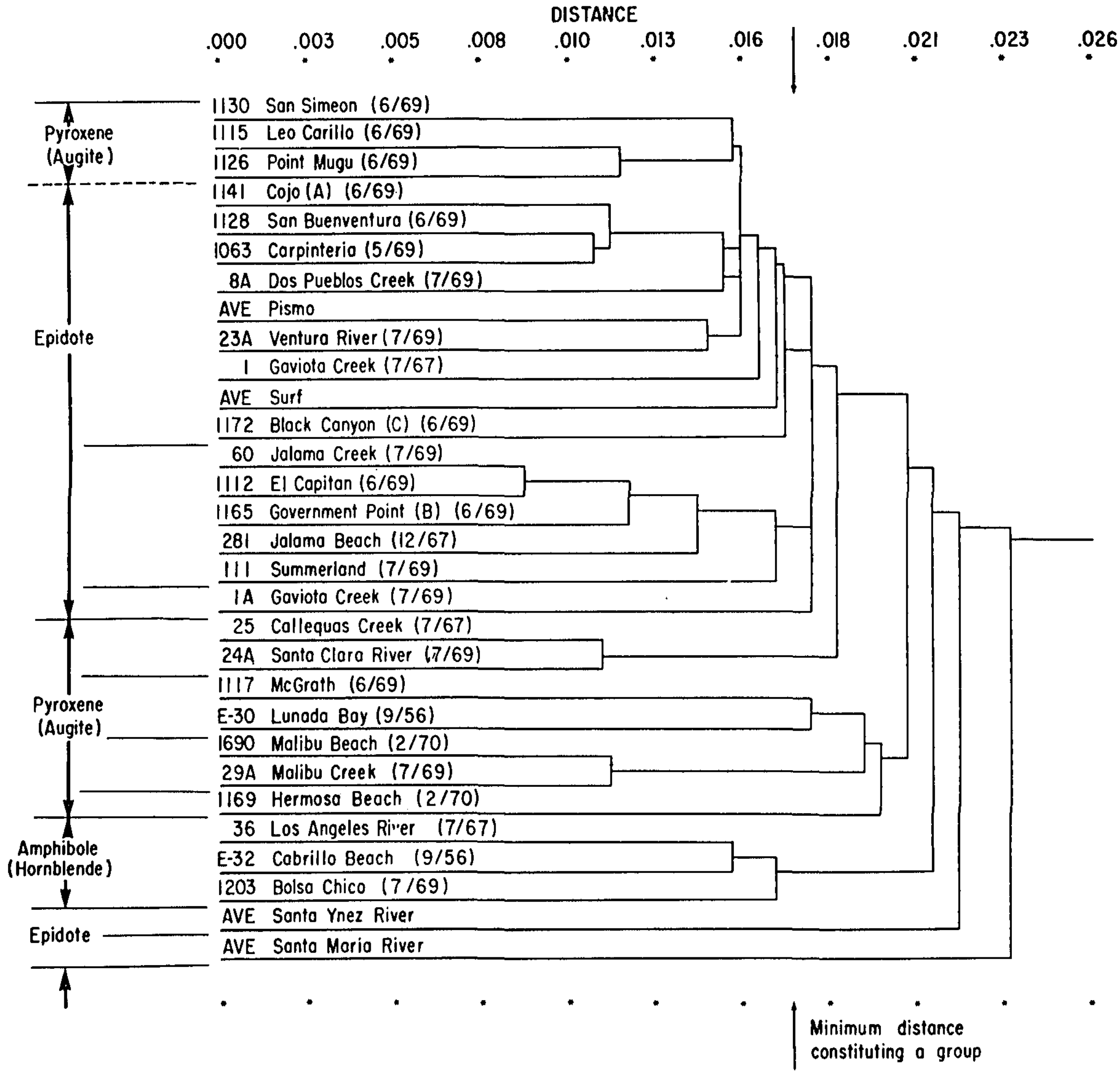


Figure 9. Dendrogram showing relationships between individual river and selected beach samples based on heavy-mineral composition exclusive of opaque minerals. Beach samples were selected to approximate the same time as the river samples. (See page 12 for explanation of distance measure.)

this may be the result of the occurrence of beach sediment at some distance upstream, similar to that found by Gorsline (1968).

The streams of the Ventura River Basin (i.e., Ventura River, Santa Clara River and Calleguas Creek) carry abundant epidote, moderate amounts of augite, hornblende, titanite, opaque and micaceous minerals, and minor but definite amounts of garnet, zircon, and apatite. A disproportionately large amount of hornblende is noted from streams in the Ventura Basin. Table III summarizes the heavy mineral content of these river samples.

As seen from Table III, Malibu Creek, representative of the streams draining the Santa Monica Mountains, contains abundant augite and opaque minerals and moderate amounts of epidote and titanite. The Los Angeles River contains abundant hornblende and opaque minerals and moderate amounts of epidote and titanite.

Figure 9 shows the relationship (based on heavy mineral suites) of river and beach sediment samples taken at approximately the same time (generally during the summer of 1969). As may be seen from Figure 9, the mineralogy of the river samples does not correlate well with that of the adjacent beaches. The exceptions to this are Malibu Creek which shows a strong correlation to Malibu Beach, and the Los Angeles River which relates to Cabrillo and Bolsa Chica Beaches of the Hornblende Province.

Many of the streams and rivers along the Southern California Coast are blocked off by a stream-mouth spit which is breached only occasionally by short periods of strong flow. During these flood periods a new supply of sediments is brought to the beaches where it joins the littoral system. The streams and rivers therefore do not have a great influence on adjacent beaches throughout much of the year, but influence the beach mineralogy only during periods of heavy flow. A similar conclusion was reached by Gorsline (1968) who found an intrusion of beach heavy minerals into the mouths of the streams.

Section V. SAND MOVEMENT ALONG THE CALIFORNIA COAST

1. Sediment Source Areas

Sand may be supplied to the beaches along the Southern California Coast by one or more of the following processes: 1) longshore transport; 2) river transport; 3) onshore transport from offshore sources; 4) reworking of dune fields; and 5) erosion of sea cliffs. Of these, the last three are of minor importance. Because, as shown in Figures 10 and 11, sand becomes generally finer offshore, a significant inshore transport of sand from offshore sources outside the breaker zone does not occur. The gradual offshore decrease in grain size on coastal zones in the study area has also been found by other researchers such as Lampietti (1964), Trask (1955), Azmon (1960), Dill (1952), and Handin (1951). Additionally, sediments farther offshore, as in the Santa Barbara Basin, consist of silts and clays (Emery, 1960, and Wright, 1967) which, coupled with depths greater than 500 feet, precludes sand being transported to the coastal beaches from offshore islands.

Dune fields largely represent a loss of sand from adjacent beaches; thus, when some sand is reclaimed by the beach (as by wind transport or by storm waves), it may be regarded as returning to its source rather than considering the dunes as a primary source. On the other hand, erosion of sea cliffs may locally produce significant quantities of sand. For example, Bowen and Inman (1966) calculate that erosion of the cliffs of Orcutt sandstone in the vicinity of Point Arguello (Bear Valley to Sudden Flats) results in a sand yield of 25,000 cubic yards per year. However, the cliffs around Point Conception and to the east (as well as many other cliffs in the study area) are mainly composed of clay and silt and contribute little in the form of sand-sized particles. Thus, erosion of the sea cliffs as a source of sand-size particles is only significant in a few localized areas.

The primary sources of sand to the beaches along the California Coast are from the rivers and streams and from longshore transport. Most of the rivers and streams are blocked from the ocean by stream-mouth spits throughout much of the year and contribute appreciable quantities of sediments only during periods of strong flow. This results in a general correlation between heavy mineral suites of stream and beach sediments within a given heavy-mineral province, but no distinct relationship between the stream sediments and those of immediately adjacent beaches. The relationship between the river and beach samples is illustrated by Figure 12, which is a dendrogram of all samples studied.

Most of the heavy minerals identified from beaches in the study area are also found in the rivers and streams in the study area, and therefore are not well suited for use in identifying specific source areas. However, both augite and hornblende are found in the beach sands east of Point Conception, although streams in the Epidote Province east of Point Conception do not contribute augite to the beaches and contribute only minor

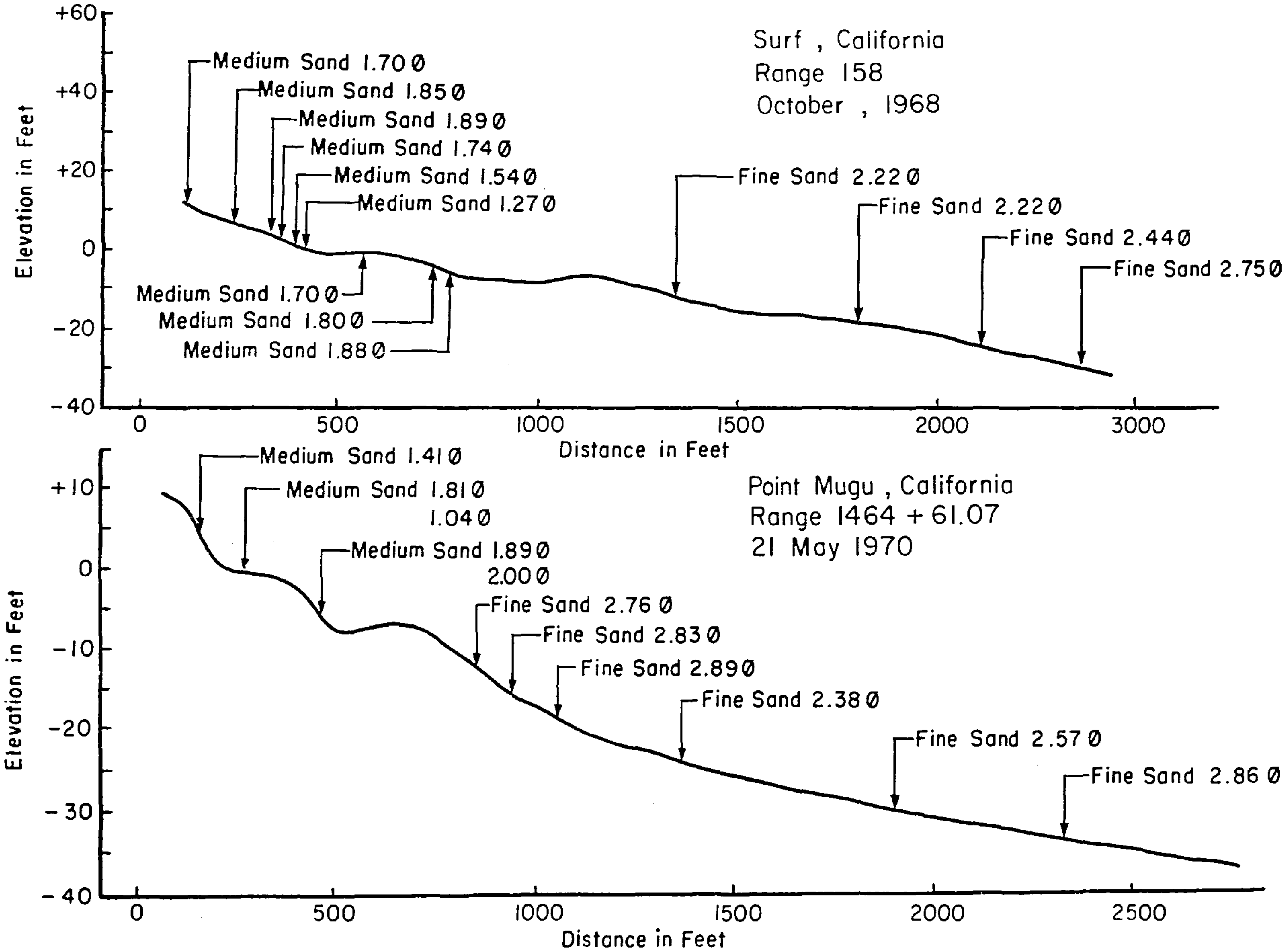


Figure 10. Beach Profiles at Surf and Point Mugu, California. Note offshore decrease in grain size.

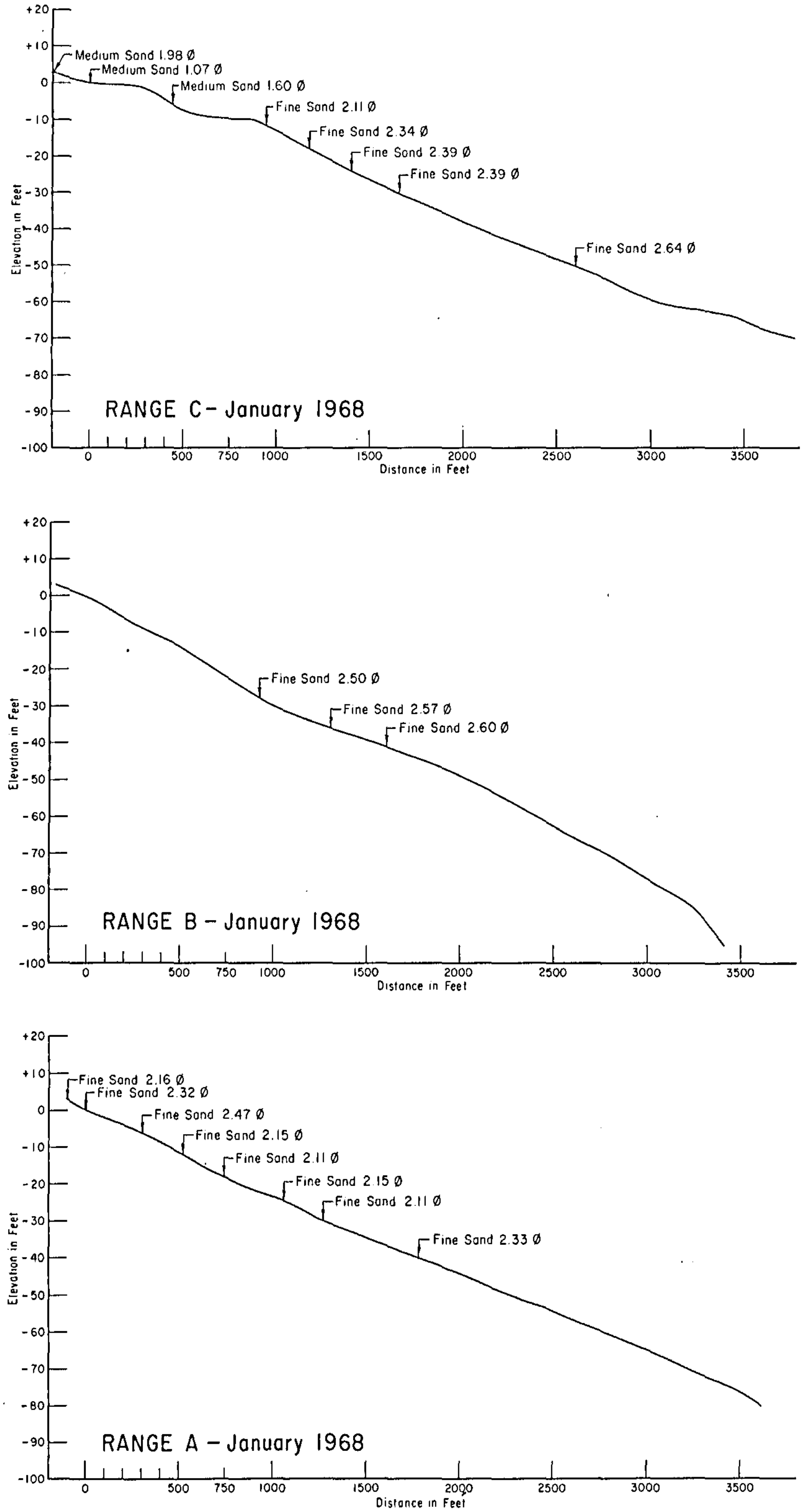


Figure 11. Beach profiles in the vicinity of Point Conception, California. Note offshore decrease in grain size.

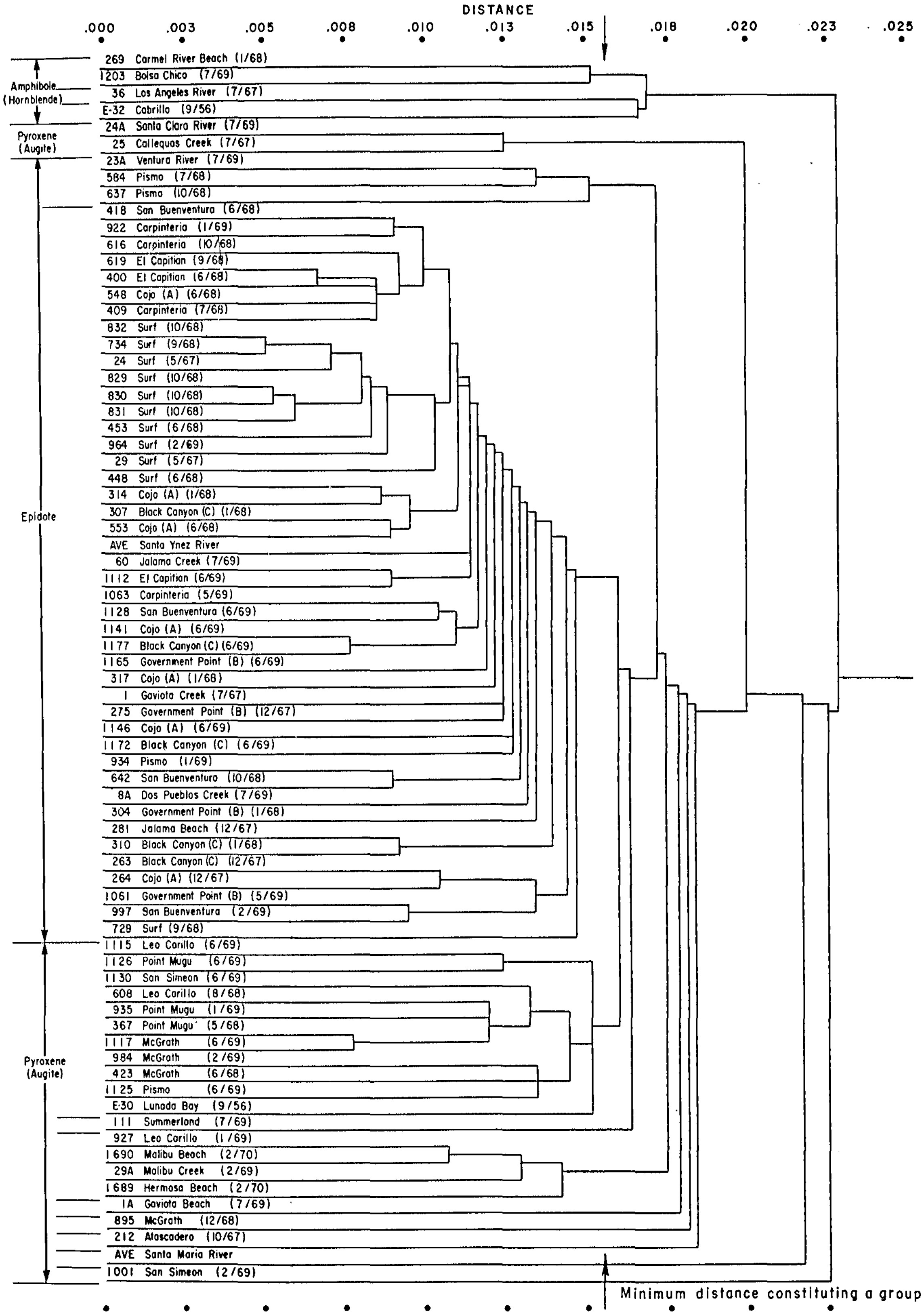


Figure 12. Dendrogram showing relationship between all samples studied, based on heavy-mineral composition exclusive of opaque minerals. (See page 12 for explanation of distance measure.)

amounts of hornblende. Therefore, a portion of the sand on these beaches must have originated from another source. However, the mere presence of augite and hornblende is not sufficient to identify the source because Augite and Hornblende Provinces exist as possible source areas both to the north and to the south of this region.

2. Evidence of Sediment Transport

Along the beaches north of Point Conception, a southward littoral drift is indicated by the southward decrease in grain size and by the gradual southward decrease of hornblende and augite away from their respective provinces to the north (see Figure 8). This is further supported by considering the ratio of less stable to more stable heavy minerals. Since the attrition rate of unstable minerals is greater than that of the stable minerals, this ratio should decrease in the direction of transport. Hornblende and augite are relatively unstable in comparison to garnet and zircon (Jackson and Sherman, 1953). As shown in Figure 13, the ratios of hornblende and augite to garnet and zircon show a pronounced southward decrease along beaches north of Point Conception. Considering the fact that streams in this region contribute sediment only during a small part of the year and that the contribution of hornblende, augite, garnet, and zircon is minor and is similar for all streams in the Epidote Province north of Point Conception, it is valid to conclude that a net southward littoral transport exists north of the Point. Using radioisotopic tracers, Duane (1970) also found a southward pattern of sediment movement along the beach at Surf, California.

However, as shown in Figure 13, the ratio of stable to unstable minerals showed a slight increase eastward for the beaches east of Point Conception. This increase is not of sufficient magnitude to be considered statistically significant (based on Wilcoxon's rank sum test (Bradley, 1968)); and therefore no conclusions were drawn from it. To determine the movement of sediment around Point Conception, tracer tests using radioisotope-tagged sand were conducted at three areas in the vicinity. Results of these tests are summarized in Figure 14. In the areas north of Point Conception and between Point Conception and Government Point, a net southward movement of sediment was indicated. However, only slight dispersal was found in the area of Cojo Anchorage and the pattern of movement was confused.

The Ventura and Santa Clara Rivers carry substantial amounts of coarse material, hornblende, and augite. Beaches just south of these rivers show a substantial increase in grain size (Figure 3) and in the percentages of hornblende and augite (Figure 8). Beaches just north of these rivers show neither the addition of coarser material, nor increases in the hornblende and augite. Thus, material contributed by these rivers is carried predominantly to the beaches south of the rivers, and net littoral transport is to the south at Ventura. Radioisotopic sand tracer tests near Point Mugu Naval Air Station also indicate a southward movement of sand although

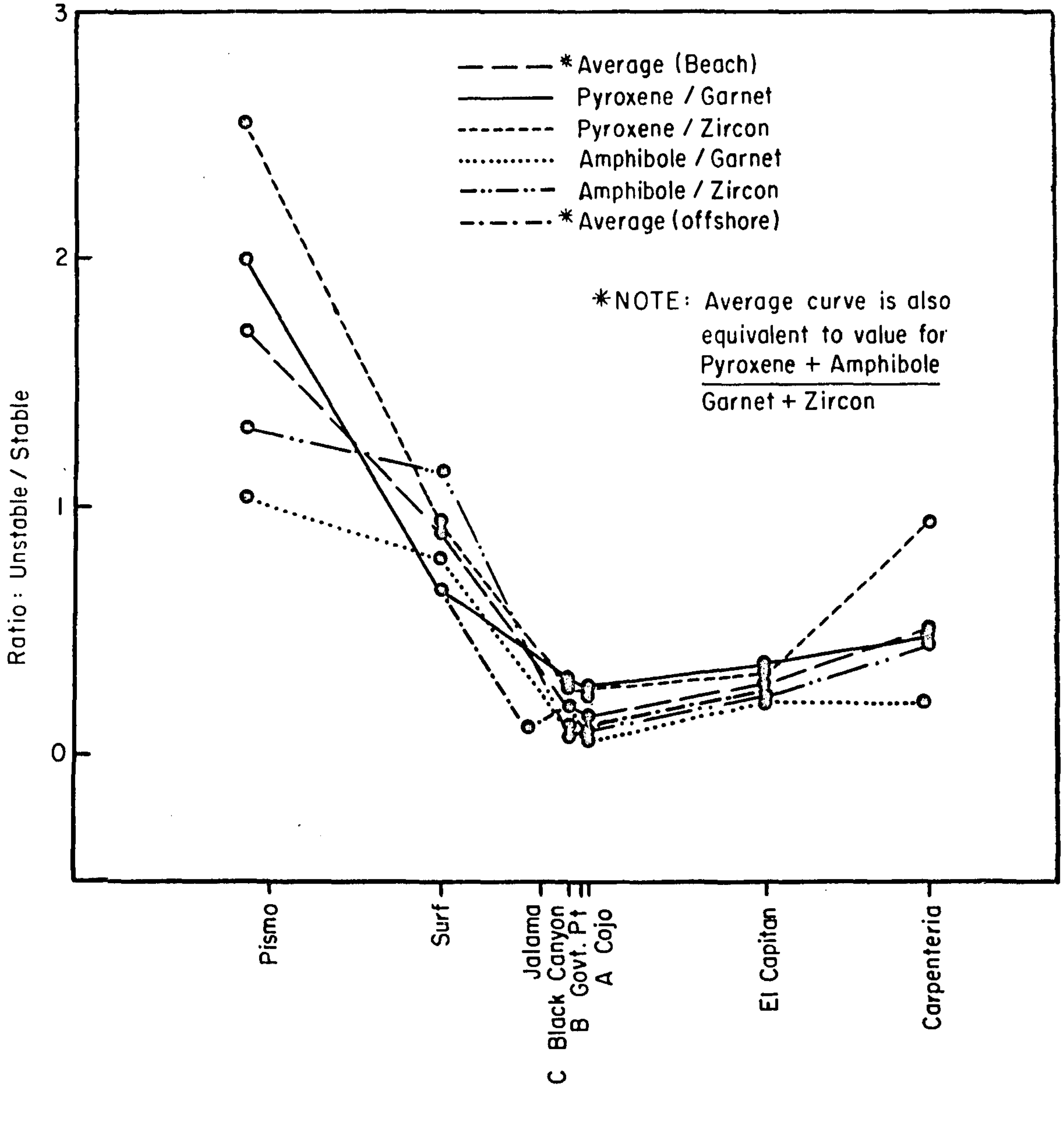


Figure 13. Ratio of unstable to stable minerals in beach samples of the Epidote Province; plotted from north to south in the longshore direction.

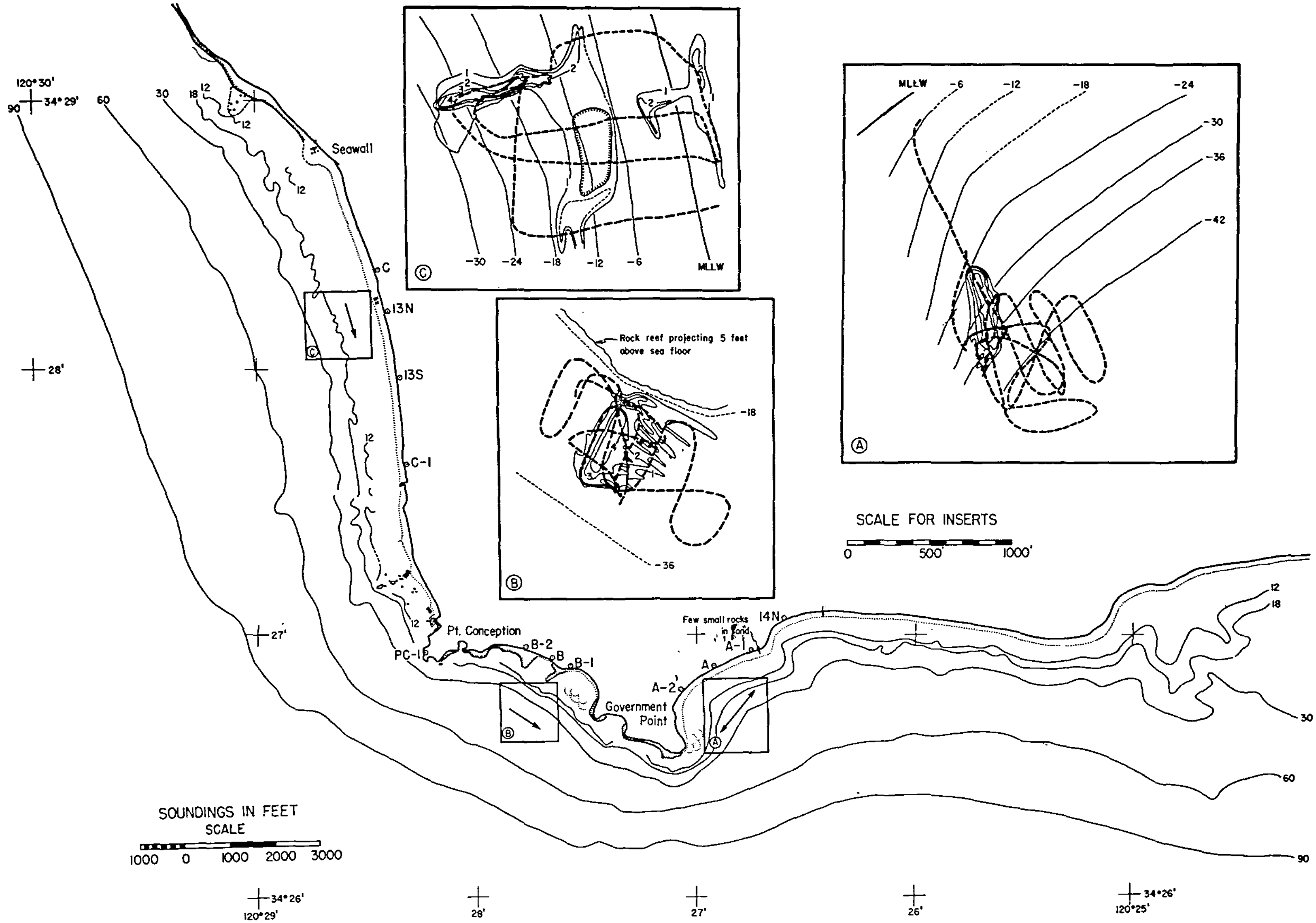


Figure 14. Sediment movement in the vicinity of Point Conception, based on tracer studies with radioisotope-tagged sand.

definite northward movement was found during a part of the experiment correlated to a change in current direction. Based on detailed hydrographic surveys, Herron (1960) found a pronounced southward net littoral transport in the Ventura area. Similarly, Handin (1951) indicates a net littoral transport to the southeast at Santa Barbara, and also a net southward movement in Santa Monica Bay. Studying the feldspar-quartz ratios, Gorsline (1968) also found a net southward movement along southern California beaches. However, periods of northward littoral transport are known from Littoral Environmental Observations (Szuwalski, 1970) and from tracer observations at Point Mugu. This indicates that some augite-bearing sand could have worked its way northward to the beaches south of Point Conception.

Based on Jackson and Sherman (1953), augite, hornblende, and epidote may be considered less stable than the other heavy minerals encountered along the California coast. Therefore, it may be inferred from the relative decrease in epidote (which, in addition to being one of the least stable minerals, shows the highest degree of weathering of the heavy minerals studied) in the vicinity of Point Conception that the Point Arguello-Point Conception complex may act as a partial barrier to sediment movement, and entrap some of the sand for an indeterminate period of time. The results of this partial blocking of sediments at Point Conception is also reflected in the smaller amounts of hornblende and augite east of Point Conception than north of it. Similar conclusions regarding sediment movement around Point Conception were reached by Trask (1952) and Azmon (1960).

Johnson (1959) estimated that the Santa Maria River carries an average of 187,000 cubic yards per year (cy/yr) of sand and that the Santa Ynez River carries an average of 570,000 cy/yr of sand. On the other hand, Bowen and Inman (1966) stated that the Santa Maria River supplies an average of 60,000 cy/yr to the beaches and the Santa Ynez River supplies an average of 48,000 cy/yr. Bowen and Inman (1966) estimated a net southerly littoral transport rate of about 60,000 cy/yr north of Point Arguello and about 100,000 cy/yr at Gato, 6 miles east of Point Conception. At Santa Barbara, the measured rate of sand entrapment is 280,000 cy/yr (Johnson, 1953). Herron (1960) reports a net southward littoral transport of 27,000 cy/yr north of the Ventura River. He also reports that the Ventura River contributes 100,000 cy/yr and the Santa Clara River contributes 800,000 cy/yr. This material is carried southward resulting in a net southward movement of 1,170,000 cy/yr between the Santa Clara River and Port Hueneme, where substantial amounts were lost to Hueneme and Mugu Canyons prior to construction of the Channel Islands Harbor. There the offshore breakwater entraps essentially all of the southward moving sand at a rate of 1,200,000 cy/yr. This material is periodically dredged and transported past the canyons to a feeder beach downcoast where it acts to stabilize previously eroding beaches. Handin (1951) reports an accretion rate of 270,000 cy/yr at the Santa Monica breakwater (northern Santa Monica Bay), 162,000 cy/yr at El Segundo groin (central Santa Monica Bay) and 30,000 cy/yr at the Redondo Breakwater (southern Santa Monica Bay).

Section VI. CONCLUSIONS

Beach sediments between Monterey Bay and Bolsa Chica Beach may be divided into five heavy-mineral provinces. The Epidote Province spans the central part of the area and extends from Avila Beach around Point Conception and southeast to Ventura. Hornblende and Augite Provinces exist both north and south of the Epidote Province.

Primary sources of sand supplied to the beaches are from rivers and from longshore transport. In general, the rivers supply sediment to the beaches only during short periods of heavy flow, and therefore the mineralogy of the river sands does not correlate well with that of adjacent beaches. The predominant direction of littoral transport is southward; however, reversals occur. North of Point Conception and in the vicinity of Ventura, grain size and heavy mineral distribution indicate a net southward movement. However, the study of heavy minerals showed no direct evidence to indicate the direction of movement along beaches from Point Conception to north of the Ventura River. Because of the lack of a unique mineral species and the lack of distinct longshore trends which could be used to identify source areas, heavy mineral studies are unsatisfactory as indicators of littoral drift for beaches between Point Conception and Ventura. For example, augite on beaches between Point Conception and Ventura, which Trask (1952) used to prove sediment movement around Point Conception, could have been derived from a southern source at times of reverse littoral transport rather than from the northern source. However, coupled with other evidence from radioisotopic sand tracer surveys such as dredging projects, it is reasonable to conclude that although the Point Conception-Point Arguello complex may act as a partial barrier, some sand does in fact move south and east around Point Conception.

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APPENDIX

GRAIN SIZE AND HEAVY-MINERAL COMPOSITION

EXPLANATION OF TABLES

Reference Number - Number assigned to an individual sample. Avg. indicates a tabulation of the average of all samples sutdied from a given location.

Location - Name of beach, stream, or other location from which sample was taken.

Depth - Depth (below MLLW) from which sample was taken. Letter "B" indicates that sample was taken from the wetted zone on the beach.

Date - Date when sample was collected (Month-Day-Year).

Mean Ø Size - Mean grain size in phi (Ø) units of whole sample.

Percentage, 63-125 micron fraction - Grains in the 63-125 micron (4 Ø - 3 Ø) size range expressed as a percentage (by weight) of the whole sample.

Percentage, Heavy Mineral (63-125 micron) - Heavy minerals in the 63-125 micron (4 Ø - 3 Ø) size class expressed as a percentage (by weight) of the 63-125 micron size fraction.

Individual Heavy Minerals - Individual species of heavy minerals expressed as a percentage (by number of grains) of the 63-125 micron heavy-mineral fraction.

Total Grains Counted - Actual number of heavy-mineral grains counted from an individual sample.

Reference Number	Beach Samples Location	Depth	Date	Mean Ø size (whole sample)	Percentage 63-125μ Fraction	Percentage Heavy-Mineral (63-125μ)	Epidote	Garnet	Amphibole (Hornblende)	Pyroxene (Augite)	Zircon	Titanite (Sphene)	Opaque	Chlorite	Mica (Muscovite & Biotite)	Monazite	Apatite	Calcite	Rutile	Tourmaline	Anatase - Brookite	Miscellaneous	Total Grains Counted
				Ø	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
269	Carmel River Beach	B	1-4-68	0.52	0.1	1.0	3.6	4.6	23.4	7.4	2.6	10.6	17.4	17.0	11.2	-	1.0	0.6	0.4	-	-	0.2	500
1001	San Simeon	B	2-2-69	0.77	0.7	50.5	2.4	2.5	0.2	3.4	2.6	7.2	65.1	6.2	7.8	-	0.1	2.0	0.3	0.1	0.1	-	1000
1130	San Simeon	B	6-4-69	1.66	1.4	74.1	2.4	3.6	0.3	4.3	3.2	4.8	73.3	3.1	3.1	0.2	0.2	1.5	0.2	-	-	-	1200
Avg	San Simeon	B		1.22	1.1	62.3	2.4	3.1	0.3	3.9	2.9	6.0	69.2	4.7	5.5	0.1	0.2	1.8	0.3	0.1	0.1	-	1100
212	Atascadero	B	10-3-67	2.29	10.5	32.6	30.2	1.8	4.8	16.6	0.4	14.0	26.2	2.6	2.8	0.4	-	0.2	-	-	-	-	500
584	Pismo	B	7-1-68	2.33	16.5	1.4	24.4	2.2	4.4	4.8	0.6	8.2	28.6	10.8	4.8	1.2	0.4	9.6	-	-	-	-	500
637	Pismo	B	10-1-68	2.46	22.3	1.0	20.2	3.4	4.0	6.6	1.6	11.4	36.0	6.2	3.0	1.0	1.0	5.6	-	-	-	-	500
934	Pismo	B	1-1-69	2.35	8.9	21.3	21.8	5.4	0.8	4.4	6.4	14.2	36.8	2.6	2.8	2.6	1.0	0.8	-	-	-	0.4	500
1125	Pismo	B	6-3-69	2.38	10.5	1.0	10.3	0.3	2.2	6.7	0.2	6.3	49.8	8.3	8.2	0.2	1.0	6.2	0.3	-	-	-	600
Avg	Pismo	B		2.38	14.6	6.2	19.2	2.8	2.9	5.6	2.2	10.0	37.8	7.0	4.7	1.3	0.9	5.6	0.1	-	-	0.1	525
024	R-158, SURF (VAFB)	B	5-18-67	1.81	1.8	4.3	38.8	5.0	3.6	4.0	1.8	13.2	28.0	1.0	0.6	2.6	0.6	0.6	-	0.2	-	-	500
448	R-158, SURF (VAFB)	B	6-5-68	1.27	0.1	3.6	23.6	5.3	1.6	1.9	5.9	7.9	48.7	1.1	1.0	2.4	0.4	0.2	-	-	-	-	1000
729	R-158, SURF (VAFB)	B	7-30-68	1.60	0.4	1.1	36.2	2.8	8.8	5.8	3.2	13.0	22.2	2.4	1.2	2.6	1.2	0.6	-	-	-	-	500
964	R-157, SURF (VAFB)	B	2-11-69	1.90	0.8	21.6	29.6	6.8	2.0	1.6	3.0	14.2	38.2	0.4	1.0	2.2	0.8	0.2	-	-	-	-	500
Avg	Surf, (VAFB)	B		1.65	0.8	7.7	32.1	4.9	4.0	3.3	3.5	12.1	34.3	1.2	1.0	2.5	0.8	0.4	-	0.1	-	-	625
029	R-158 SURF (VAFB)	-30'	5-18-67	2.65	46.9	3.3	33.4	3.6	2.0	2.8	1.8	17.8	28.8	1.4	5.8	2.0	0.4	0.2	-	-	-	-	500
453	R-158 SURF (VAFB)	-30'	6-5-68	2.63	35.9	8.8	35.2	7.4	1.0	2.4	2.0	10.6	33.2	0.4	2.6	2.8	0.6	0.2	-	0.2	-	0.8	500
734	R-158 SURF (VAFB)	-30'	9-30-68	2.75	51.7	6.5	33.4	5.0	2.6	2.0	3.6	10.4	33.4	-	2.6	4.8	0.6	-	-	0.2	0.6	0.6	500
829	Black Sand, Core 1 SURF (VAFB)	-13'	10-3-68	2.24	17.6	10.2	31.8	6.0	2.6	3.8	2.6	13.8	33.0	-	3.4	2.2	-	-	-	-	-	0.8	500
830	Black Sand, Core 2 SURF (VAFB)	-13'	10-3-69	2.37	20.1	16.0	30.2	4.6	3.2	5.2	2.4	12.8	36.6	-	3.2	1.2	-	-	-	-	-	0.6	500

831	Black Sand , Core 3 Surf (VAFB)		10-3-68	2.21	13.7	9.8	27.0	4.9	2.2	3.3	4.5	12.4	40.7	-	2.8	1.6	-	-	-	-	-	0.6	500
831	Black Sand, Core 3 SURF (VAFB)	-13'	10-3-68	2.21	13.7	9.8	27.0	4.9	2.2	3.3	4.5	12.4	40.7	-	2.8	1.6	-	-	-	-	-	1.0	511
832	Black Sand, Core 4 SURF (VAFB)	-13'	10-3-68	2.29	17.8	9.5	37.8	4.6	2.2	3.6	3.0	12.4	29.8	0.2	3.0	2.2	0.2	0.4	-	-	-	0.6	500
Avg	SURF (VAFB)	-30'		2.45	29.1	9.2	33.4	5.2	2.1	2.8	2.6	12.9	32.6	0.5	3.3	2.9	0.4	0.1	-	0.1	0.1	0.6	501
281	Jalama Beach	-31'	12/67	2.23	8.9	27.2	8.4	7.9	1.0	1.4	12.7	7.3	54.1	3.1	1.6	1.3	0.1	0.7	-	0.1	0.1	-	700
263	Black Canyon, C Heavy Mineral Area	B	12-5-67	1.74	1.1	99.5	10.2	8.4	0.4	1.1	10.3	3.8	64.9	-	0.3	0.6	0.1	-	-	-	-	-	1200
307	Black Canyon Range C	B	1-31-68	1.96	1.0	35.2	20.3	6.8	1.5	1.0	7.0	9.7	48.0	1.5	1.2	1.3	0.7	0.8	-	0.2	-	-	600
1172	Black Canyon Range C	B	6-5-69	2.17	1.4	3.8	16.3	2.3	0.3	3.2	1.5	9.3	45.7	7.8	9.0	0.3	0.7	3.3	0.2	-	-	-	600
Avg	AREA C	B		1.96	1.2	46.2	15.6	5.8	0.7	1.8	6.3	7.6	52.9	3.1	3.5	0.7	0.5	1.4	0.1	0.1	-	-	800
310	Black Canyon Range C	-30'	1-31-68	2.30	1.5	18.5	11.2	7.1	1.1	1.6	11.1	5.2	58.3	2.4	1.1	0.4	0.3	0.4	-	-	-	-	750
1177	Black Canyon Range C	-30'	6-5-69	2.56	5.4	8.6	13.0	5.3	0.8	3.2	8.0	12.7	43.8	6.7	5.0	0.3	0.2	1.0	-	-	-	-	600
Avg	AREA C	-30'		2.43	3.5	13.6	12.1	6.2	1.0	2.4	9.6	9.0	51.1	4.6	3.1	0.4	0.3	0.7	-	-	-	-	675
275	Government Point Range B	-28'	12/67	2.50	19.1	2.3	35.0	2.8	2.6	1.6	2.8	3.8	36.4	6.8	4.4	0.4	1.0	2.4	-	-	-	-	500
304	Government Point Range B	-30'	1-31-68	2.57	31.2	3.4	24.2	4.7	2.0	1.3	5.7	4.2	47.8	4.2	3.5	1.0	0.3	1.0	-	0.2	-	-	600
1061	Government Point Range B	-20'	5-2-69	2.16	1.7	68.6	4.6	7.6	-	0.8	12.2	7.6	65.4	0.7	0.8	-	0.3	0.1	-	-	-	-	900
1165	Government Point Range B	-30'	6-5-69	2.50	4.4	21.9	9.1	5.6	0.3	1.6	10.9	9.7	53.7	4.0	3.6	0.4	0.6	0.6	-	-	-	-	700
Avg	AREA B	-27'		2.43	14.1	24.1	18.2	5.2	1.2	1.3	7.9	6.3	50.8	3.9	3.1	0.5	0.6	1.0	-	0.1	-	-	675

Reference Number	Beach Samples Location	Depth	Date	Mean ø size (whole sample)	Percentage 63-125µ Fraction	Percentage Heavy Mineral (63-125µ)	Epidote	Garnet	Amphibole (Hornblende)	Pyroxene (Augite)	Zircon	Titanite (Sphene)	Opaque	Chlorite	Mica (Muscavite & Biotite)	Monazite	Apatite	Calcite	Rutile	Tourmaline	Anatase - Brookite	Miscellaneous	Total Grains Counted
				ø	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
264	Cojo, A Heavy-Minerals Area	B	12-6-67	1.87	1.0	96.0	7.5	9.5	0.1	0.7	11.8	5.0	64.4	-	0.5	0.5	-	-	-	-	-	-	1000
314	Cojo Range A	B	1-31-68	2.01	2.1	21.7	25.5	7.7	0.7	1.0	5.0	7.5	47.7	1.5	1.7	0.5	0.5	0.8	-	-	-	-	600
548	Cojo Range A	B	6-19-68	2.32	6.6	5.1	36.2	4.4	1.0	1.8	2.6	7.2	39.4	2.8	2.2	0.8	0.6	1.0	-	-	-	-	500
1141	Cojo Range A	B	6-5-69	2.12	2.3	11.3	13.5	5.3	0.7	3.3	5.8	12.8	45.3	5.0	5.2	0.2	0.7	2.2	-	-	-	-	600
Avg	AREA A	B		2.08	2.8	35.5	20.7	6.7	0.6	1.7	6.3	8.1	49.2	2.3	2.4	0.5	0.5	1.0	-	-	-	-	675
317	Cojo Range A	-30'	1-31-68	1.97	7.7	7.9	18.7	8.3	1.4	0.7	8.0	4.4	51.7	3.1	2.3	0.3	0.4	0.6	-	-	-	-	700
553	Cojo Range A	-30'	6-19-68	2.11	6.4	10.6	19.0	8.5	0.5	0.7	6.8	9.8	47.5	3.2	2.5	0.5	0.5	0.5	-	-	-	-	600
1146	Cojo Range A	-30'	6-5-69	2.22	4.0	6.1	15.5	3.5	0.5	1.5	4.5	10.3	49.3	6.2	7.3	0.3	0.3	0.5	0.2	-	-	-	600
Avg	AREA A	-30'		2.10	6.0	8.2	17.7	6.8	0.8	1.0	6.4	8.2	49.5	4.2	4.0	0.4	0.4	0.5	0.1	-	-	-	633
400	El Capitan	B	6-3-68	1.98	1.1	27.7	37.4	2.6	1.2	1.4	2.4	10.6	34.4	3.4	4.0	1.2	0.6	0.8	-	-	-	-	500
619	El Capitan	B	9-1-68	2.11	2.9	9.3	36.2	3.6	2.2	1.8	2.8	10.4	30.2	4.6	5.4	0.8	0.8	1.2	-	-	-	-	500
1112	El Capitan	B	6-17-69	1.76	1.0	40.0	11.8	8.2	0.3	2.3	9.5	11.2	48.2	2.2	3.7	0.3	0.5	1.2	0.5	-	0.2	-	600
Avg	El Capitan	B		1.95	1.6	25.7	28.5	4.8	1.2	1.8	4.9	10.7	37.6	3.4	4.4	0.8	0.6	1.1	0.2	-	0.1	-	533
111	Summerland	B	7/69	2.07†	-	-	17.2	11.2	2.0	1.6	8.8	9.0	30.0	6.6	10.8	0.2	-	2.4	0.2	-	-	-	500
409	Carpinteria	B	7-1-68	2.11	7.1	28.3	32.8	4.8	0.6	1.4	3.0	12.6	34.2	5.2	3.4	0.4	0.6	1.0	-	-	-	-	500
616	Carpinteria	B	10-1-68	2.44	15.7	2.1	33.2	2.2	0.4	2.2	1.0	11.8	33.0	6.2	6.6	0.2	0.8	2.4	-	-	-	-	500
922	Carpinteria	B	1-6-69	2.21	2.9	4.6	30.8	7.2	2.4	3.0	2.8	12.0	29.2	5.2	5.6	0.8	0.6	0.4	-	-	-	-	500
1063	Carpinteria	B	5-7-69	2.01	2.5	8.1	26.4	4.0	1.0	2.4	2.8	16.2	32.8	4.6	7.4	0.4	0.6	1.4	-	-	-	-	500
Avg	Carpinteria	B		2.19	7.1	10.8	30.8	4.6	1.1	2.3	2.4	13.2	32.3	5.3	5.8	0.5	0.7	1.3	-	-	-	-	500

418	San Buenaventura	B	6-7-68	1.81	1.9	10.2	28.2	3.8	1.2	4.6	1.8	10.2	36.0	4.4	6.2	0.4	1.6	1.6	-	-	-	-	500
642	San Buenaventura	B	10-6-68	1.69	0.6	15.0	21.2	8.0	0.8	4.0	6.0	16.0	38.6	3.2	1.2	0.4	0.4	0.2	-	-	-	-	500
997	San Buenaventura	B	2-5-69	1.44	0.3	78.9	3.3	7.4	0.3	2.0	14.8	10.5	59.3	0.6	1.3	-	-	0.1	0.5	-	0.1	-	800
1128	San Buenaventura	B	6-5-69	2.08	5.3	5.9	19.2	5.8	1.4	4.0	3.0	16.0	35.2	4.8	7.4	0.2	1.8	0.2	0.4	-	0.2	0.4	500
Avg	San Buenaventura	B		1.76	2.0	27.5	18.0	6.3	1.0	3.7	6.4	13.2	42.3	3.3	4.0	0.3	1.0	0.5	0.2	-	0.1	0.1	575
423	McGrath	B	6-7-68	0.81	0.8	2.6	17.5	3.8	2.7	9.5	0.8	17.9	27.0	9.1	9.5	-	0.4	1.9	-	-	-	-	263
895	McGrath	B	12-4-68	0.98	0.9	20.4	2.7	2.0	0.3	2.7	7.3	4.1	75.0	2.5	2.5	0.1	0.1	0.8	-	-	-	-	1200
984	McGrath	B	2-5-69	0.98	0.1	14.6	11.8	0.8	4.6	7.0	1.4	14.2	38.2	10.2	10.6	-	0.2	0.8	-	-	0.2	-	500
1117	McGrath	B	6-5-69	1.94	2.1	48.3	9.0	4.0	7.8	9.6	2.0	15.2	36.4	9.8	4.6	0.2	0.8	-	0.4	-	0.2	-	500
Avg	McGrath	B		1.18	1.0	21.5	10.3	2.7	3.9	7.2	2.9	12.9	44.2	7.9	6.8	0.1	0.4	0.9	0.1	-	0.1	-	616
367	Point Mugu	B	5-1-68	1.98	1.1	22.4	10.0	3.2	8.6	9.8	2.4	14.8	28.0	11.0	8.0	-	3.6	0.2	-	-	0.4	-	500
935	Point Mugu	B	1-3-69	0.82	0.6	20.7	5.5	4.8	6.2	7.3	4.8	9.2	47.3	7.5	6.3	-	0.7	0.2	-	-	-	-	600
1126	Point Mugu	B	6-2-69	1.67	0.7	44.9	5.1	5.5	3.4	5.0	4.9	8.9	59.3	4.1	2.6	-	1.0	-	0.3	-	-	-	800
Avg	Point Mugu	B		1.49	0.8	29.3	6.9	4.5	6.1	7.4	4.0	11.0	44.9	7.5	5.6	-	1.8	0.1	0.1	-	0.1	-	633
608	Leo Carrillo	B	8-9-68	1.12	0.1	16.7	4.1	3.7	2.9	8.1	4.6	7.9	57.1	5.7	5.0	-	0.3	1.0	-	-	-	-	700
927	Leo Carrillo	B	1-3-69	1.49	0.8	25.0	10.8	3.2	4.8	13.8	3.4	14.0	40.0	4.2	5.2	-	0.6	-	-	-	-	-	500
1115	Leo Carrillo	B	6-2-69	0.99	0.4	36.2	7.7	5.6	1.7	6.4	3.6	11.0	55.4	3.7	3.9	-	0.7	0.1	0.1	-	-	-	700
Avg	Leo Carrillo	B		1.20	0.4	26.0	7.5	4.2	3.1	9.4	3.9	11.0	50.8	4.5	4.7	-	0.5	0.4	T*	-	-	-	633
1690	Malibu Beach	B	2-11-70	1.42	2.0	23.4	17.0	2.4	8.4	19.4	1.8	16.0	25.0	5.0	4.4	-	0.6	-	-	-	-	-	500
1689	Hermosa Beach	B	2-11-70	1.42	0.3	68.7	4.3	4.0	3.4	10.6	3.6	7.5	61.5	1.6	2.8	0.1	0.5	0.1	-	-	-	-	800
E-30	Lunada Bay	B	9/56	1.94	T*	24.0†	7.6	1.0	7.6	14.2	1.6	11.4	28.2	8.6	8.6	0.2	1.4	7.0	0.2	-	-	2.4	500
E-32	Cabrillo Beach	B	9/56	1.80	2.5†	14.5†	9.6	1.0	33.4	12.0	0.6	10.4	12.6	10.0	5.2	0.8	1.4	2.6	0.2	-	-	0.2	500
1203	Bolsa Chica	B	7-8-69	0.65	0.7	5.0	5.4	2.4	31.4	6.2	1.2	9.4	10.0	22.8	9.4	-	1.8	-	-	-	-	-	500
	* Trace † Estimate																						

Reference Number	River Samples Location	Miles from Ocean	Date	Mean ø size (whole sample)	Percentage 63-125µ Fraction	Percentage Heavy Mineral (63-125µ)	Epidote	Garnet	Amphibole (Hornblende)	Pyroxene (Augite)	Zircon	Titanite (Sphene)	Opaque	Chlorite	Mica (Muscovite & Biotite)	Monazite	Apatite	Calcite	Rutile	Tourmaline	Anatase - Brookite	Miscellaneous	Total Grains Counted
				ø	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	%	
T-991	Santa Maria River (from Trask, 1952)	14	1/52				24	6	1	1	4	12	48	-	-	-	3	-	-	-	-	1	
T-990	Santa Maria River (from Trask, 1952)	5	1/52				33	4	1	6	-	8	41	-	-	-	5	-	-	-	-	2	
Avg Pre-flood	Santa Maria River (from Trask, 1952)		51				8	10	T*	14	9	6	52	-	-	-	1	-	-	-	-	1	
Avg	Santa Maria River	10					18.2	7.5	0.7	8.7	5.5	8.0	48.2	-	-	-	2.5	-	-	-	-	1.2	
T-994	Santa Ynez River (from Trask, 1952)	23	1/52				15	7	T*	2	3	6	65	-	-	-	1	-	-	-	-	1	
T-993	Santa Ynez River (from Trask, 1952)	10	1/52				27	8	1	T	7	10	43	-	-	-	3	-	-	-	-	1	
Avg Pre-flood	Santa Ynez River (from Trask, 1952)	21	51				11	5	1	1	7	2	72	-	-	-	T*	-	-	-	-	1	
Avg	Santa Ynez River	19					16.0	6.2	0.8	1.1	6.0	5.0	63.0	-	-	-	1.0	-	-	-	-	1.0	
60	Jalama Creek	0.1	7/69				14.5	7.5	0.8	0.8	9.2	9.0	47.5	3.2	4.0	-	0.5	2.7	0.3	-	-	-	600
1	Gaviota Creek	0.1	7/67				28.2	2.6	1.0	0.2	0.6	10.0	39.8	5.2	10.2	0.4	0.8	0.4	-	-	-	0.6	500
1A	Gaviota Creek	0.1	7/69				25.5	3.3	3.2	-	2.3	5.5	36.0	6.8	16.0	0.2	1.2	-	-	-	-	-	600
Avg	Gaviota Creek						26.8	3.0	2.1	0.1	1.4	7.8	37.9	6.0	13.1	0.3	1.0	0.2	-	-	-	0.3	550
8A	Dos Pueblos Creek	0.1	7/69				29.0	4.4	2.2	0.4	7.2	12.2	34.8	3.2	5.2	-	1.2	-	-	-	-	0.2	500
23A	Ventura River	0.1	7/69				19.2	1.6	7.2	4.6	1.4	9.8	34.4	10.8	7.8	0.2	0.8	2.0	-	-	-	0.2	500
24A	Santa Clara River	0.1	7/69	1.55	9.5	10.1	17.4	0.6	16.0	7.8	0.6	10.2	34.4	7.2	4.2	-	1.6	-	-	-	-	-	500
25	Calleguas Creek	0.1	7/67				28.6	2.2	16.0	11.2	0.6	11.6	12.0	10.0	5.0	-	2.2	0.6	-	-	-	-	500
29A	Malibu Creek	0.1	7/69				17.4	1.6	3.6	20.4	1.6	14.6	31.0	3.0	3.8	0.6	0.4	1.8	-	-	-	0.2	500
36	Los Angeles River	0.1	7/67				9.2	0.6	22.8	5.4	1.4	10.8	32.6	11.6	4.2	-	1.4	-	-	-	-	-	500

*Trace

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*)

Coastal Engineering Research Center (CERC)
Corps of Engineers, Department of the Army
Washington, D. C. 20016

2a. REPORT SECURITY CLASSIFICATION

UNCLASSIFIED

2b. GROUP

3. REPORT TITLE

HEAVY MINERALS IN BEACH AND STREAM SEDIMENTS AS INDICATORS OF SHORE PROCESSES BETWEEN MONTEREY AND LOS ANGELES, CALIFORNIA

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

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

Charles W. Judge

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1970	52	46

8a. CONTRACT OR GRANT NO.

b. PROJECT NO.

c.

d.

9a. ORIGINATOR'S REPORT NUMBER(S)

Technical Memorandum No. 33

9b. OTHER REPORT NO(S) (*Any other numbers that may be assigned this report*)

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES

12. SPONSORING MILITARY ACTIVITY

13. ABSTRACT

A study of heavy minerals on the California Coast was made at CERC as an adjunct to the Radioisotopic Sand Tracer (RIST) and the Littoral Environmental Observation (LEO) programs. Beach samples taken during various times of the year were supplemented by samples from offshore and the rivers. Heavy minerals in the 63-125 micron fraction of the samples were identified by optical techniques. Five provinces were identified: 1) a northern Hornblende province from north of Monterey Bay to Piedras Blancas Point; 2) a northern Augite Province from Piedras Blancas Point to Avila Beach; 3) an Epidote province from Avila Beach to Ventura; 4) a southern Augite Province from Ventura to Palos Verdes Point; and 5) a southern Hornblende Province from Point Fermin south. The ratios of the less stable augite and hornblende to the more stable garnet and zircon indicated a southward littoral transport north of Point Conception. Increase in grain sizes and in augite and hornblende content south of the input from the Ventura and Santa Clara Rivers indicated a southward net littoral transport there. Similar trends could not be found between Point Conception and Ventura. Because of possible multiple sources for augite and reversals in littoral transport, heavy minerals are not definitive indicators of littoral drift from Point Conception to Ventura. However, considering other evidence from radioisotopic tracer surveys, historical surveys and dredging projects, it is reasonable to conclude that, although Point Conception-Point Arguello may act as a partial barrier, some sand moves south and east around them.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Heavy minerals						
Epidote						
Augite						
Hornblende						
Garnet						
Zircon						
Littoral transport						
Littoral barrier						
Sand analysis						
Point Conception, California						

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1. Heavy minerals
2. Littoral barrier
3. Littoral transport
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