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COASTAL SEDIMENTATION: POINT SAN PEDRO TO MIRAMONTES POINT, CALIFORNIA

by
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Berkeley, California
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Abstract

The distribution and dispersal patterns of sand-size particles has been investigated along a portion of the California coast south of San Francisco. The effectiveness of long-term, net littoral transport in the area has been evaluated through hydrodynamic considerations and through considerations of the dispersal patterns of sand. The distribution and dispersal patterns presented are based upon results of a vector analysis of the raw heavy mineral data. Four sedimentary provinces have been delineated. One blankets the continental shelf in the area studied and represents pre-modern sediment deposited during the last major regression and transgression of the sea. The remaining three represent Holocene deposits on the pre-modern sediment. The latter are only of local extent and are contiguous with their sources. These mineralogical changes along the coast preclude the existence of net littoral transport under present conditions. This conclusion agrees well with that predicted by hydrodynamic considerations. The contrasting picture presented by the widespread, relatively homogeneous pre-modern province and the localized, varied Holocene deposits is primarily due to changes in littoral transport attendant with the rise in sea level to its present position.

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INTRODUCTION

The processes of coastal sedimentation and especially littoral transport are of concern to both engineers and geologists. Correct interpretation of littoral transport is essential to the engineer through its effect upon coastal structures such as groins, jettys, and breakwaters and the adjacent areas. Lack of consideration for processes of littoral transport may negate the very purpose of a structure by causing deposition of the sediment load or necessitating costly maintenance to keep the facilities in operation. Such an alteration of the natural processes may destroy a state of dynamic equilibrium and cause damaging erosion downcoast from the structure in addition to upcoast deposition. For the geologist the processes and patterns of coastal sedimentation are of basic importance in the interpretation of ancient sedimentary deposits. It can be expected that processes active now were operable in ages past as well. An understanding of the mechanisms of sedimentation and consequently the origins of present distribution patterns is the key to explaining those deposits long since removed from the environment of their deposition.

The objective of this investigation is to interpret the areal distribution of sedimentary types or "provinces" with respect to the processes involved in their origin and especially littoral transport. Transport may be studied from both a theoretical consideration of hydrodynamic conditions and a consideration of sediment distribution as determined by field investigations. From the actual distribution of sediment types and the implications concerning transport a check on the validity of conclusions based upon purely theoretical considerations may be made.

Mode of Investigation

The patterns of littoral transport existing in a given area result from the interplay of two basic factors: 1) the characteristics of waves incident upon the shoreline of the area and, 2) the availability of sediment for transport. Wave refraction diagrams have been used to determine the overall wave pattern in the area studied and thus give the long-term tendencies of littoral transport. To provide a detailed picture of the distribution of sediment and an estimate of the long-term, net littoral transport a field study has been conducted.[1] Samples from terraces, beaches, and the continental shelf to depths of 220 feet have been collected and analyzed with respect to the heavy mineral content and grain-size distribution. The distribution pattern of the sediments is based upon the former as analyzed by means of a vector analysis program.

The investigation has been limited entirely to sediment of sand size.[2]

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[1] "Long-term" as used here is based upon geological consideration of events occurring during the present stand of sea level. It thus refers to a period of about 3000 years. It will be used throughout the text with this connotation.

[2] The limits of the sand-size particle range according to the Wentworth Scale are 61 - 2000μ.

ACKNOWLEDGEMENTS

I am indebted to and would like to express my gratitude to a number of people who have rendered invaluable assistance to me in the execution of this study and in the preparation of this report. Dr. Tj. H. van Andel of Scripps Institution of Oceanography has been of great assistance in providing facilities and supervision for the grain-size and vector analyses and in critically reviewing the manuscript. Professors J. W. Johnson and C. M. Gilbert have been of assistance throughout the study through their suggestions and reviewing of the report. Mr. John Cherry initially aroused my interest in this type of study and was of assistance in the initial planning. Discussions with Messrs. A. M. Sarna-Wojcicki and N. T. Hall have provided many new ideas. Mr. J. Nicholls read the manuscript. The preparation of the samples was done by Messrs. A. Smith and R. Shlemon. Messrs. D. Moore and A. Smith assisted in the field. The cartography was done by Mr. W. Kot and Mrs. E. Winkler. Miss M. Kiely assisted in the compilation of the tables and preparation of the appendices. The manuscript was typed by Mrs. M. French.

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GEOLOGIC AND PHYSIOGRAPHIC SETTING

Geology

The area studied lies approximately twenty miles south of San Francisco on the San Francisco peninsula (see Figure 1). This area was chosen for the study because of the variety of geologic formations which are exposed along the coast and consequently are subject to vigorous wave attack. Thus, a wide variety of mineral suites might be supplied to the littoral sediment system. It was also deemed possible that, as different formations commonly have different grain-size characteristics, the movement of sediment might be traced by grain-size modes as well as mineral assemblages if sorting has not destroyed the differences.

The sedimentary formations outcropping on the coast are the Chico (?) and Martinez formations which consist of well indurated shales and sandstones, the Purisima formation which is characterized by friable shales and mudstones, and the poorly consolidated Quaternary terraces. Plutonic rocks are exposed on the flanks of Montara Mountain. The distribution of the various rock types is shown in Figure 2.

The Chico and Martinez formations are characterized by well indurated interbedded shales and sandstones where they are exposed along the coast. Both formations are jointed and break down into resultant large blocks that litter the shoreline and provide excellent protection from wave attack (see Figure 3). These formations are very resistant to erosion as evidenced by

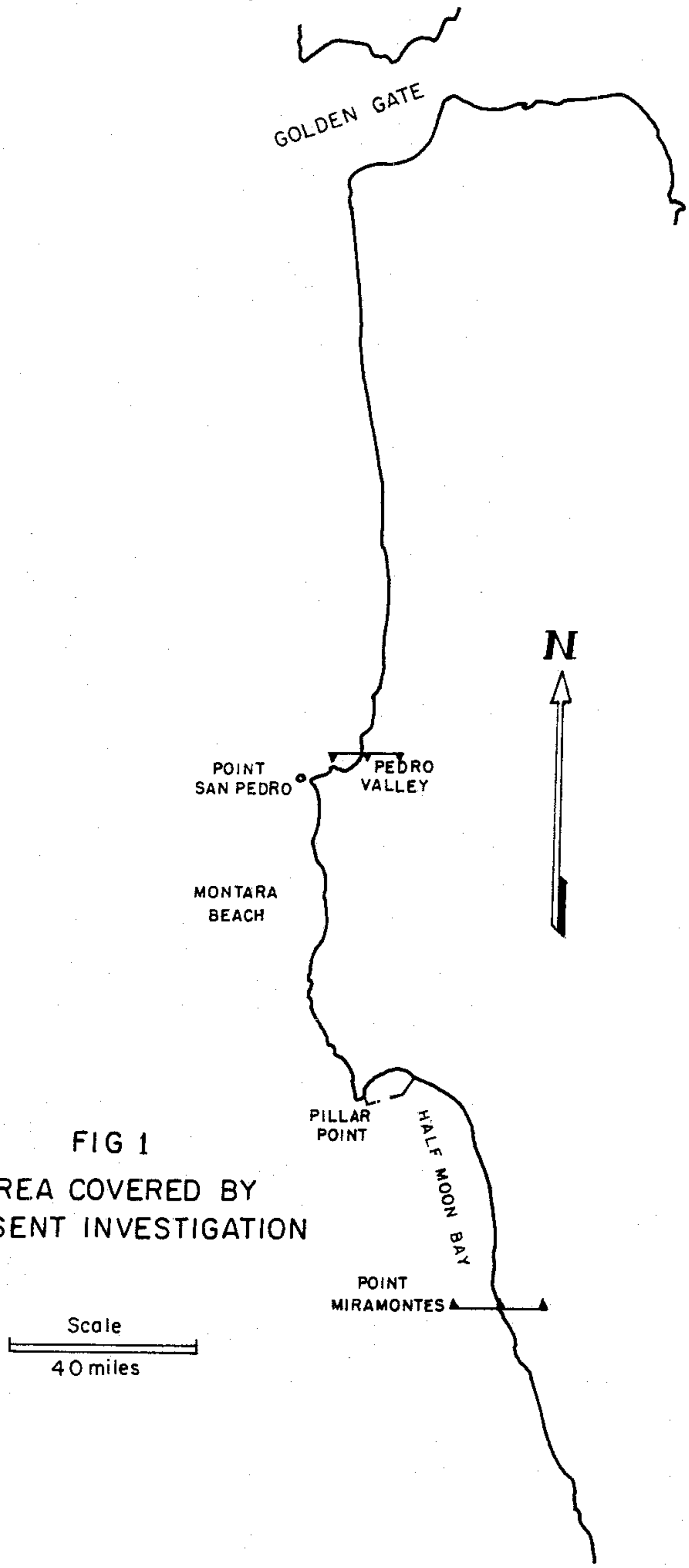


FIG 1

AREA COVERED BY PRESENT INVESTIGATION

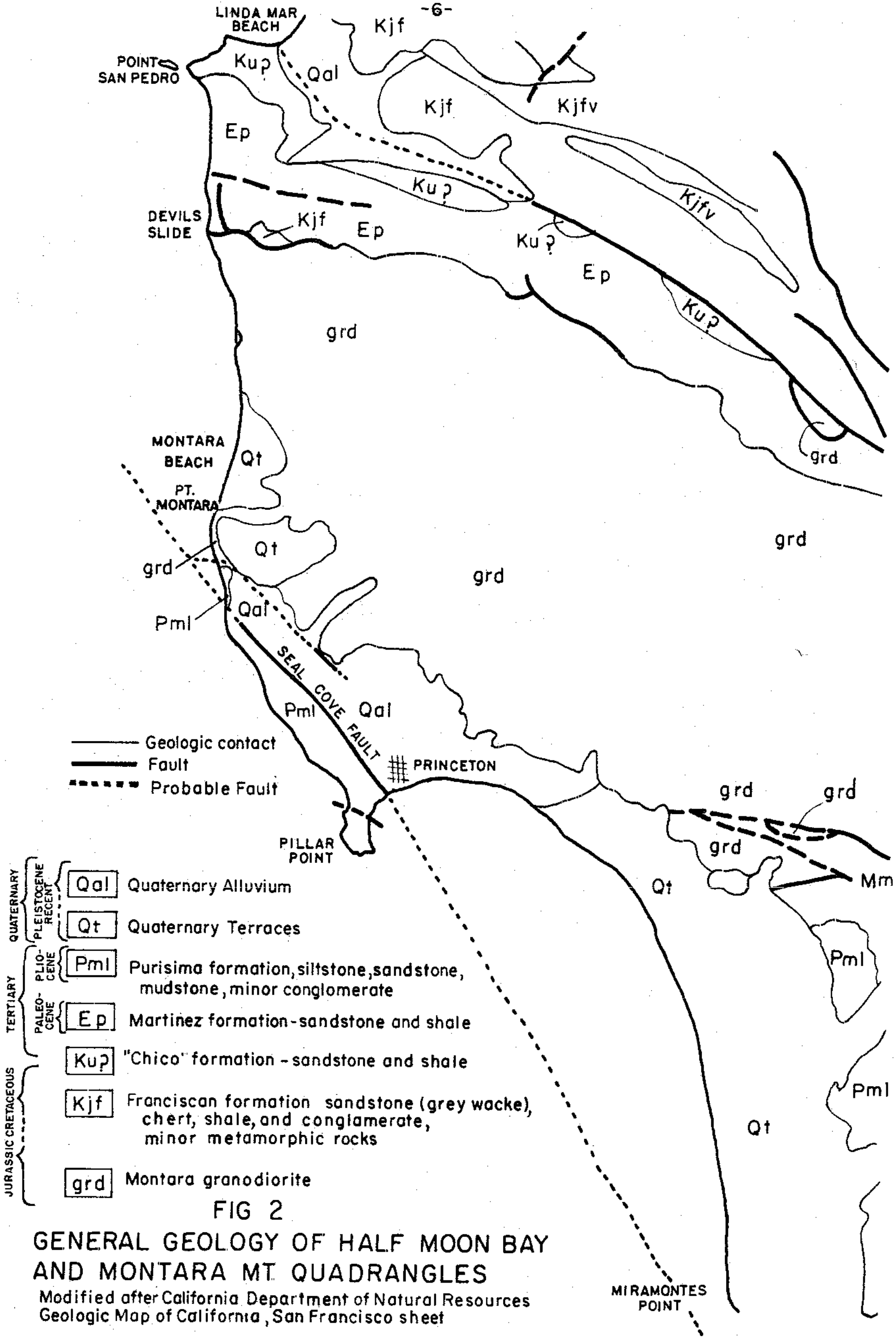


FIG 2

GENERAL GEOLOGY OF HALF MOON BAY AND MONTARA MT QUADRANGLES

Modified after California Department of Natural Resources Geologic Map of California, San Francisco sheet

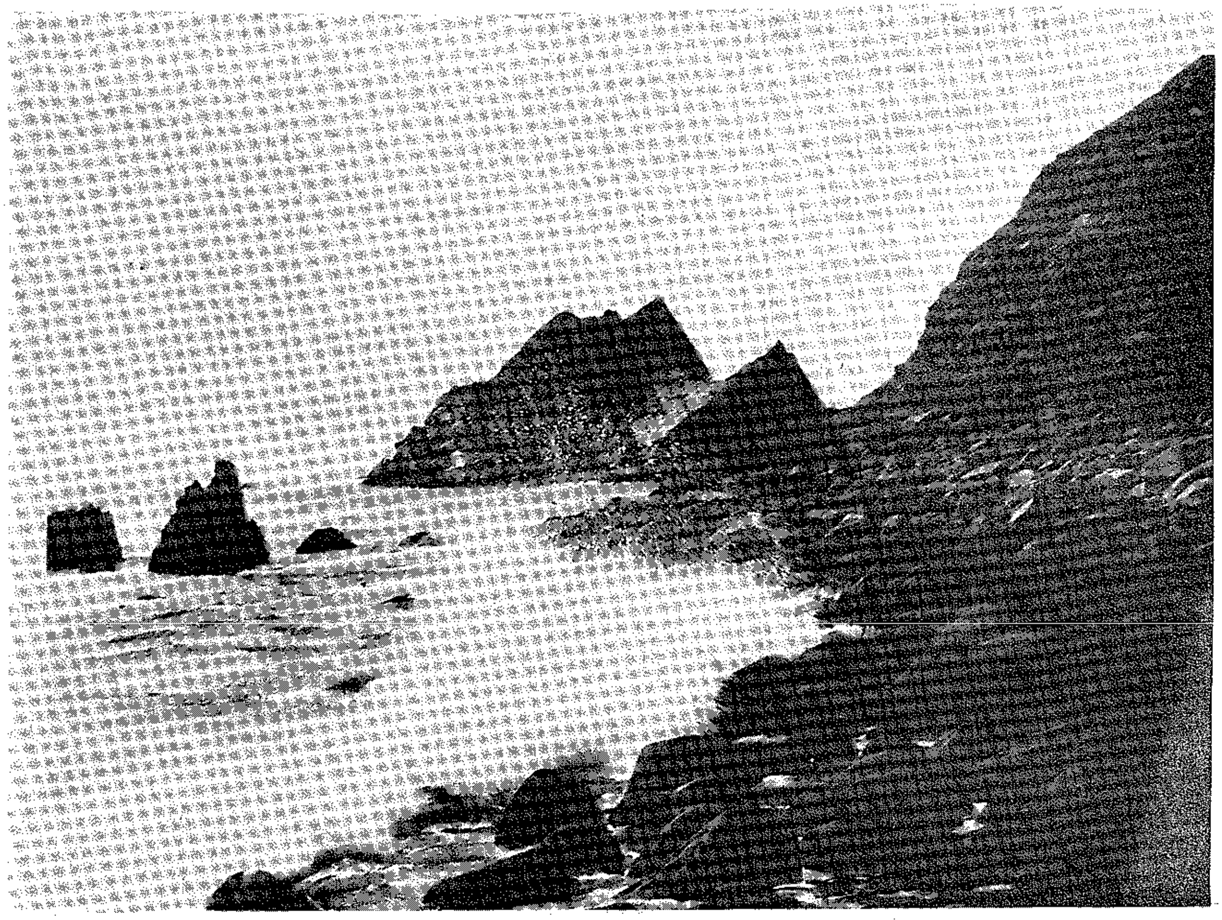


FIG. 3 BOULDER BEACH IN THE PT. SAN PEDRO AREA

(Photo looks due West at Pedro Rock)

the slopes of the headland on which they occur (see Figure 6).

Due to extensive tectonic activity the Montara granodiorite is highly shattered on both a macroscopic and a megascopic scale. As a result of this it is deeply weathered. Drill cores have penetrated up to eighty-eight feet of weathered material (U. S. Army Corps of Engineers, 1957). The granodiorite is only moderately resistant to erosion.

The Quaternary terraces have been derived chiefly from the Montara granodiorite. They are composed of coarse gravels and sands. The deposits backing Montara Beach and Half Moon Bay are very poorly consolidated. They are not resistant to erosion and as a result have been eroded back to positions and configurations of equilibrium relative to the predominant swell conditions. These terraces have been a source for considerable quantities of sand during the present stand of sea level.

The Purisima formation outcrops in the area studied primarily as a result of movement along the Seal Cove Fault. It is composed basically of moderately well indurated siltstones, mudstones, shales, and fine-grained sandstones. A small section north of the fault contains well indurated sandstones interbedded with poorly consolidated pebbley conglomerates consisting of granodiorite boulders in a granodiorite-derived matrix (Glenn, 1959). When dry, as it is exposed in the cliffs along Pillar Point, it is very friable. When damp, as along the shoreline, it is moderately resistant to erosion. The predominantly fine-grained character precludes significant contribution of sand.

Physiography

The physiography of the area between Point San Pedro and Miramontes Point may be considered in two parts: the coastal physiography and the offshore physiography. Both profoundly influence littoral transport and hence coastal sedimentation, the former through the presence of promontories which act as littoral barriers and control over erosion rates (locally supplied detritus), and the latter through its dominant influence on the refraction of incident waves.

The character of the coastal physiography is evident from inspection of Figures 4, 5 and 6. The shore itself largely reflects the topography of the area backing it. The mountainous areas completely lack beaches or are characterized by talus piles rather than sand (Figure 3). The terrace areas are fronted by sandy beaches. The Point Montara - Pillar Point area, while in the lowland, is characterized by a rocky or cliffed shoreline with only a thin veneer of sand in some areas. Wave erosion may be significant in all of the areas not protected by beaches or rubble piles. Mass-wasting processes are only significant in the mountainous areas with steep slopes.

The physiography of the area offshore is extremely uniform except for a small area extending from north of Seal Cove to south of Pillar Point. Extending over the entire area beyond the 100 foot depth contour is a continuous, flat, featureless plain of sand. This area extends shoreward to depths of twenty feet and less north of Point Montara (see Figure 7). South of Point Montara the physiography of the sea floor changes abruptly

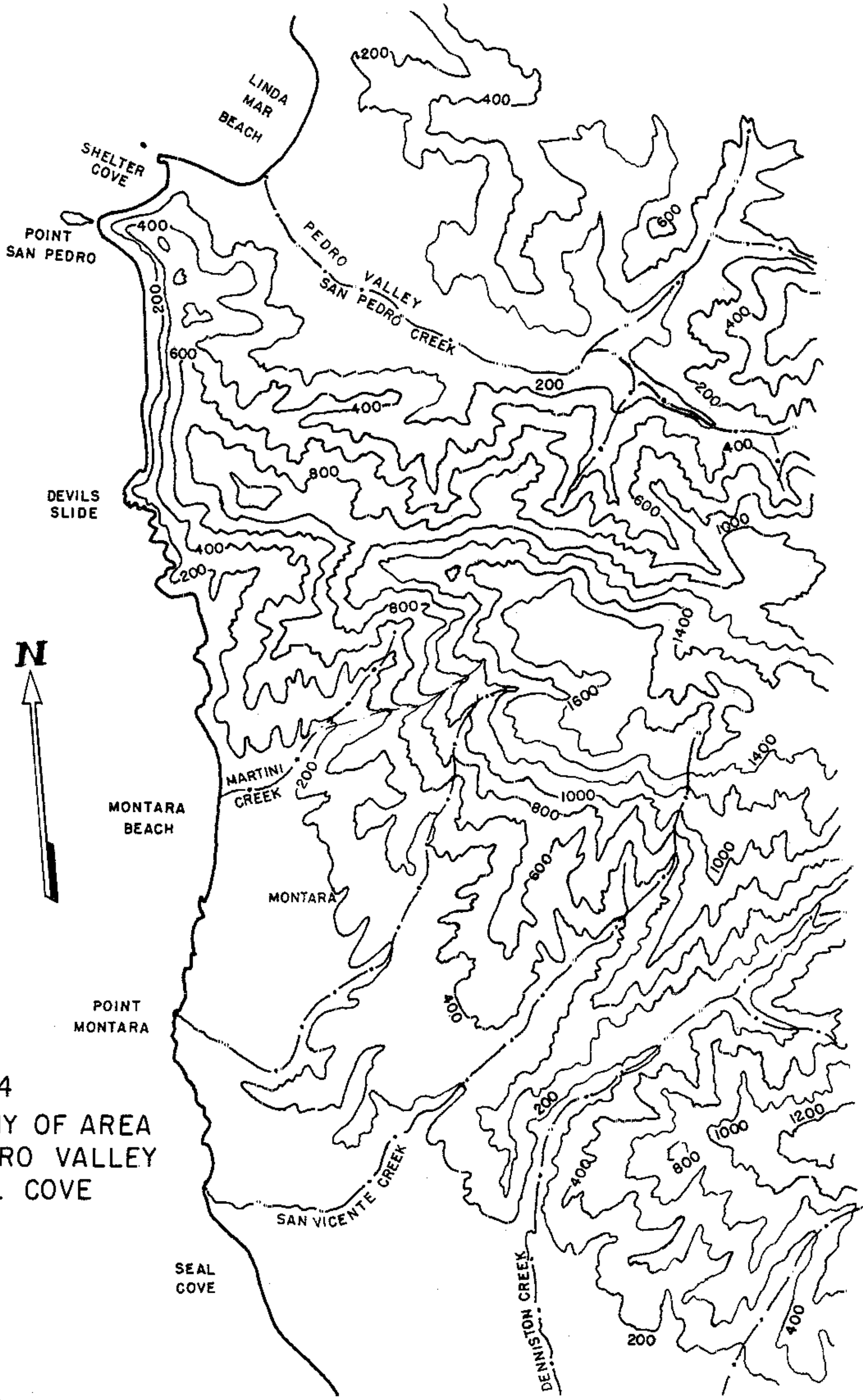


FIG. 4
PHYSIOGRAPHY OF AREA BETWEEN PEDRO VALLEY AND SEAL COVE

Scale
1.0 miles
Contour interval is 200 feet

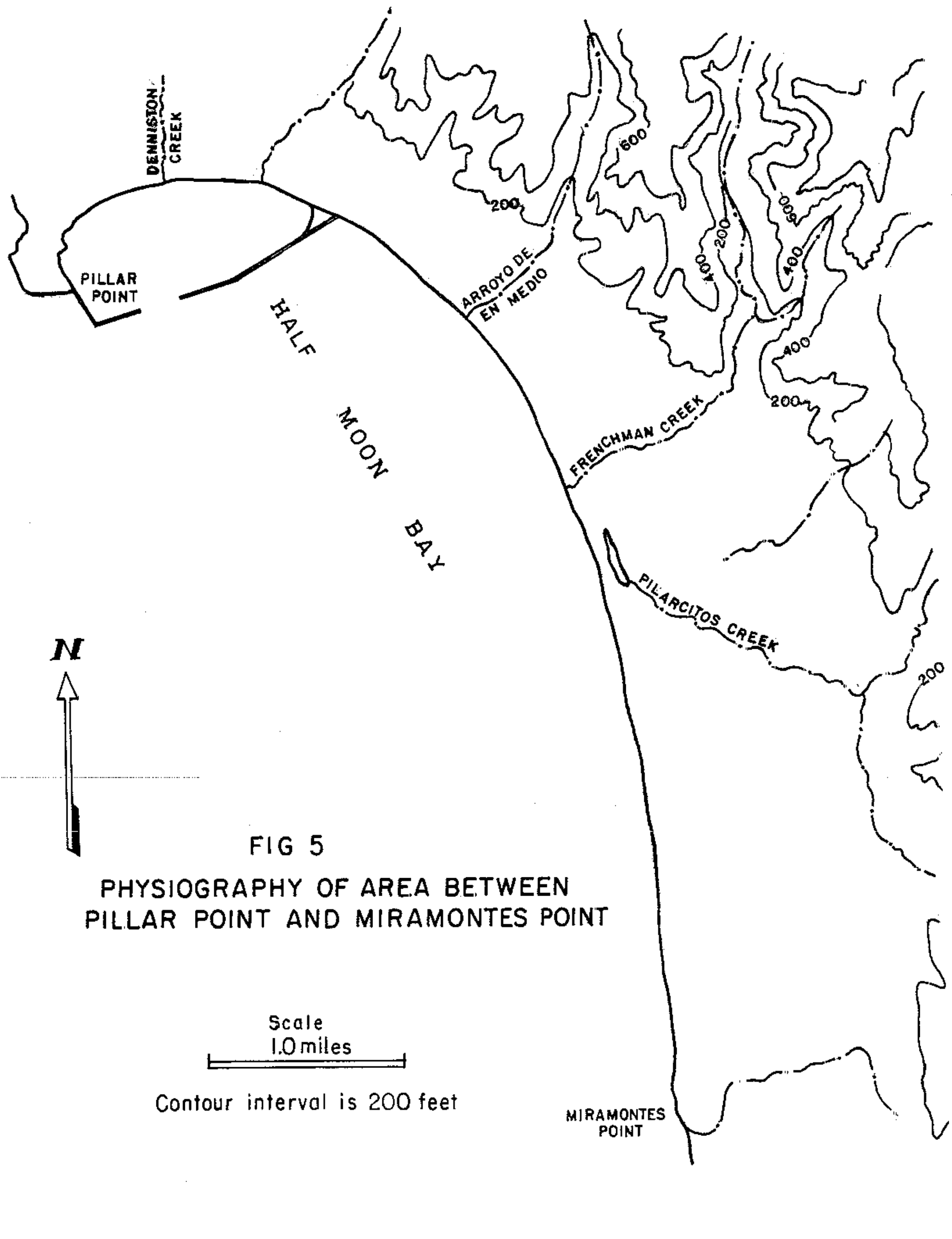


FIG 5

PHYSIOGRAPHY OF AREA BETWEEN PILLAR POINT AND MIRAMONTES POINT

Contour interval is 200 feet

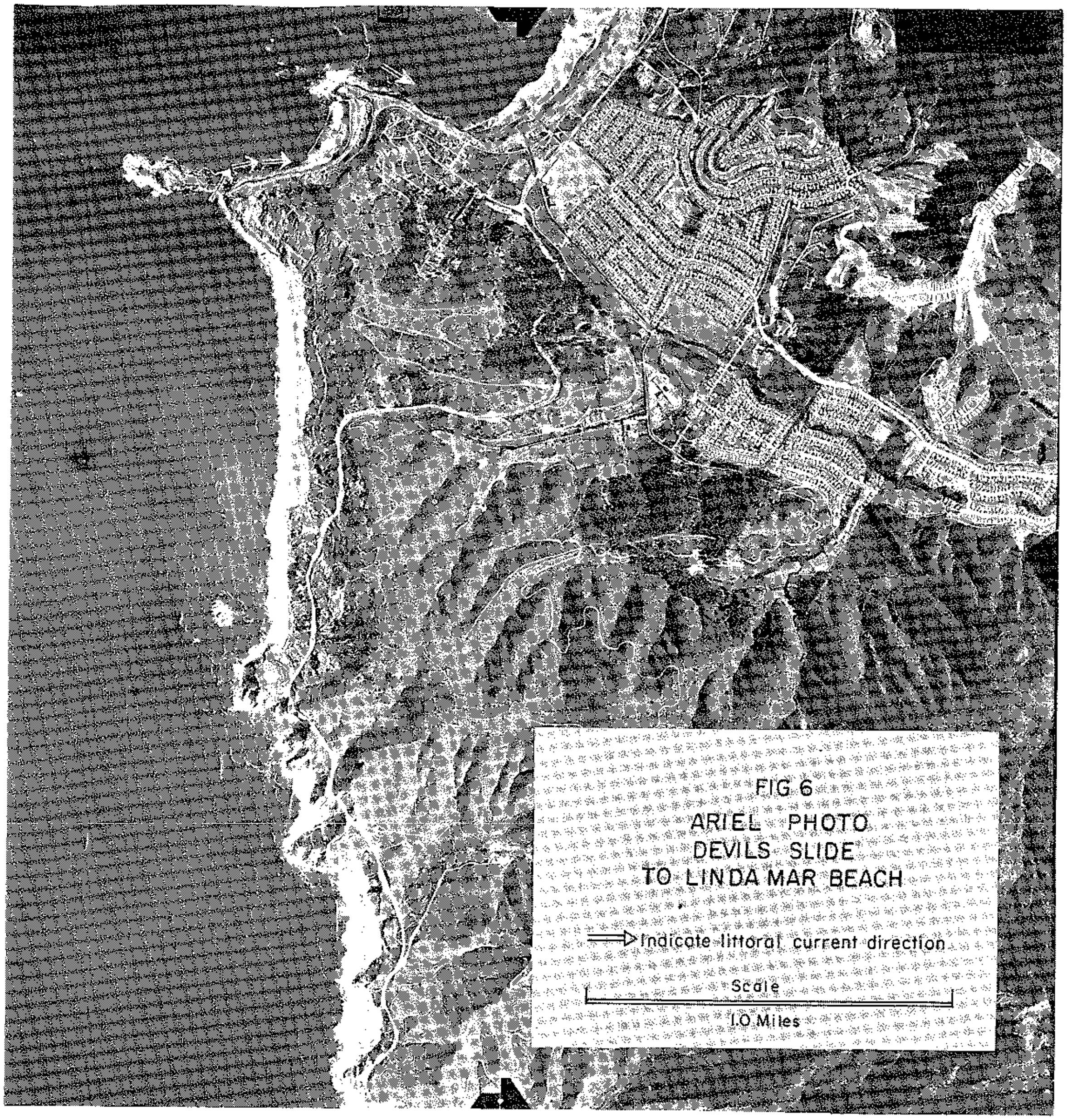


FIG 6
ARIEL PHOTO
DEVILS SLIDE
TO LINDA MAR BEACH
Indicate littoral current direction
Scale
1.0 Miles

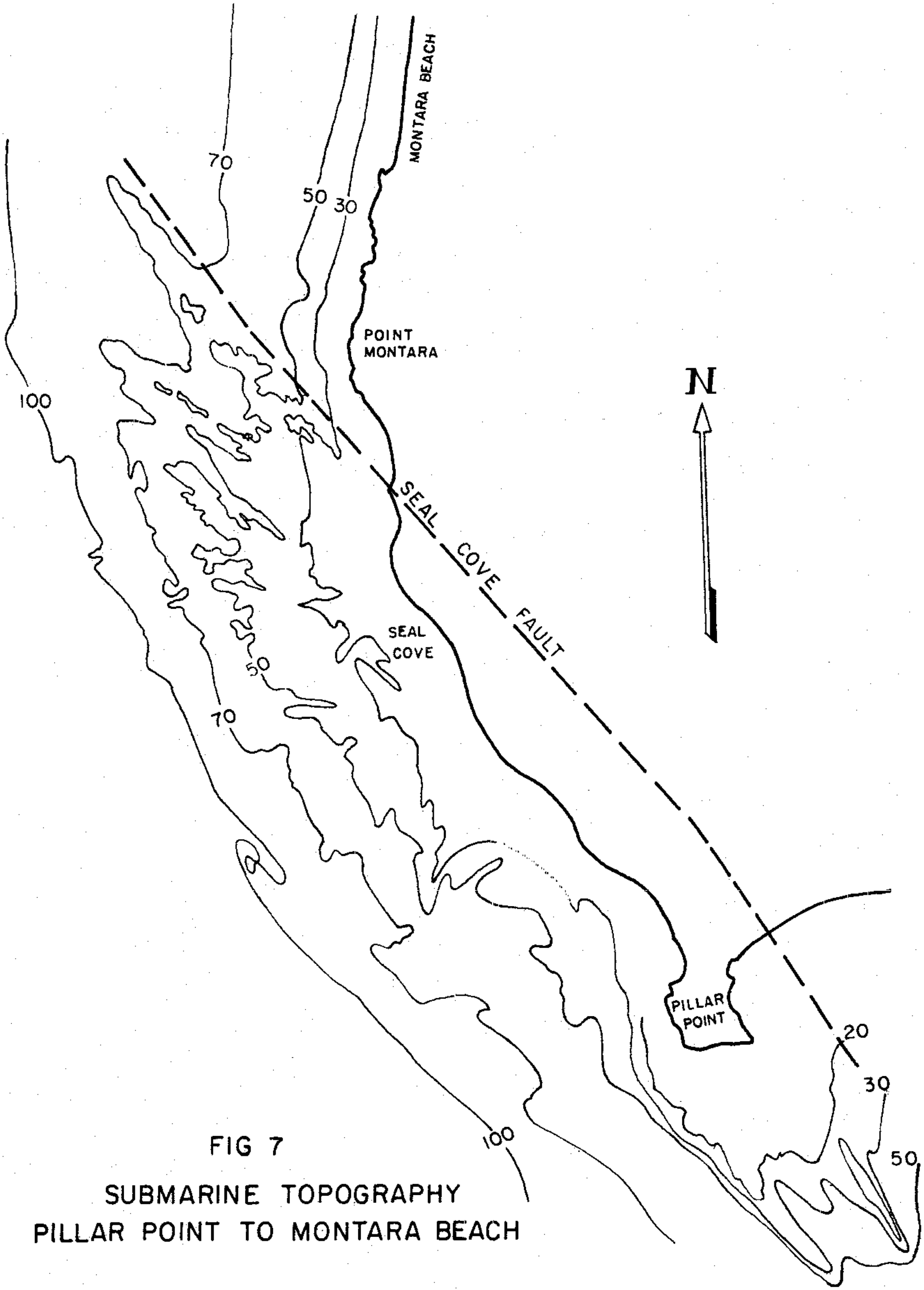


FIG 7

SUBMARINE TOPOGRAPHY
PILLAR POINT TO MONTARA BEACH

Scale
1.0 miles
Depth in feet

shoreward of the 100 foot depth contour. The bottom in this area is characterized by northwest trending reefs and an absence of extensive sand-covered areas (Figure 7). The reef system extends south of Pillar Point toward Miramontes Point (Figure 8). Throughout its length the reef is almost unbroken and parts of it are awash at low tide (Figure 9). This area is apparently a consequence of uplift on the western side of the Seal Cove Fault. The configuration of Half Moon Bay is largely a result of this reef through the refraction of waves.

GENERAL ANALYSIS OF SEDIMENT TRANSPORT

The two basic factors involved in sediment transport are: 1) the supply or availability of sediment and 2) the hydraulic conditions produced by the incidence of waves upon the coast of the area involved. The latter may be examined and their role in producing sediment transport investigated through the use of wave refraction diagrams.

Through refraction the energy of the incident waves is concentrated on coastal and submarine promontories and irregularities. As a result, shorelines tend toward equilibrium orientations as determined by the pattern of the refracted waves. In areas where equilibrium orientations have not been achieved, relatively strong longshore currents are produced by the angular incidence of waves upon the shore. These currents are the principal agent of littoral sediment transport (Jennings, 1955; Johnson, 1956; Einstein and Krone, 1961). Coastal currents (unrelated genetically to waves) are

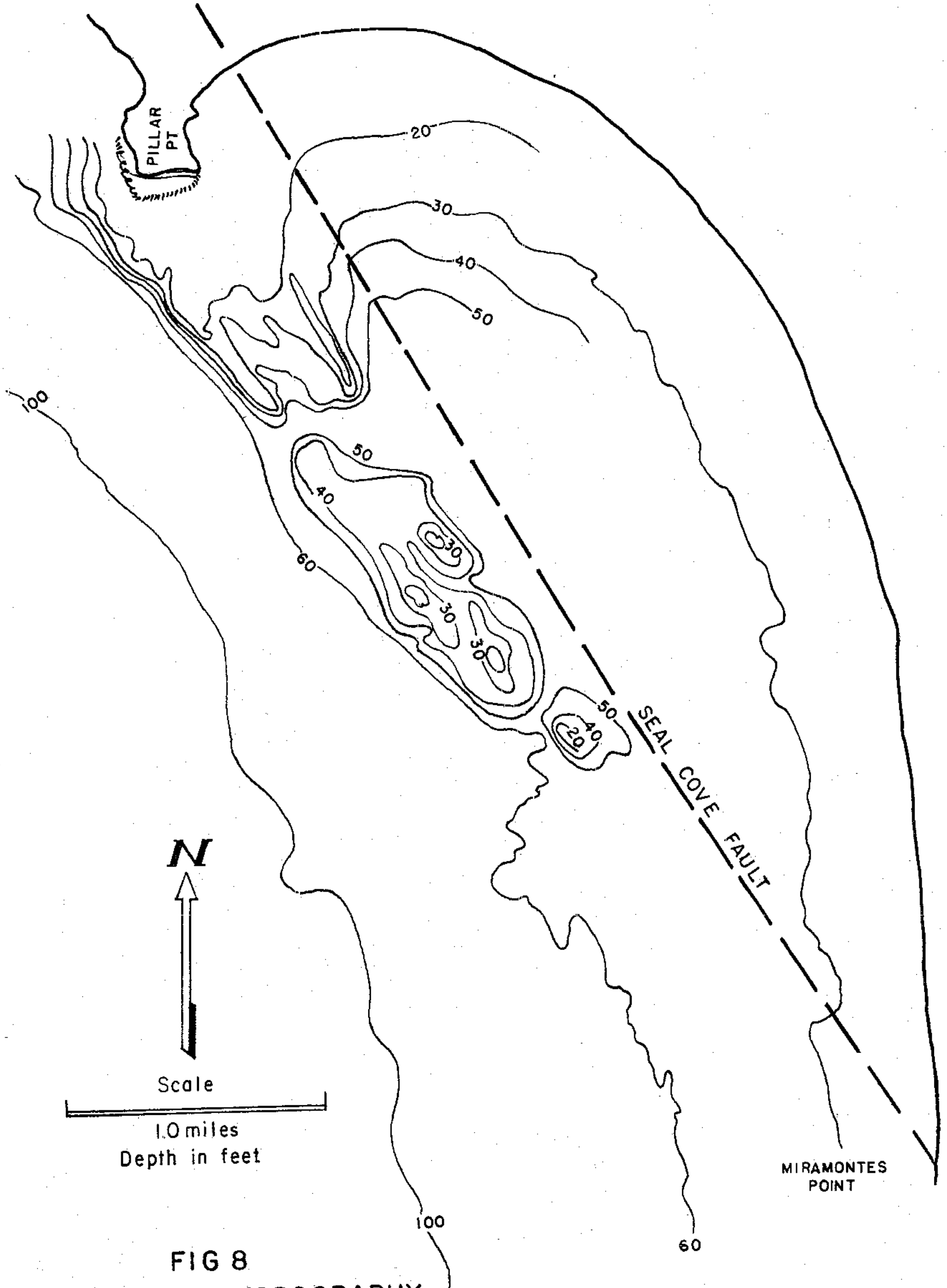


FIG 8
SUBMARINE TOPOGRAPHY
PILLAR POINT TO
MIRAMONTES POINT

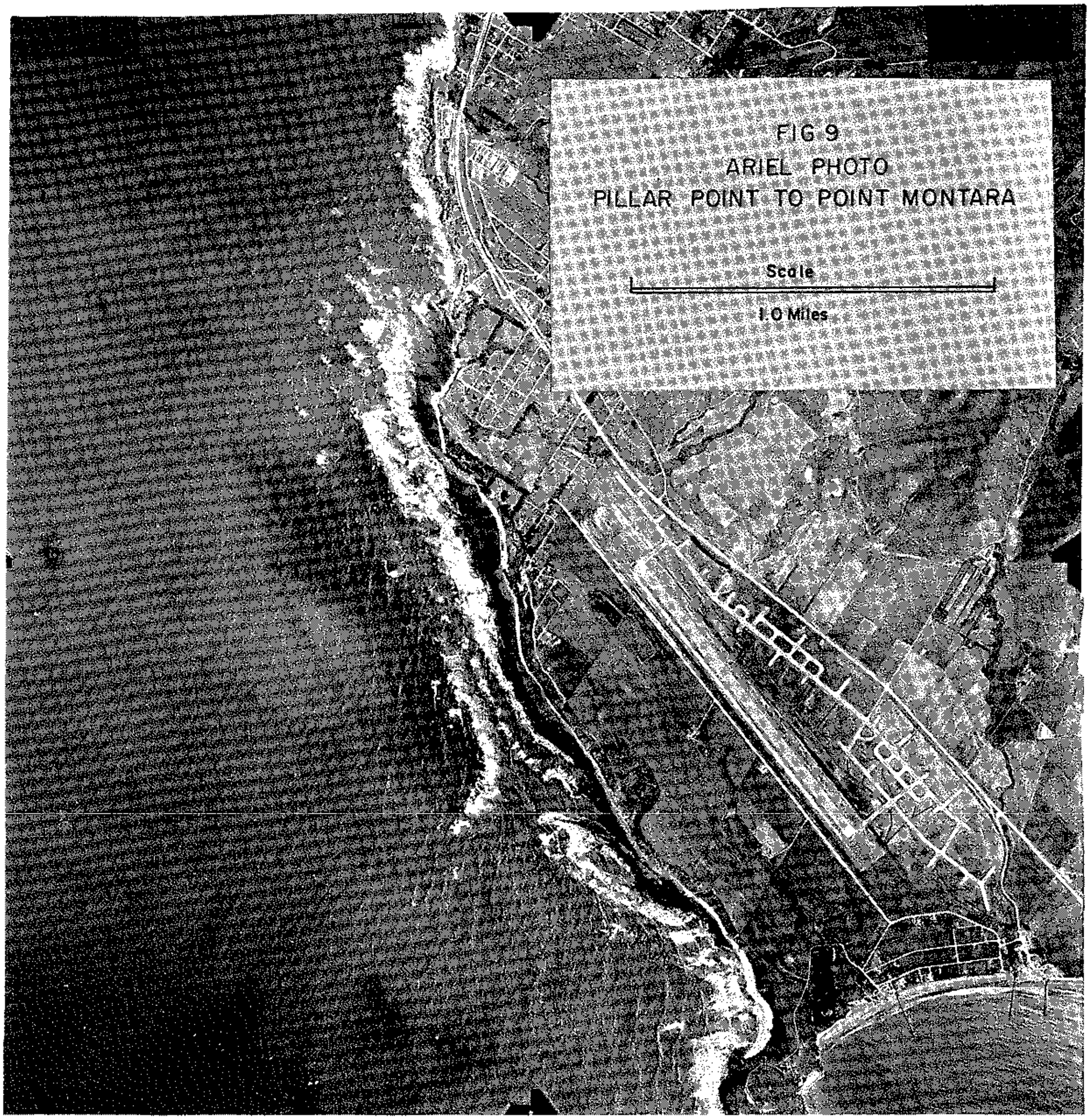
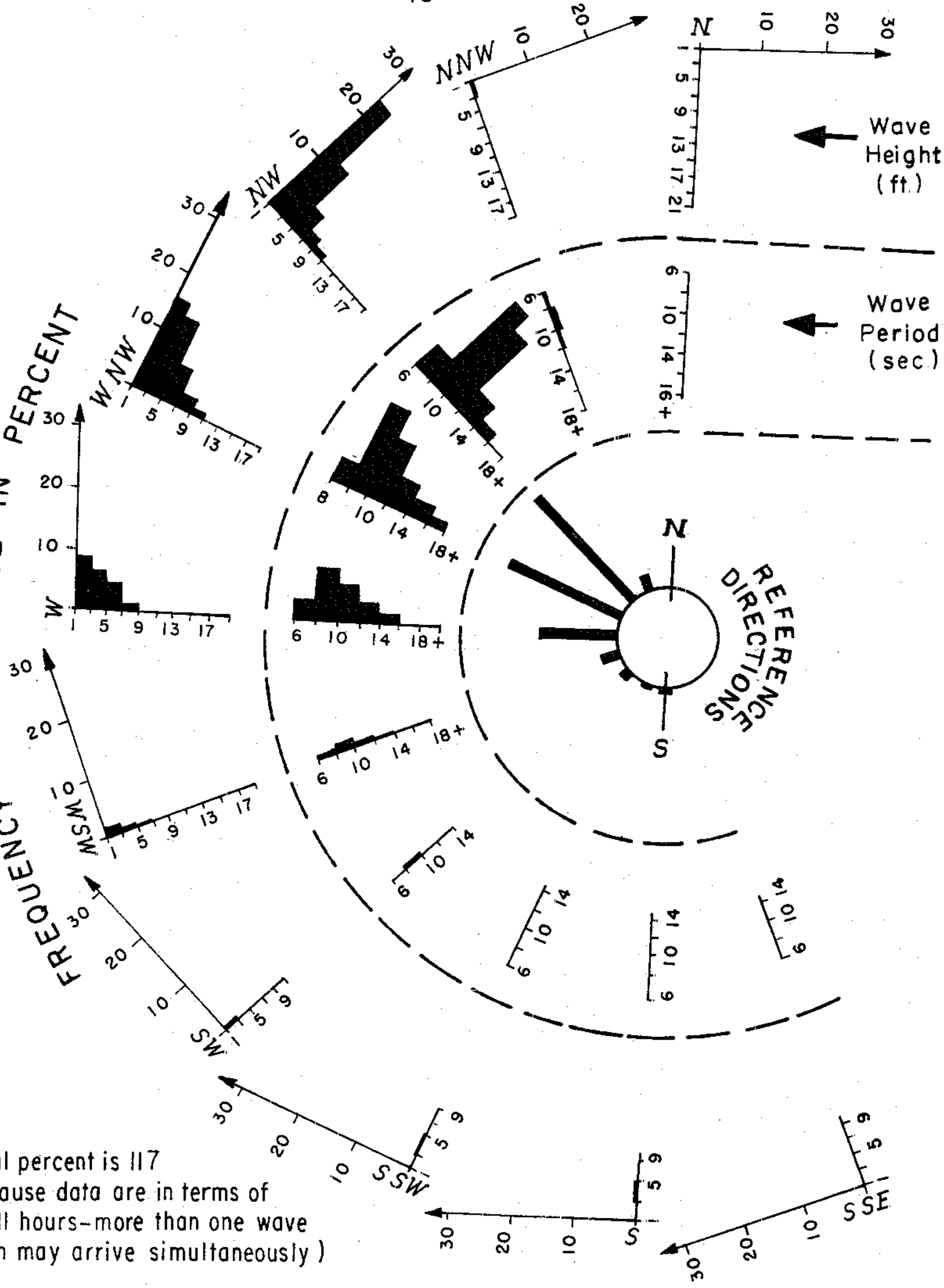


FIG 9
ARIEL PHOTO
PILLAR POINT TO POINT MONTARA
Scale
1.0 Miles

generally not an effective agent in the transport of sand along coasts (Jennings, 1955; Shepard and Innman, 1960). The incidence of waves on a shoreline can be shown for generalized conditions by wave refraction diagrams, and in this manner an indication of the net littoral transport of sediment may be obtained. Swell conditions, as opposed to sea, are the dominant factor in establishing an equilibrium orientation on a coastline (Davis, 1958; Sylvester, 1959, 1963). Thus, net, long-term sediment transport and deposition in the littoral and nearshore zones are predominantly controlled by the prevailing swell conditions. The refraction diagrams used in the following general analysis of hydraulic transport conditions are derived from consideration of the predominant swell conditions.

Area under Consideration

The wind and wave conditions upon which the general analysis of sediment transport between Point San Pedro and Miramontes Point is based have been obtained by hindcast techniques and prepared by the National Marine Consultants (1960) for a station fifty-five miles west of the Golden Gate. Figure 10 presents the data in graphical form showing percentage occurrence of swell with respect to both direction and period. These data are for the years 1956, 1957, and 1958. According to the National Marine Consultants (1960) the data represent long-term conditions in the area. The median direction of swell is approximately WNW, and the median period is nine seconds. These values have been used in the construction of wave refraction



(Total percent is 117 because data are in terms of swell hours—more than one wave train may arrive simultaneously)

FIG 10

AVERAGE SWELL CONDITIONS

(AFTER CHERRY, 1964)

diagrams for the area studied. The diagrams themselves were originally constructed on U.S. Coast and Geodetic Survey hydrographic charts with a scale of 1:10,000.

Figures 11 and 12 are the refraction diagrams for the areas north of Pillar Point and Half Moon Bay respectively. From the parallel incidence of waves at Montara Beach it can be seen that this area has attained an equilibrium orientation The same is true of the entire shoreline of Half Moon Bay. The latter represents the half heart-shaped equilibrium configuration discussed by Sylvester (1959) in conjunction with model studies of the effects of waves of angular incidence upon a shoreline of varied lithology. The mudstones, shales and sandstones of Pillar Point and the poorly consolidated terrace deposits backing the bay provide a very close natural parallel to the conditions of his experiments, and the configuration of the bay corresponds to that achieved by Sylvester. The extensive reef system extending southeast from Pillar Point is a feature not included in Sylvester's experiments, and this has altered the final orientation and configuration somewhat due to the greater refraction of the incident waves.

The remainder of the area, with a few exceptions, is characterized by non-equilibrium coastal orientation. These are areas where a consideration of hydrodynamic conditions indicates that net littoral transport is primarily to the south if transport does occur. This is especially true in the shallow offshore zone (20-40 feet) where refraction has not yet turned the waves parallel to the shore thus providing a longshore component. The turbulence

FIG 11
REFRACTION DIAGRAM FOR THE AREAS BETWEEN
PILLAR POINT AND MONTARA BEACH
SWELL W N W., WAVE PERIOD
9 SECONDS

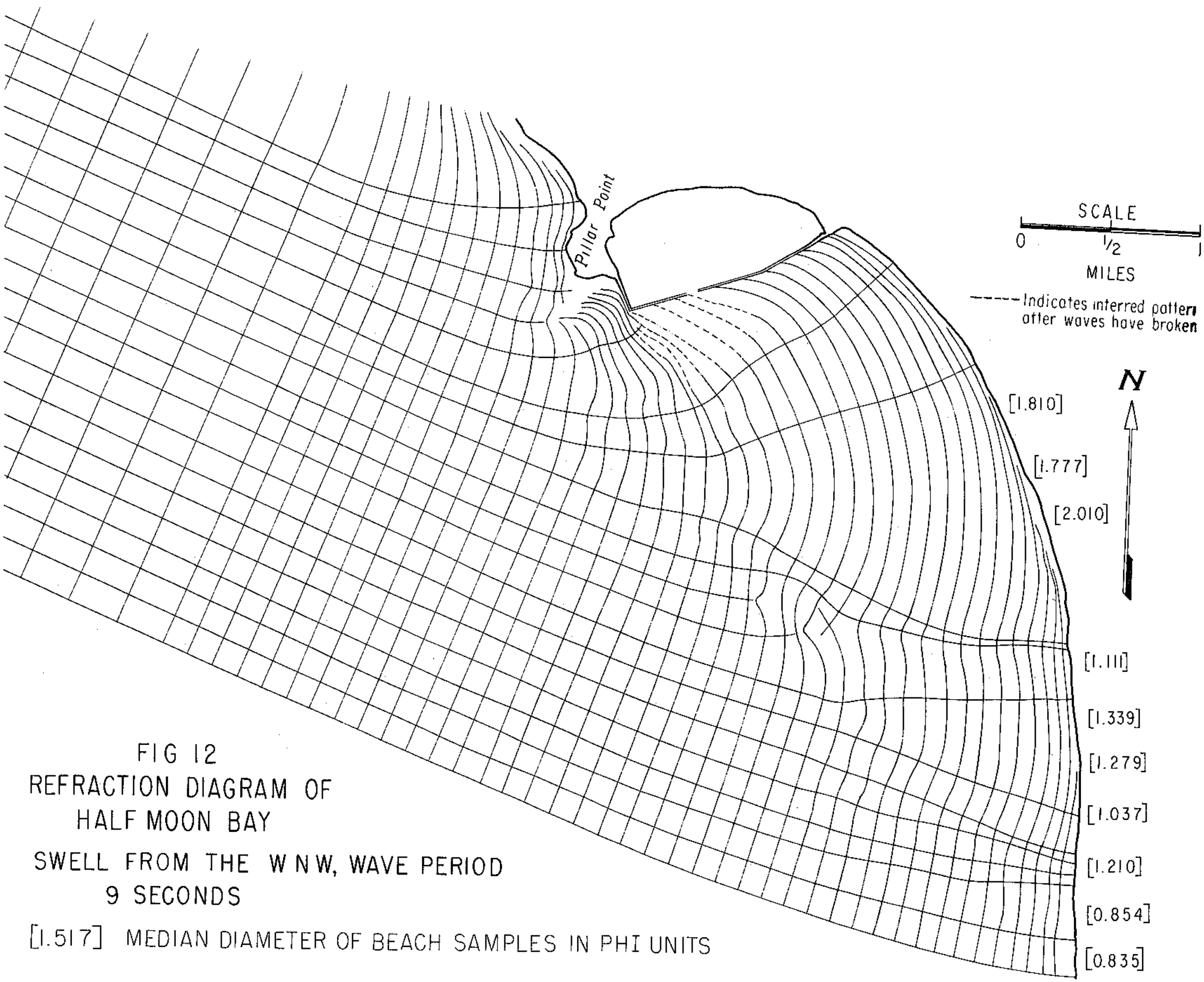


FIG 12
REFRACTION DIAGRAM OF
HALF MOON BAY

SWELL FROM THE W N W, WAVE PERIOD
9 SECONDS

[1.517] MEDIAN DIAMETER OF BEACH SAMPLES IN PHI UNITS is probably sufficient for suspension also. The angular incidence can be seen particularly well in the area south of Montara Beach (see Figure 11); note also the offshore breakers and consequent turbulence (Figure 9). In the area south of Point San Pedro the waves have a slight angular incidence, but are parallel to the cobble beaches in some areas (Figure 6).

From the above conditions an overall littoral transport pattern based solely upon hydrodynamic considerations can be obtained. Point San Pedro represents the only almost certain barrier to sand transport to the south. The refraction of waves in this area produces currents which flow either north or east (see current indications on Figure 6). Evidence of the northward flowing currents can be seen in the shallow channel between San Pedro Rock and the mainland where the currents move northward during almost all wave and tidal conditions. Southward transport in the surf zone is thus precluded. Sediment may be transported around headlands in the shallow offshore zone (Johnson, 1956) and thus some transport to the south is possible through this mechanism. The areas of Montara Beach and Half Moon Bay have already been discussed as areas in equilibrium with present hydrodynamic conditions. These areas thus must represent areas in which little or no transport occurs. The area north of Montara Beach and particularly the area between Point Montara and Pillar Point are areas where wave conditions suggest that transport to the south is probable.

The above implies that little or no net littoral transport occurs in the area under consideration. Along straight beaches up to eighty per cent of the transport of sand occurs inside the breaker zone (Mason, 1953). Montara Beach can be considered a straight beach and this is applicable to it. The beach is oriented parallel to the incident waves and represents a case of stable equilibrium, not one of dynamic equilibrium. No net movement of sand through this area is to be expected. The same case holds for the interior of Half Moon Bay. There is no build-up of sand at the northern end of Montara Beach and for this reason it can be assumed that very little is being supplied to this area - no more than can be transported in the offshore zone. If little or no sand moves past Montara Beach, little or none is supplied to the transport area south of it. Consequently, there is little transport in the latter area either, despite the probability that longshore currents are strong in this area. The preceding is based on the assumption that local contributions of sediment to the littoral system are negligible in the area south of Montara Beach.

The preceding analysis of the net, long-term sediment transport is only generalized and leaves several questions unanswered. Depth data are not adequate inside of the twenty-five foot depth contour. The importance of transport in depths greater than that of the surf zone can in no way be evaluated. The analysis deals only with hydrodynamic conditions, and no consideration of the availability of sediment for transport is made. These questions and omissions can be answered and filled by a detailed analysis of the littoral transport pattern obtained through a field study. Furthermore, the importance of the omissions in the general analysis may be evaluated and, more important, the validity of the conclusions drawn on the basis of generalized hydrodynamic considerations checked.

FIELD STUDY

In order to determine the pattern or patterns of sedimentation and especially the net, long-term littoral transport in the area studied, a field study of the distribution of sand was conducted. Both offshore and beach samples were collected as representative of the areal distribution of sand today, and samples of local bedrock and terraces were taken to determine the possible local sources of sand. The offshore samples were collected by means of a drag sampler. The samples represent the top 2-4cm of sediment taken in a linear strip of 100 to 200 feet in length (the distance over which the sampler was dragged). Traverses outward from the coast to depths of 220 feet were made in order to produce a grid pattern. The beach samples were taken by means of a 3-inch steel tube driven into the sand at the "mid-tide"[1] level. Each terrace sample was limited to an individual bed or stratigraphic unit. All of the samples were collected during the period of June to August, 1964. The beach samples represent the accumulation of sand which occurs during the summer months, and they

[1] The "mid-tide" level of the beach is defined by Bascom (1951) as that portion of the beach which is subjected to wave action at the mid-tide elevation.

are thus representative of sand in the long-term littoral transport system.[1]

Samples were washed to remove the clay fraction (less than 5% by weight), split to manageable proportions and sieved to cut-off size limits for both grain-size and mineralogical analyses.

The grain-size analysis was made by the Scripps Institution of Oceanography recording settling tube (van Andel, 1964). The settling tube was used because it provides an analysis based upon settling velocity. This represents a consideration of size, shape and specific gravity. Analysis with sieves is limited to consideration of diameter and to a lesser degree shape with none for specific gravity. Obviously the settling tube more closely approaches the natural conditions in which sediments tend to segregate themselves than does the artificial classification based on sieve analyses. The continuous recordings were read at one-quarter phi[2] intervals for the size range of 2000-61μ (sand-size particles on the Wentworth Scale). Size statistics and frequency curves were calculated on a CDC-3200 computer at the University of California at San Diego.

The mineralogical analysis consisted of a heavy mineral study. Only the 61-246μ size fraction was used. Heavy mineral separations were made

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1 Krumbein (1944) and Trask (1959) have concluded from studies of beaches in the San Francisco area that the summer months represent periods of accumulation of sand on the beaches. Samples collected during the summer months consequently represent sand recently removed from the coastal sediment transport system.

2 The phi (ϕ) unit is defined as the negative logarithm to the base 2 of the grain diameter in millimeters.

with impure Bromoform (specific gravity 2.86). Magnetic minerals were removed with a hand magnet, and the remaining heavy minerals were mounted in Canada balsam on a petrographic slide. Line counts of the slide were made using a polarizing microscope equipped with a mechanical stage. Grain counts were made on the basis of one hundred translucent grains excluding biotite, chlorite, aggregate grains, and grains lacking optical continuity. The number of opaque grains was tabulated but does not enter into the calculation of mineral percent (Doeglas, 1940; van Andel, 1950).

Heavy Mineral Distribution

Results of the heavy mineral analysis are presented in Appendix I. Analysis of the areal distribution of heavy mineral suites has been conducted by means of a vector analysis technique. The analysis and applications of it are those discussed by Imbrie and van Andel (1964).

The heavy mineral analysis has identified a number of variables (mineral species) in terms of which each sample may be described. The variables which describe each given sample may be considered to define an algebraic vector and thus each sample may be represented by this vector. With the use of factor analysis one can resolve the raw data vectors into a few theoretical reference vectors; vector analysis can then be used to resolve the latter into selected data vectors that actually represent compositionally extreme samples. These are end-members or reference vectors. All other vectors (samples not representing extreme compositions) are resolved into proportional contributions of the end-members (actual samples). In this manner the relationships between samples are investigated on the basis of all variables. This type of vector analysis corresponds to the Q-mode procedure in that it focuses attention on samples as opposed to variables (R-mode).[1]

Should provenance and the dispersal pattern be the primary control of heavy mineral composition and the end-members thus primarily represent source assemblages, mixtures of sediment from various sources may be broken down into their component parts and dispersal patterns identified.

The applicability and advantages of this type of analysis in the present investigation are readily evident. Coastal sediments are a product of locally supplied detritus plus that introduced to the area by littoral transport. The relative amounts of local and incoming sediment depend upon the rates of supply from the two sources. In investigating the relative importance of different sources one is necessarily concerned with the distribution pattern of the nearshore sediments (in this study the distribution of heavy minerals). Conventional methods of analysis of heavy mineral distribution data depend upon heavy mineral associations which are generally averages or typical suites which can be used to distinguish heavy mineral provinces. Vector analysis is based upon end-members which represent the extremes of composition in the samples examined. The resulting analysis

[1] For a complete discussion of this method see Imbrie, J. and Tj. H. van Andel; Geol. Soc. Am. Bull., Vol. 75, p. 1131-1156.

is a breakdown of each sample into the proportions of each referece vector (end-member) that contributes to its composition. Proportionalities may then be contoured on maps which present the regional distribution of the proportional distribution of each end-member. This is then a gradational pattern in which mixtures and transitions may be readily recognized. It should be emphasized that these results are a purely mineralogical distribution; however, if the end-members do reflect source as opposed to assemblages produced by weathering, selective sorting or diagenesis, the advantages of such an analysis in determining dispersal patterns and hence littoral transport are obvious. The vector analysis provides a quantitative measure of the relative importance of each end-member. When the latter are related to source, an estimate of the relative importance of various sources and the quantity of littoral transport may be obtained when the ratio of heavy minerals to light minerals in each different association is taken into account.

Six end-members explain a large part of the variance of the data set. These six vectors or mixtures of various proportions of them will account for the composition of the samples collected in the area studied. As is commonly the case two vectors (1412 and 1493) account for a large part of the variance. Of the remaining vectors, 1515 and 1522 are important and represent suites present in at least several samples. Vectors 1474 and 1547 are of lesser importance (see Table I). The vector analysis of the data set is presented in Appendix II. The data for each sample are in the

Table I

Percentage of Total Variation
Explained by Each Vector

Vector	Per Cent of Variation	Cumulative Per Cent
1412	94.6	94.6
1493	2.3	96.9
1515	1.2	98.1
1522	0.8	98.9
1549	0.4	99.3
1474	0.3	99.6

form of proportions; neither they nor their squares sum to unity.

The samples in which a given vector occurs in significant amounts almost invariably have a definite and contiguous areal distribution (see Figures 13, 14 and 15 for sample stations). The areas in which vectors 1412 or 1493 represent a large proportion of the composition cover more than 90% of the area studied. The other vectors generally have importance only in one localized area and are largely insignificant in samples outside this area. The distribution of the various vectors is shown in Figures 16-20.[1]

Vector 1412 is an offshore sample collected from a depth of approximately 220 feet. From Figure 16 one can see that the samples containing large proportions of vector 1412 are very widespread, but are limited to the zone beyond the 70 foot depth contour. Vector 1493 is somewhat less widespread. Sample 1493 is a terrace sample taken from the terraces backing Montara Beach and is essentially a pure hornblende suite. The vector occurs in large proportions in all of the samples taken from areas backed by either granodiorite bedrock or terraces derived from the granodiorite, but especially the latter (see Figures 18 and 19). Occurrence in amounts exceeding .50-.60 is invariably confined to depths less than approximately 90 ft. The remaining four vectors have a very limited areal distribution. Vectors 1522 and 1547 do not clearly delineate specific areas. The former is a zircon-hornblende assemblage that has only been found in a few beach samples.

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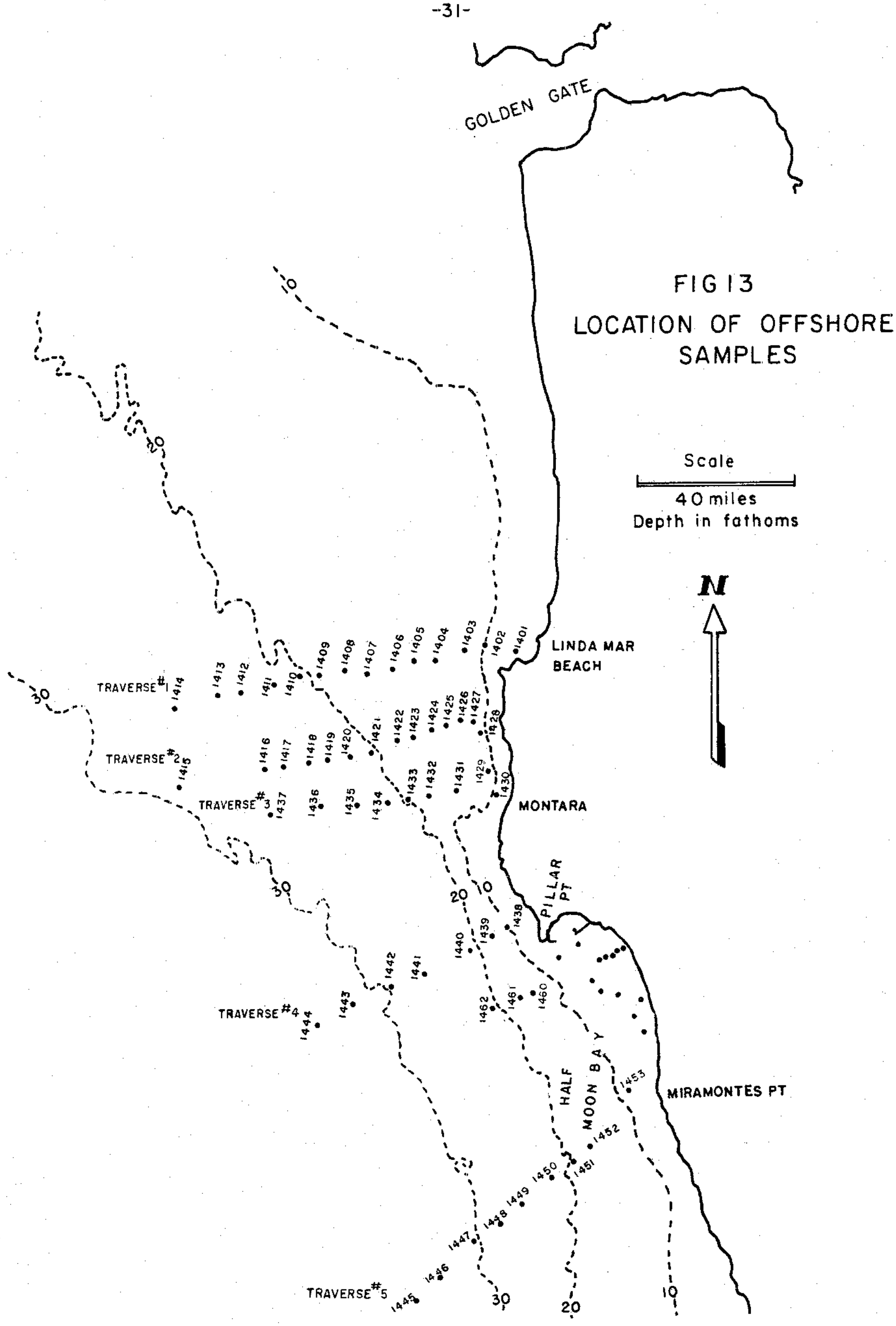
[1] On the contour maps negative proprotions have been plotted as zero.


GOLDEN GATE
FIG 13
LOCATION OF OFFSHORE SAMPLES
Scale
40 miles
Depth in fathoms
N
LINDA MAR BEACH
MONTARA
PILLAR PT
MIRAMONTES PT
HALF MOON BAY
TRAVERSE #1
TRAVERSE #2
TRAVERSE #3
TRAVERSE #4
TRAVERSE #5
10
20
30

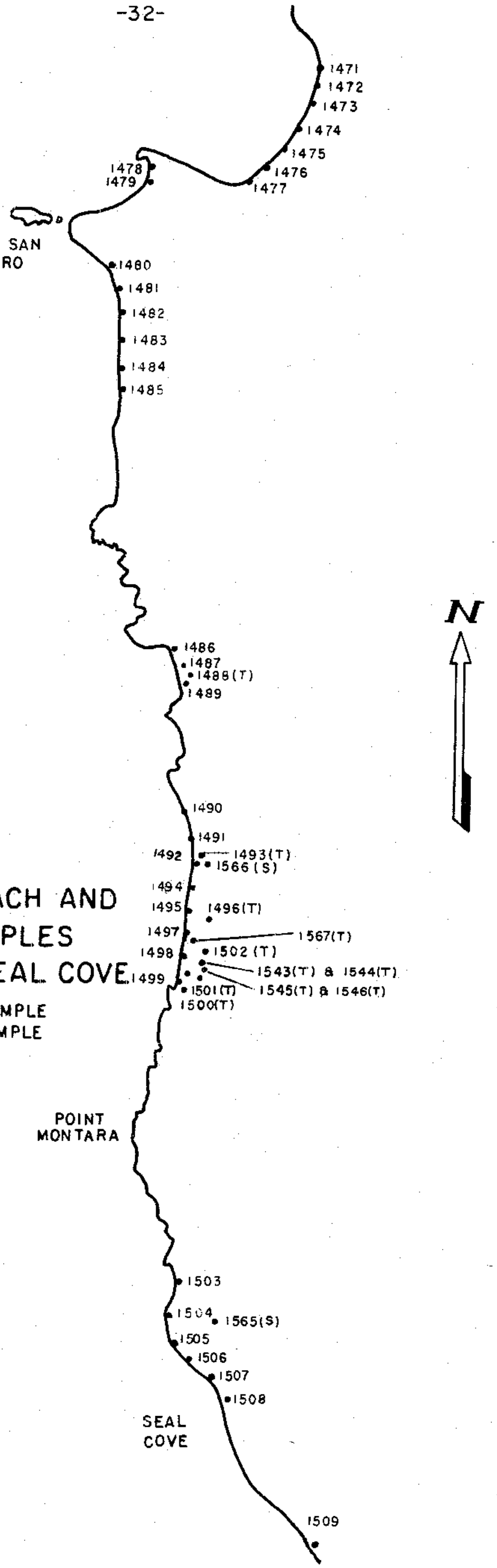


FIG 14

LOCATION OF BEACH AND TERRACE SAMPLES LINDA MAR TO SEAL COVE

(T) DENOTES TERRACE SAMPLE
(S) DENOTES STREAM SAMPLE
Scale
1.0 miles

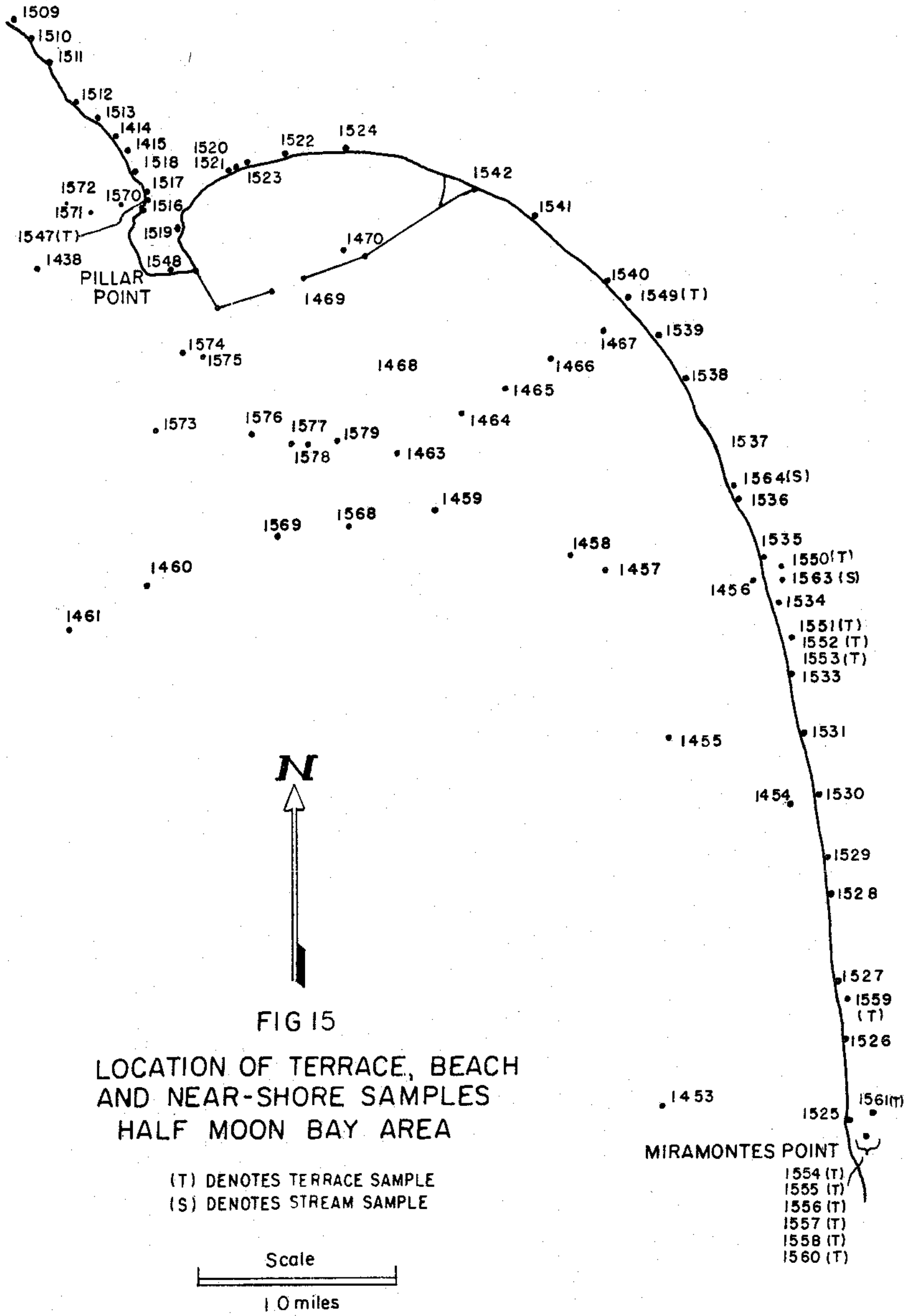


FIG 15

LOCATION OF TERRACE, BEACH AND NEAR-SHORE SAMPLES HALF MOON BAY AREA

(T) DENOTES TERRACE SAMPLE
(S) DENOTES STREAM SAMPLE

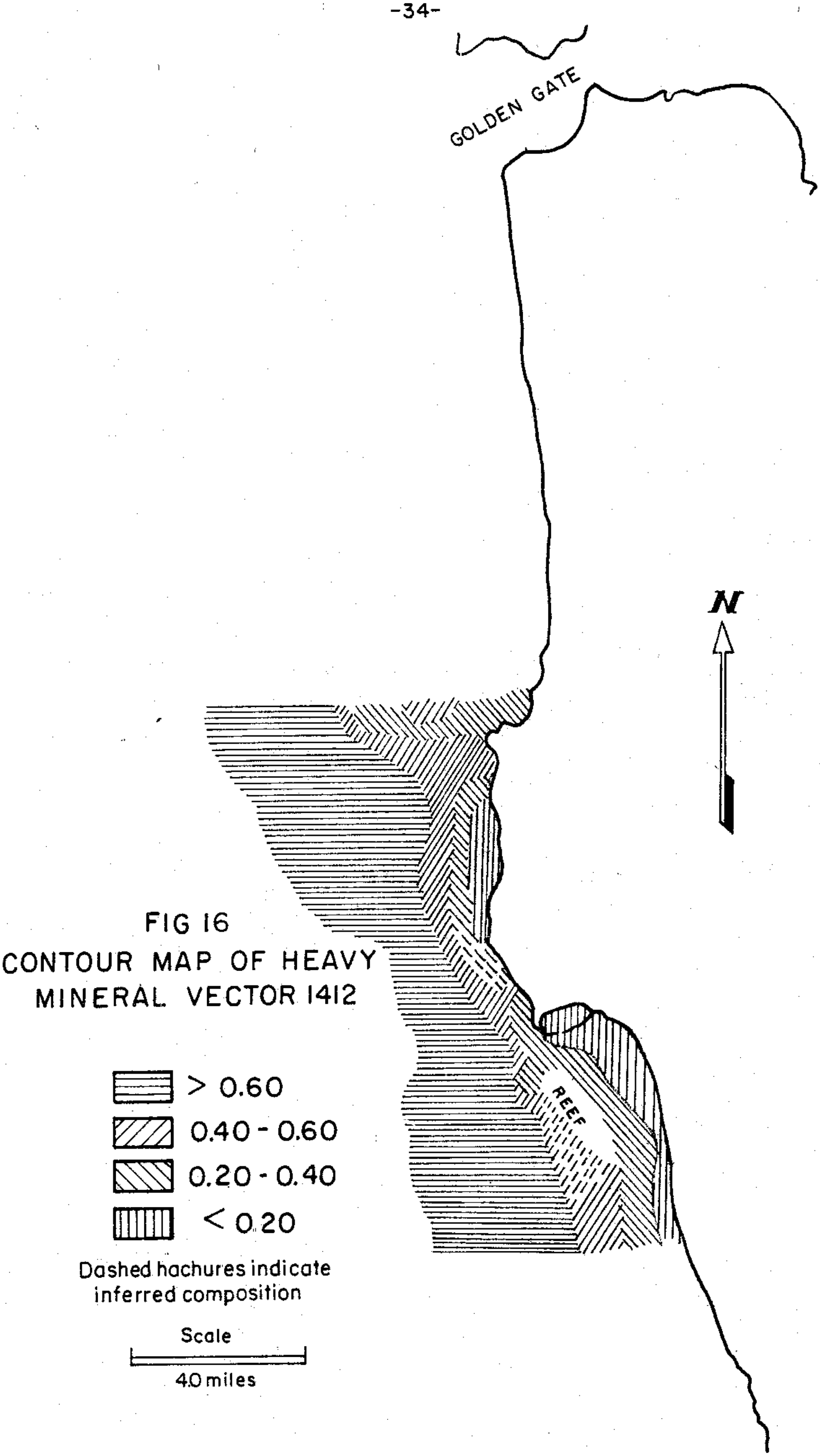


FIG 16
CONTOUR MAP OF HEAVY MINERAL VECTOR 1412

FIG 17

CONTOUR MAP FOR HEAVY MINERAL VECTOR 1412 IN HALF MOON BAY AREA

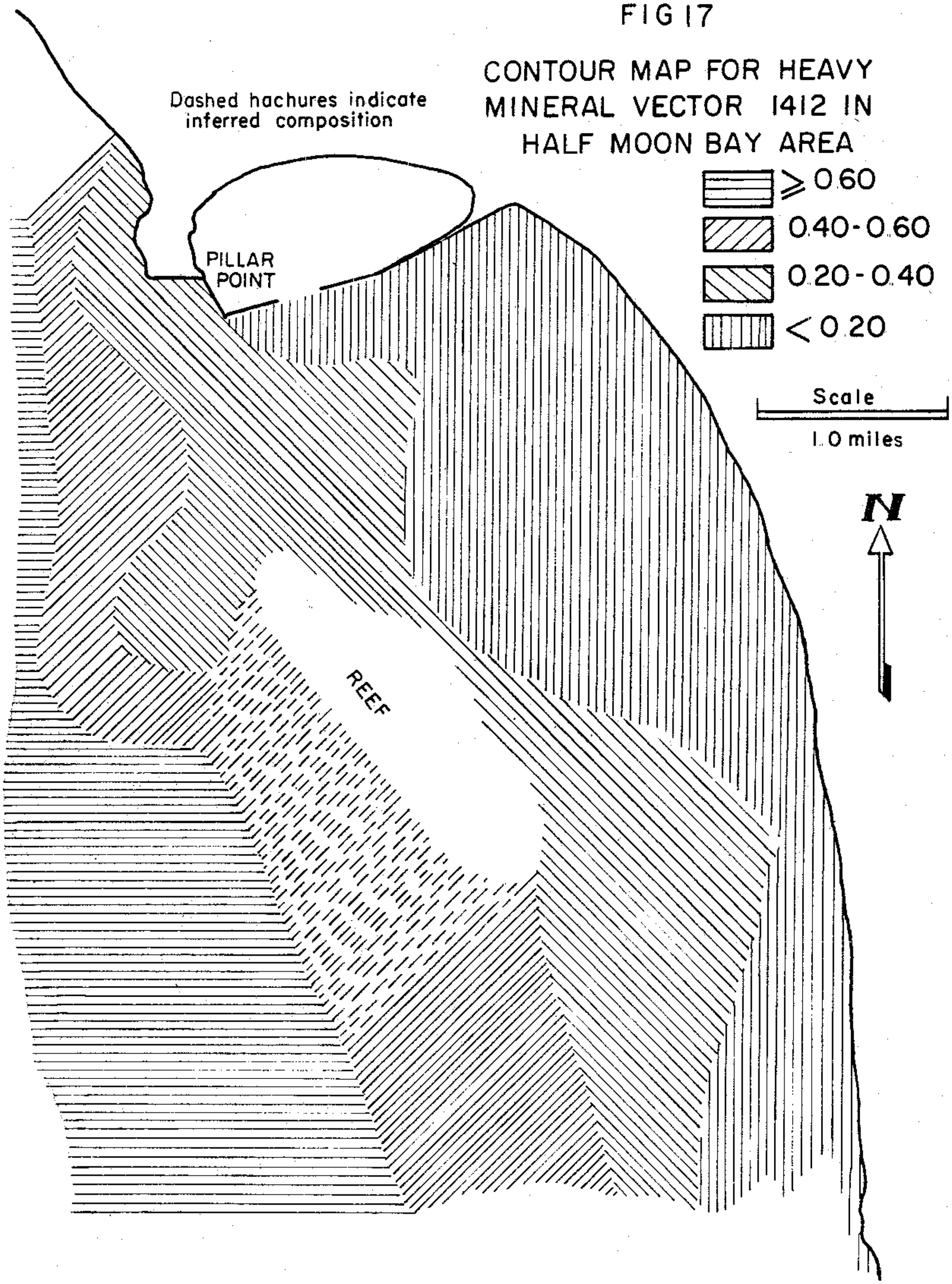


FIG. 18

CONTOUR MAP FOR HEAVY MINERAL VECTOR 1493

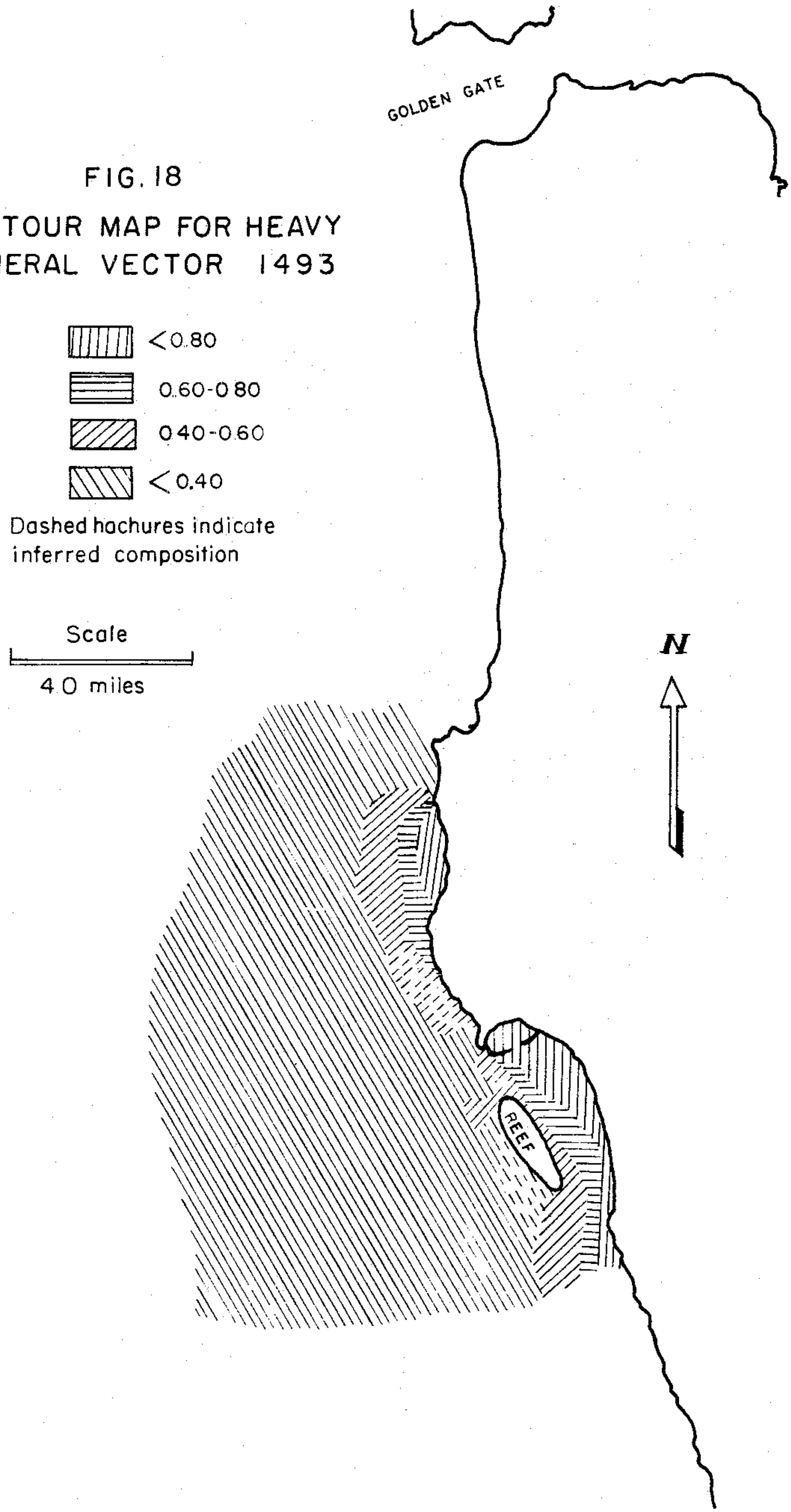
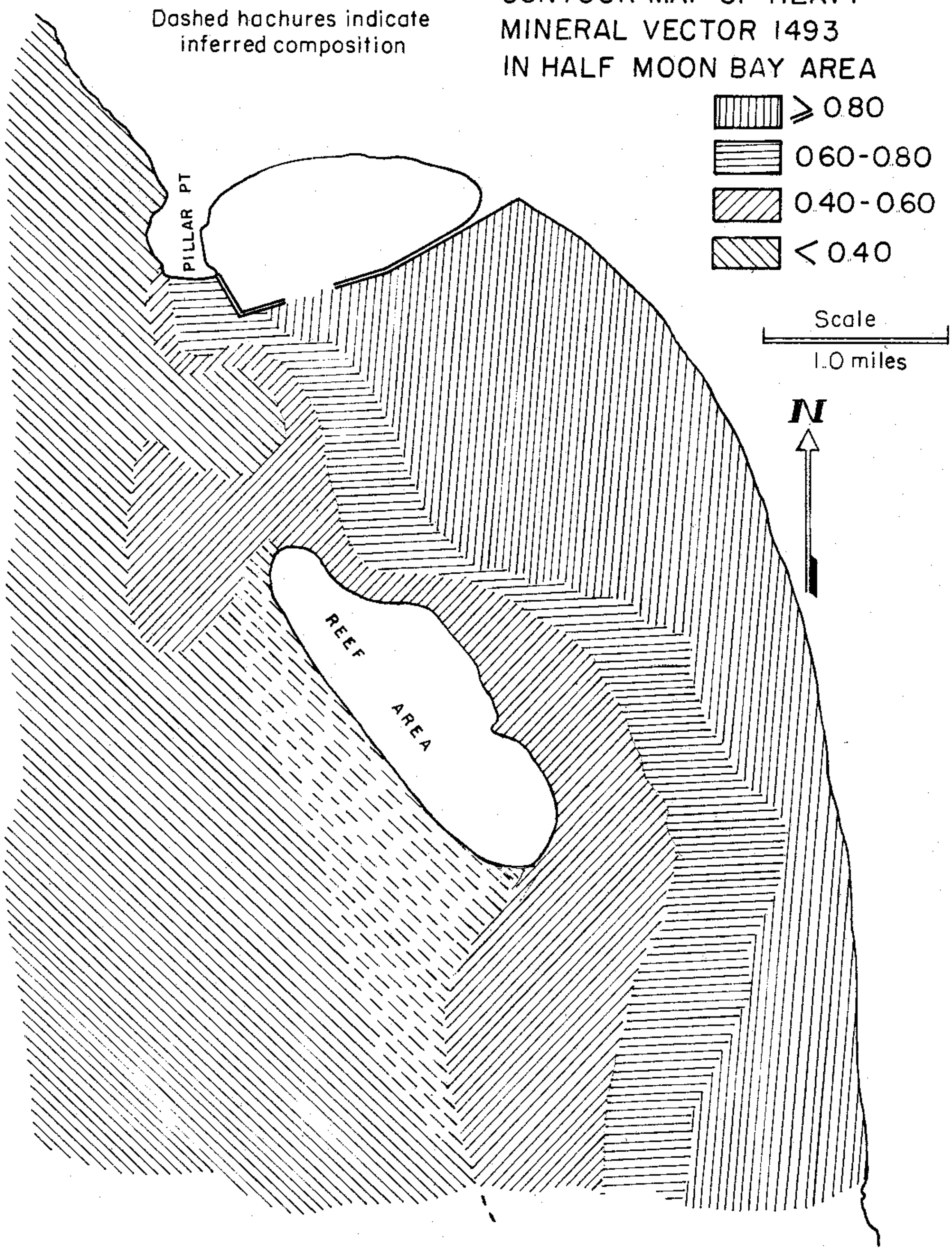


FIG 19

CONTOUR MAP OF HEAVY MINERAL VECTOR 1493 IN HALF MOON BAY AREA



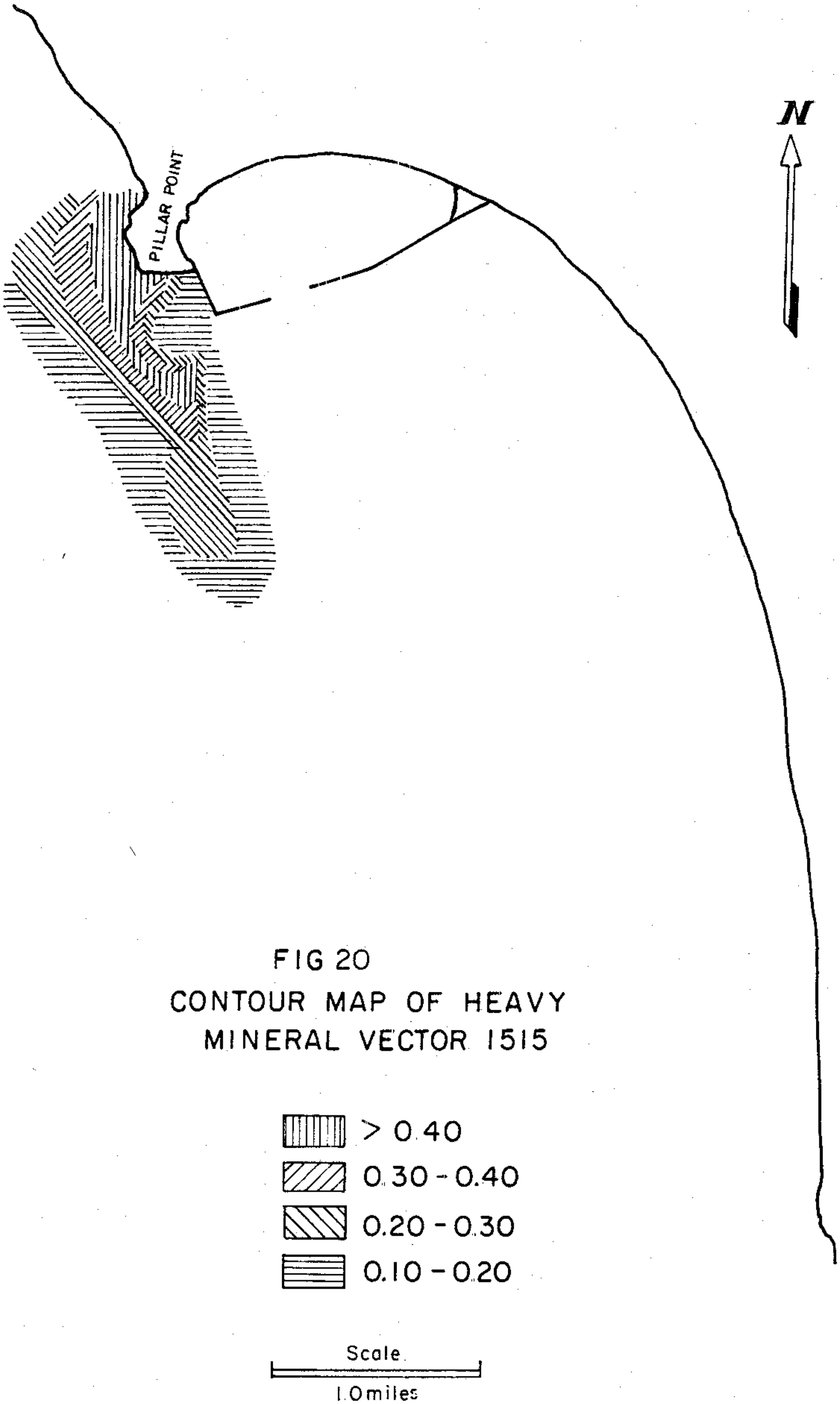


FIG 20
CONTOUR MAP OF HEAVY
MINERAL VECTOR 1515

Vector 1547 is a bedrock sample of the Purisima formation which crops out along the western side of the Seal Cove Fault at Pillar Point. This sample is marked by a relatively high sphene content (16%). In both of the latter cases the minerals differentiating these vectors most markedly from the other vectors (zircon and sphene) may have several sources other than the areas from which these samples were taken. Their occurrence in samples generally cannot be considered as strong criteria for determining provenance. Vector 1474 is a pyroxene-hornblende suite that does have a definite area of occurrence, but the area is very small and the data are not consistent enough to make contouring its distribution rewarding. Vector 1515 is a carbonate -rich[1] assemblage. Its occurrence is clearly defined areally. It is limited to the high energy areas of the Pillar Point and Half Moon Bay reef system. A detailed tabulation of the heavy mineral composition of the vectors is presented in Table II.

Selective Sorting

Inspection of Figures 16-20 indicates that the sand occurring in this area can be grouped into separate zones on the basis of similarity of composition. These zones may be primarily genetic in origin, or they may be due

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1 The carbonate grains are often cryptocrystaline aggregates and probably are shell fragments. Optical properties (2V- 10° -20°, negative, R. I. = 1.530-1.685) and X-ray patterns prove this to be aragonite and thus support the idea of an organic origin. The samples containing large proportions of vector 1515 were collected by means of SCUBA; on these diving trips the mollusc population and the quantity of shell fragments present were observed to be very large.

Table II
Heavy Mineral Composition
of the
Reference Vectors

Vector	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite-Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Indeterminate
1412	49	11	18	02	00	00	14	02	01	00	00	01	01	01	00	00	00
1493	93	00	00	00	00	02	01	01	00	01	02	00	00	00	00	00	00
1515	39	03	04	00	44	03	02	01	01	00	01	02	00	00	00	00	00
1522	29	02	03	00	00	07	01	02	03	01	51	00	00	00	01	00	00
1547	32	04	11	00	00	16	00	07	04	04	07	00	02	02	07	03	01
1474	45	28	14	00	00	02	02	03	03	02	01	00	00	00	00	00	00

to non-genetic processes such as selective sorting.[1] If any are genetic in origin and thus represent 'sedimentary petrological provinces' in the sense used by Edelmann,[2] they may be used to determine the provenance and dispersal of sediment and the littoral transport patterns in this area. To ascertain the importance of sorting in producing the observed areal distribution of heavy mineral assemblages, the per cent occurrence of each diagnostic heavy mineral has been plotted against median grain-size in the sand-size fraction after the manner of van Andel and Poole (1960) (see Figures 21 to 23). Only carbonate and zircon show direct correlation with median grain-size distribution. There is a trimodal distribution in the augite and hypersthene figures, but this primarily reflects the grain-size distribution of all the samples; analysis of the hornblende distribution relative to median diameter shows the same modes. The composition of the samples in the areas characterized by an abundance of carbonate (vector 1515) or zircon (vector 1522) is probably due to selective sorting rather than provenance. The other areas represented by large proportions of vectors 1412, 1474, or 1493 are not a product of selective sorting. Neither post-depositional weathering nor diagenesis exert significant influence on composition either. These areas do reflect provenance in their composition and consequently processes of

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[1] See Rittenhouse (1943) for a discussion of selective sorting and hydraulic equivalents.

[2] Edelmann (1933) defined a group of sediments constituting a natural unit by age, origin and distribution as a 'sedimentary petrological province.'

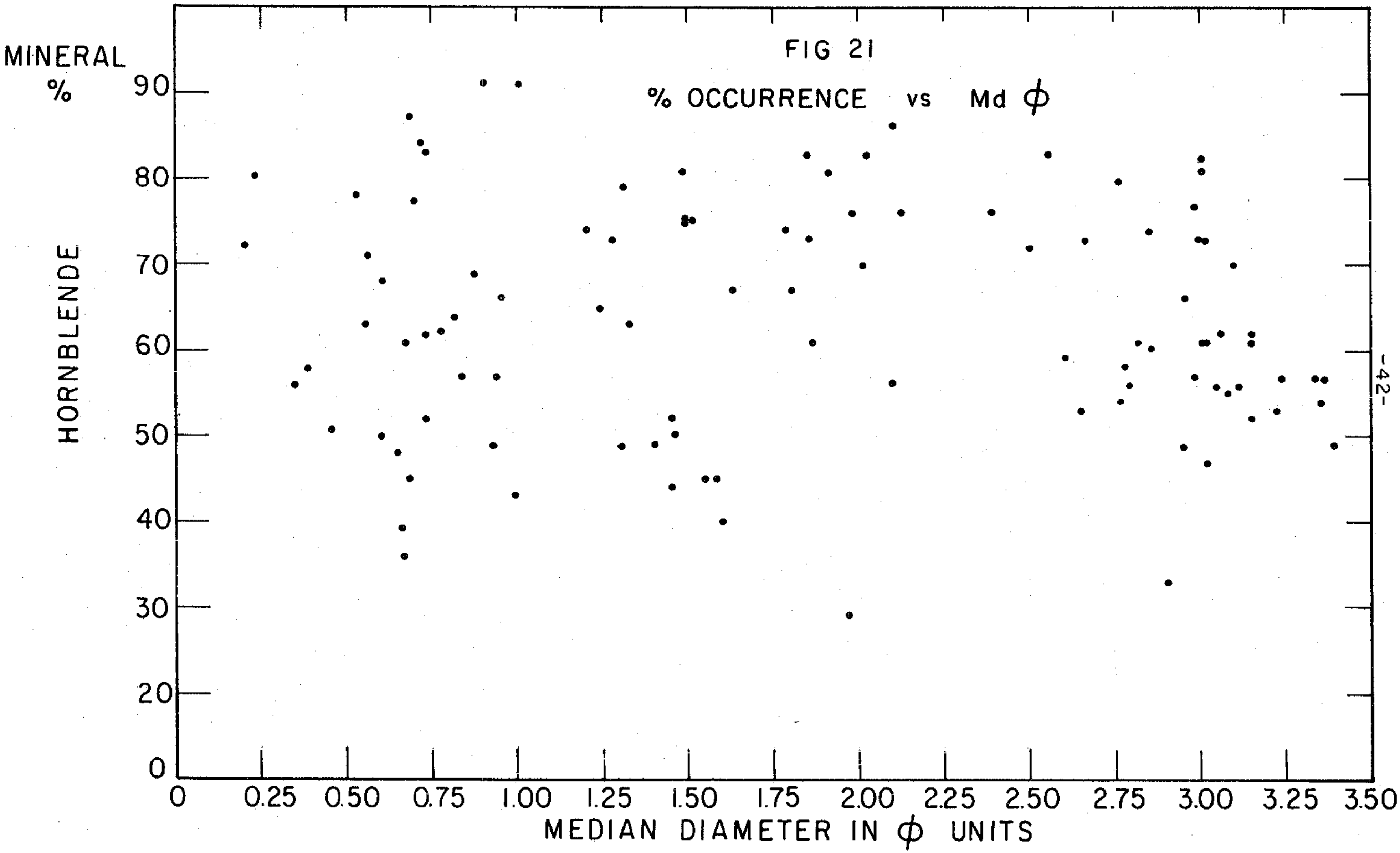
FIG 21
% OCCURRENCE vs Md ϕ
MINERAL %
HORNBLENDE
90
80
70
60
50
40
30
20
0
0
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
MEDIAN DIAMETER IN ϕ UNITS

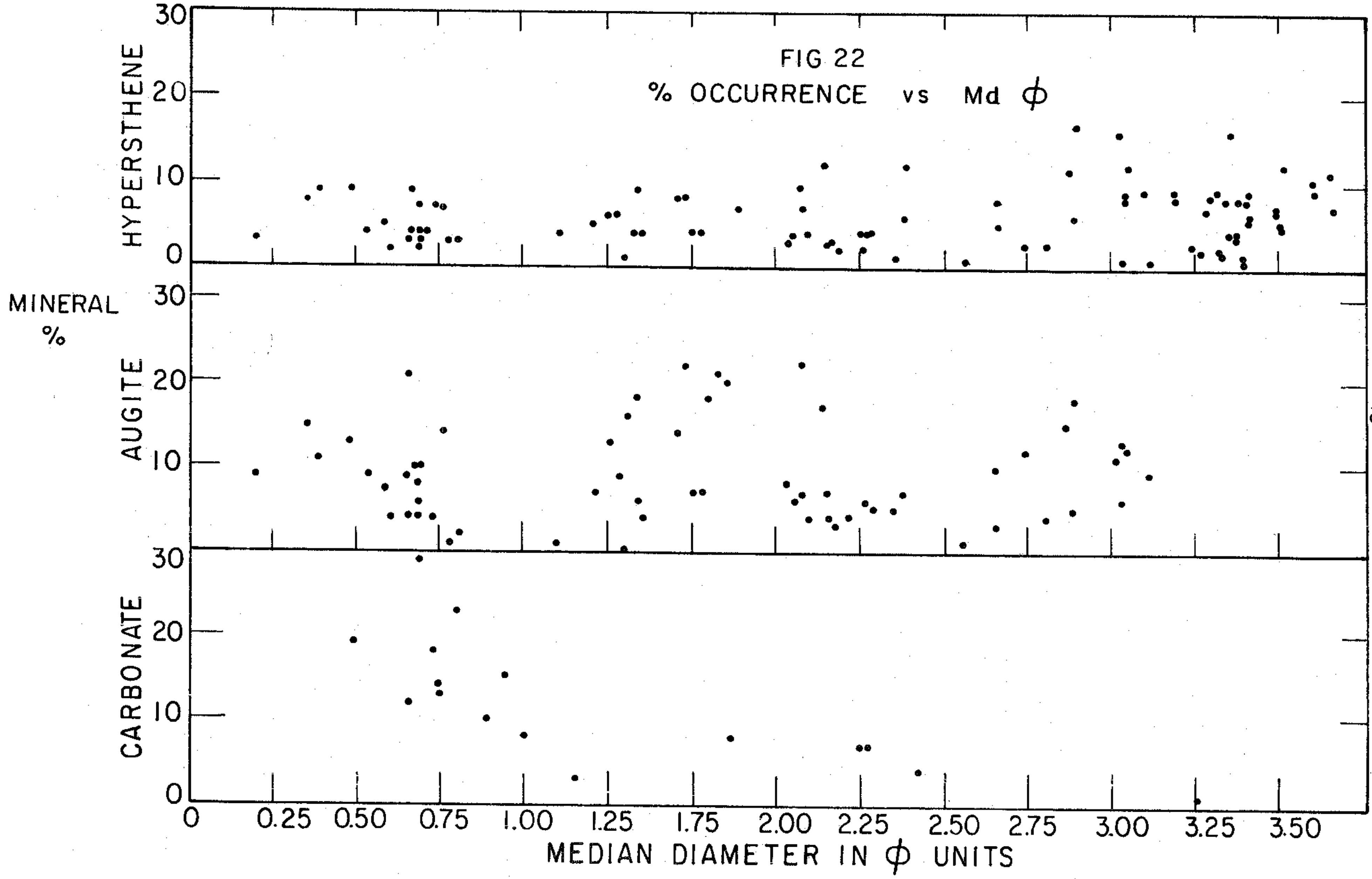

FIG 22
% OCCURRENCE vs Md φ

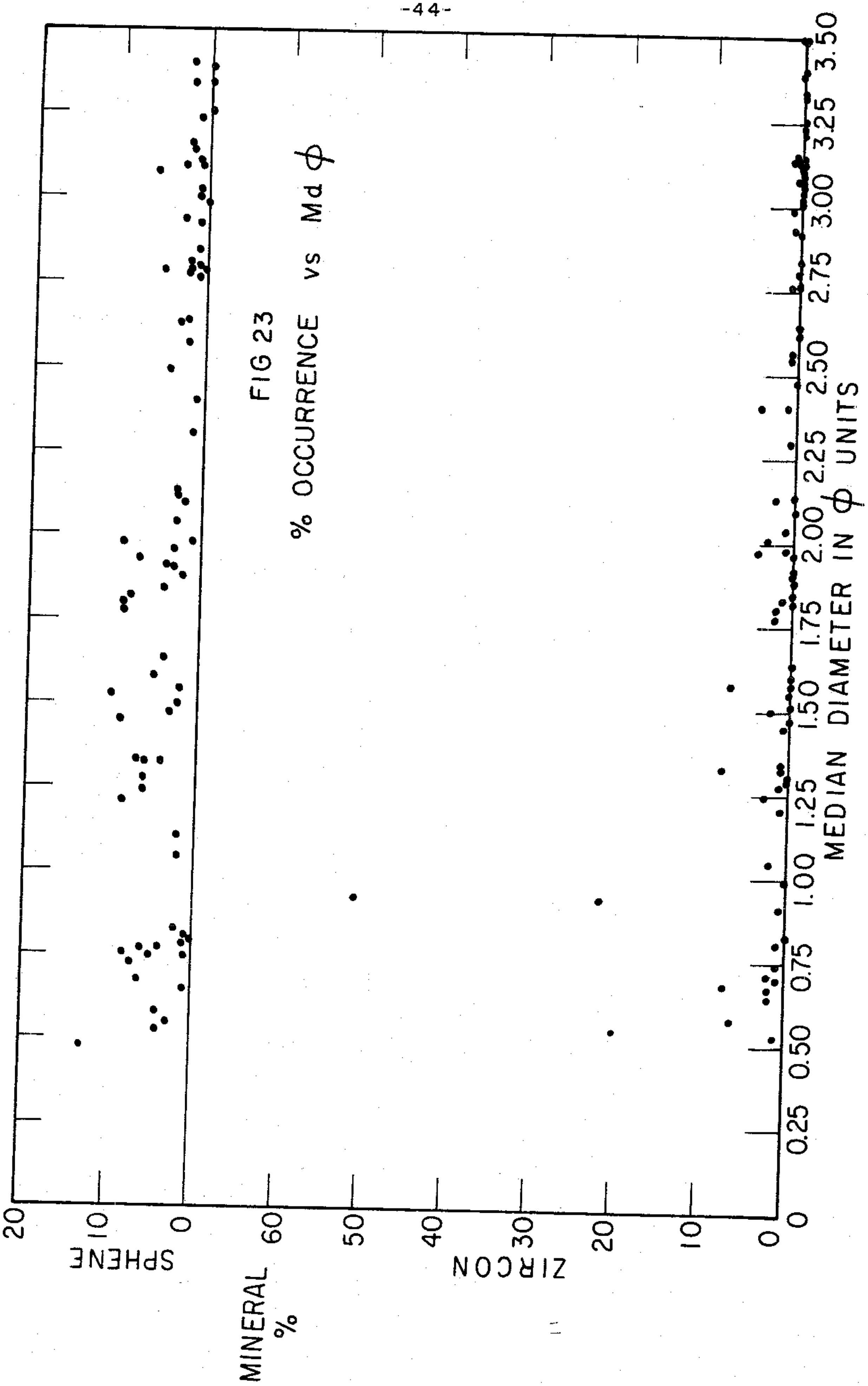
FIG 23
% OCCURRENCE vs Md φ
MEDIAN DIAMETER IN φ UNITS
0.25
0.50
0.75
1.00
1.25
1.50
1.75
2.00
2.25
2.50
2.75
3.00
3.25
3.50
SPHENE
20
10
0
ZIRCON
60
50
40
30
20
10
0
MINERAL
%

transportation and deposition and are 'sedimentary petrotogical provinces.'

Selective sorting appears to have played at least a minor role in producing the assemblages found in some samples other than those characterized by vectors 1515 and 1522. These samples are limited to the reefs and a few beaches. An increase in the hypersthene to augite ratio to approximately 1:1 is found in a number of the samples near Pillar Point (1512, 1514, 1518, 1570, 1571). This is attributed to sorting because there is no source for such a suite in the area, and the variation in composition of adjacent samples is very large indicating that some localized process is producing the differences. The wave energy variations in the reef area and adjacent shore are large and thus provide a possible explanation for compositional variation. Sorting may also play a part in producing the relatively high sphene content in the samples south of Point San Pedro, but evidence is too limited to warrant any definite conclusions. The composition of adjacent samples does vary considerably indicating some localized influence. Sorting is significant in the areas mentioned above, but is not important in producing the overall distribution of heavy minerals.

Heavy Mineral Provinces

On the basis of the distribution of the heavy mineral vectors discussed above, the area under study may be divided into four provinces. Combining the data from the vector contour maps will delineate the boundaries of these provinces and the zones of mixing of adjacent assemblages. Province 1 has been defined on the basis of a predominance of vector 1412, provinces

2 and 3 on the basis of vector 1493 and province 4 on the basis of vector 1474. The mixing zones are the areas in which sands from both adjacent provinces are abundant; as a rule, sands composed of vectors from adjacent provinces in relative amounts of .40 - .60 have been termed mixing zones (see Figure 24 and Table III).[1]

There are several discrepancies between the vector contour maps (Figures 16-20) and the provinces (Figure 24). The contour maps present the regional distribution of the proportional distribution of the vectors. Interpolating these to a distribution pattern which is significant with respect to provenance necessitates some interpretation and explanation. This arises from the fact that not all the end-members are representative of source assemblages.

North of Pillar Point Figure 16 indicates that vector 1412 is present in amounts of only .20 - .40. This is due to the abundance of carbonate (vector 1515) and the high hypersthene to augite ratio (attributed to vector 1474) which may be the product of sorting; the actual presence of the assemblage represented by vector 1474 is highly improbable. The carbonate has already been shown to be a product of a special local environment. Recalculation of mineral percentages without the carbonate

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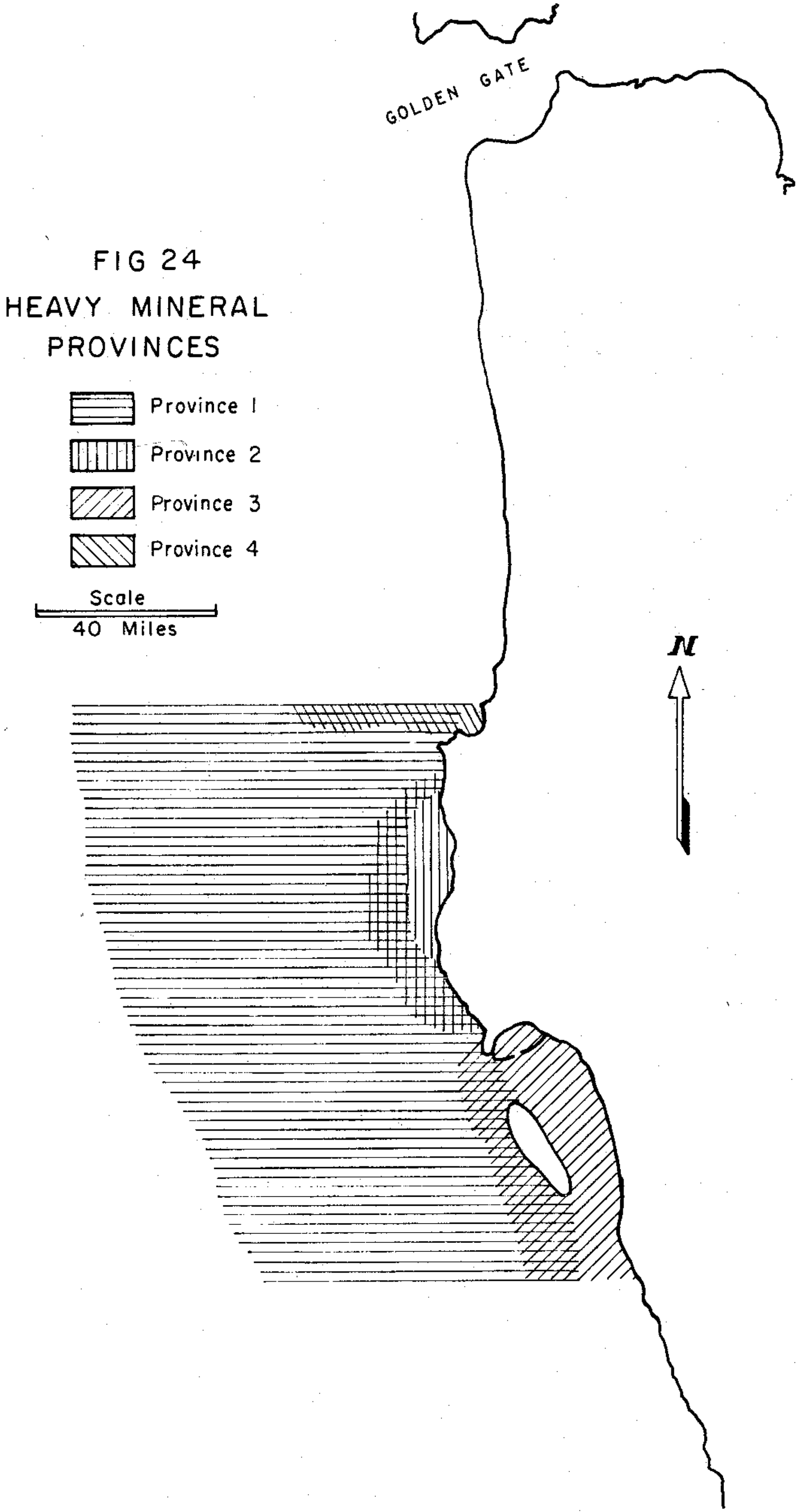
[1] The use of these vectors in the delineation of provinces is justified because they are compositionally representative of the source assemblages. The distribution pattern of these vectors (1412, 1474 and 1493) must, then, reflect dispersal and littoral transport patterns.


GOLDEN GATE
FIG 24
HEAVY MINERAL PROVINCES
Province 1
Province 2
Province 3
Province 4
Scale
40 Miles
N

		HORNBLENDE	HYPERSTHENE	AUGITE	OXYHORNBLENDE	CARBONATE	SPHENE	TREMOLITE - ACTINOLITE	EPIDOTE	GARNET	ZOISITE	ZIRCON	ENSTATITE	GLAUCOPHANE	LAWSONITE	APATITE	CLINOZOISITE	ANDALUSITE
1	$\bar{X}$	57.5	8.98	15.8	2.00	0	2.34	4.36	2.09	1.82	0.52	0.96	2.12	0.32	0.27	0.48	0.34	0
	σ	6.13	2.78	3.92	1.85	0	2.31	2.40	1.72	2.19	0.84	1.61	2.34	0.51	0.69	0.78	0.67	0
2	$\bar{X}$	83.7	3.33	3.75	0.08	0	3.25	1.41	1.67	1.33	0.25	0.75	0.33	0	0	0.08	0	.08
	σ	6.30	1.25	2.59	0.28	0	3.65	1.98	1.60	1.11	0.60	1.30	0.47	0	0	0.28	0	0.28
3	$\bar{X}$	74.4	3.86	6.14	0.99	0	4.26	1.91	2.17	0.77	0.37	3.60	0.20	0.17	0	0.51	0.54	0
	σ	10.4	2.15	2.57	1.34	0	3.54	1.75	1.50	1.04	0.72	9.48	0.40	0.38	0	0.81	0.81	0
4	$\bar{X}$	44.3	25.9	18.6	0.43	0	4.43	1.00	2.43	1.43	0.57	0.29	0.14	0	0	0	0.29	0.29
	σ	3.69	2.03	4.27	0.73	0	2.32	1.41	1.29	0.73	0.73	0.43	0.34	0	0	0	0.70	0.45
1 - 2	$\bar{X}$	69.0	5.89	9.33	1.37	0	3.00	2.44	3.22	1.44	0.78	2.22	0.67	0.11	0	0	0.33	0
	σ	7.35	2.38	3.71	1.94	0	1.94	1.83	1.31	1.77	1.03	2.78	0.94	0.31	0	0	0.67	0
1 - 3	$\bar{X}$	64.6	7.35	12.89	1.30	0	3.88	3.50	1.00	0.88	0.38	1.63	0.13	0.63	0	0.38	1.00	0
	σ	7.58	3.46	4.04	1.12	0	1.36	1.87	1.00	0.93	0.70	1.11	0.33	1.32	0	0.48	1.11	0
1 - 4	$\bar{X}$	55.3	14.5	12.8	1.66	0	1.33	6.33	2.19	0.67	0.83	0.33	1.33	1.33	0	0.33	1.67	0
	σ	5.15	4.07	2.11	1.11	0	0.75	1.97	0.69	0.47	0.46	0.47	0.49	0.94	0.10	0.47	0.37	0

TABLE III MEAN AND STANDARD DEVIATION OF MINERAL CONTENT OF THE PROVINCES AND MIXING ZONES generally indicates an assemblage not unlike that characterizing province 1 but with a higher hypersthene and hornblende content. This assemblage is basically that of province 1 with some alteration in composition through sorting and the addition of minor amounts of the assemblage characterizing province 2 (vector 1493).

Province 1 has been extended to the shore in the Point San Pedro area also. In this area the predominant suite is that characterizing province 1 (.45-.80), and the province 2 suite is notably absent in significant amounts (with one exception). Vector 1547 commonly occurs in amounts up to .40. This is probably due largely to the sphene content of the beach samples collected here. This is an area of high wave energy and sphene, a mineral of high specific gravity, may have been concentrated through sorting. Sphene does occur in many of the samples in province 1 in minor amounts and could well be the origin of this sphene. Certainly there is no source for vector 1547. A local source of sand is possible, but it is very difficult to explain the occurrence of samples with proportions of .60 and .80 vector 1412 under conditions of significant local supply. The sand in this area is basically that of province 1.

The mixing of provinces 1 and 4 has a seemingly improbable boundary. The sample control is adequate, however, and a boundary at least similar to that presented in Figure 24 must be drawn. The general absence of vector 1474 (which characterizes province 4) from samples of traverse 2 indicates that this suite is not present in this area. It is also consistently absent in significant amounts from samples collected on the beaches just to the north and to the south of Point San Pedro. This indicates that a boundary such as the one shown does occur, and further that the province is largely confined to areas to the north of the area studied. Investigation of sediments in the area north of Linda Mar Beach exhibit a composition similar to that of vector 1474 further substantiating the idea that province 4 is the southern-most region of a province to the north (D. Moore; personal communication, 1965).

The distribution of sand in the area considered is characterized by a series of 4 provinces. Province 1 includes most of the area involved. Provinces 2, 3 and 4 are essentially embayments extending outward into province 1 from the shore, as clearly shown by the vector contour maps. Provinces 2 and 3 are defined on the basis of the same vector (1493) but are classed as discrete provinces because of geographical separation. The latter provinces are of limited extent, seldom extending beyond a depth of 60-70 feet and rarely spreading any appreciable distance along the coast. Mixing zones of these provinces and province 1 invariably extend to a maximum limiting depth of 90 feet. The mixing zones are attenuated toward the south, but are abruptly terminated on their northern boundaries.

<u>Grain-size Distribution</u>

Most of the samples collected have been analyzed with respect to their grain-size distribution. Very few irregularities occur in the distribution pattern of samples collected in the area under study. In general the median diameter of samples decreases with increasing depth; the coarsest samples occur on the beaches or in high energy environments of the reefs north and south of Pillar Point. Figures 25 and 26 present the median grain-size and grain-size mode data for the offshore samples; Figures 27 and 28 present the same data for terrace, beach and shallow water samples. Nearly all of the samples are unimodal, even in areas where sediment from two distinct sources is mixed as off Montara Beach. From the unimodal character and inspection of cumulative frequency curves (plotted on 1/4 ϕ intervals) it is evident that the offshore samples are well sorted with few exceptions.

A marked exception to the above condition exists in the samples collected in the area off Half Moon Bay and Pillar Point at depths ranging from 90 to 120 feet. The bulk of the material in these samples is composed of pebble-size particles with maximum diameters up to 4 cm in rare instances; 2 cm is generally the maximum size. The sand-size fraction is bimodal or trimodal (see Figure 26). The area of coarse, poorly sorted samples appears sharply bounded as in each case the adjacent deeper sample on the traverses (samples 1441 and 1450) is characterized by well sorted, fine sand. Sample 1453 is from shallower water than that of 1452 (60 feet vs. 90 feet) but contains no exceptionally coarse fraction corresponding to that found in samples 1452 and 1451 despite the fact that it was collected in a higher energy environment.

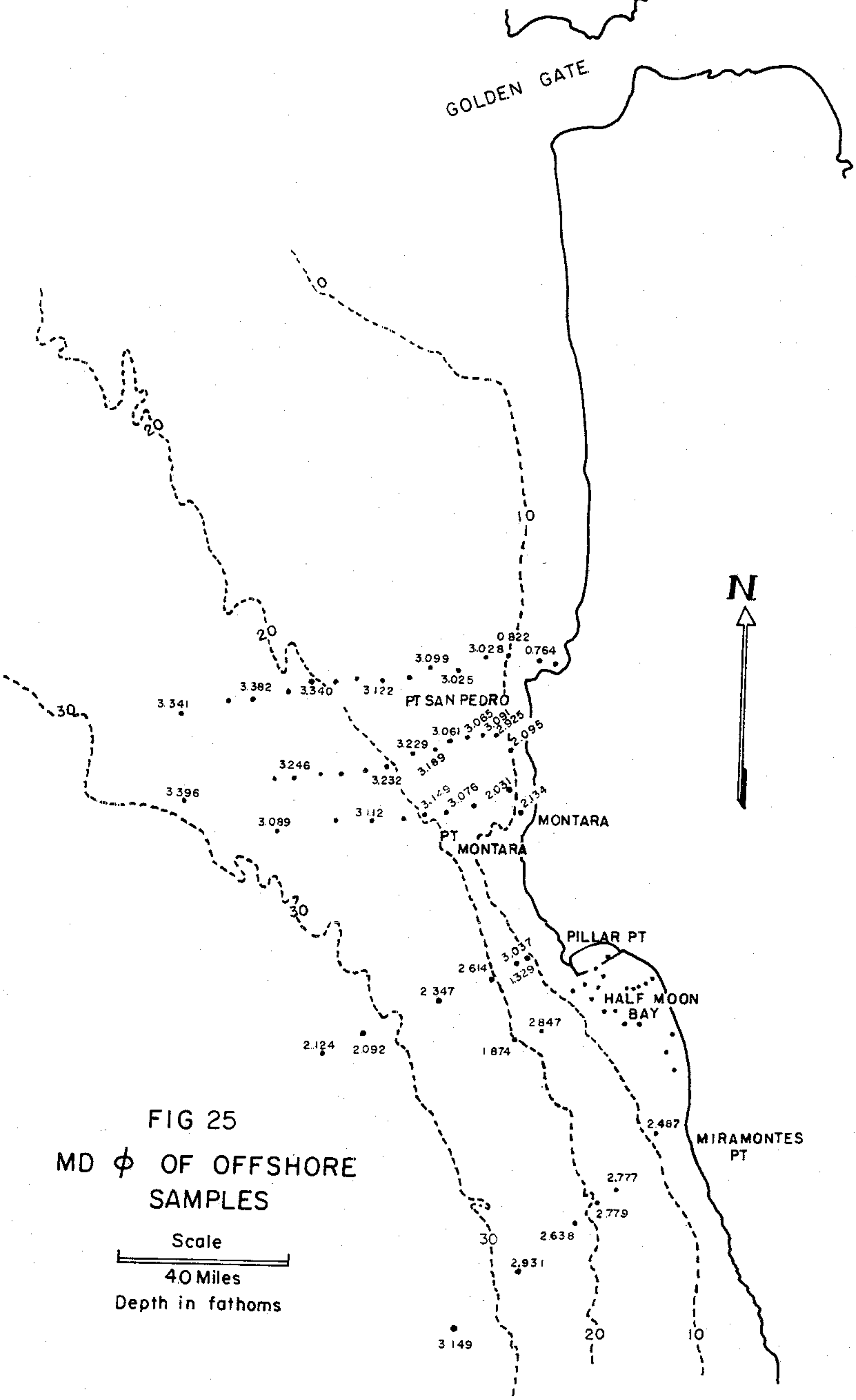


FIG 25
MD ϕ OF OFFSHORE SAMPLES

Scale
4.0 Miles
Depth in fathoms

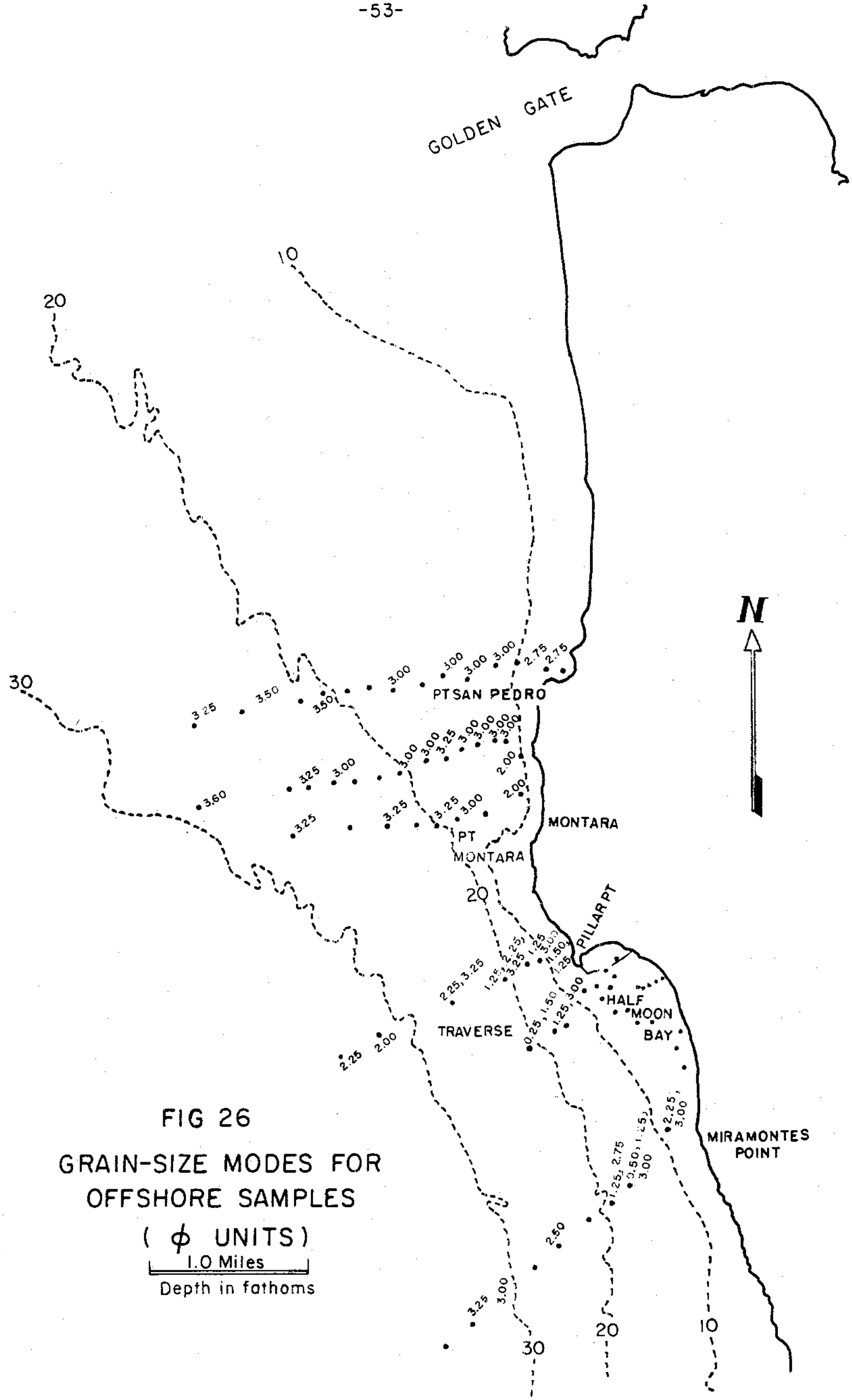


FIG 26

GRAIN-SIZE MODES FOR OFFSHORE SAMPLES (ϕ UNITS)

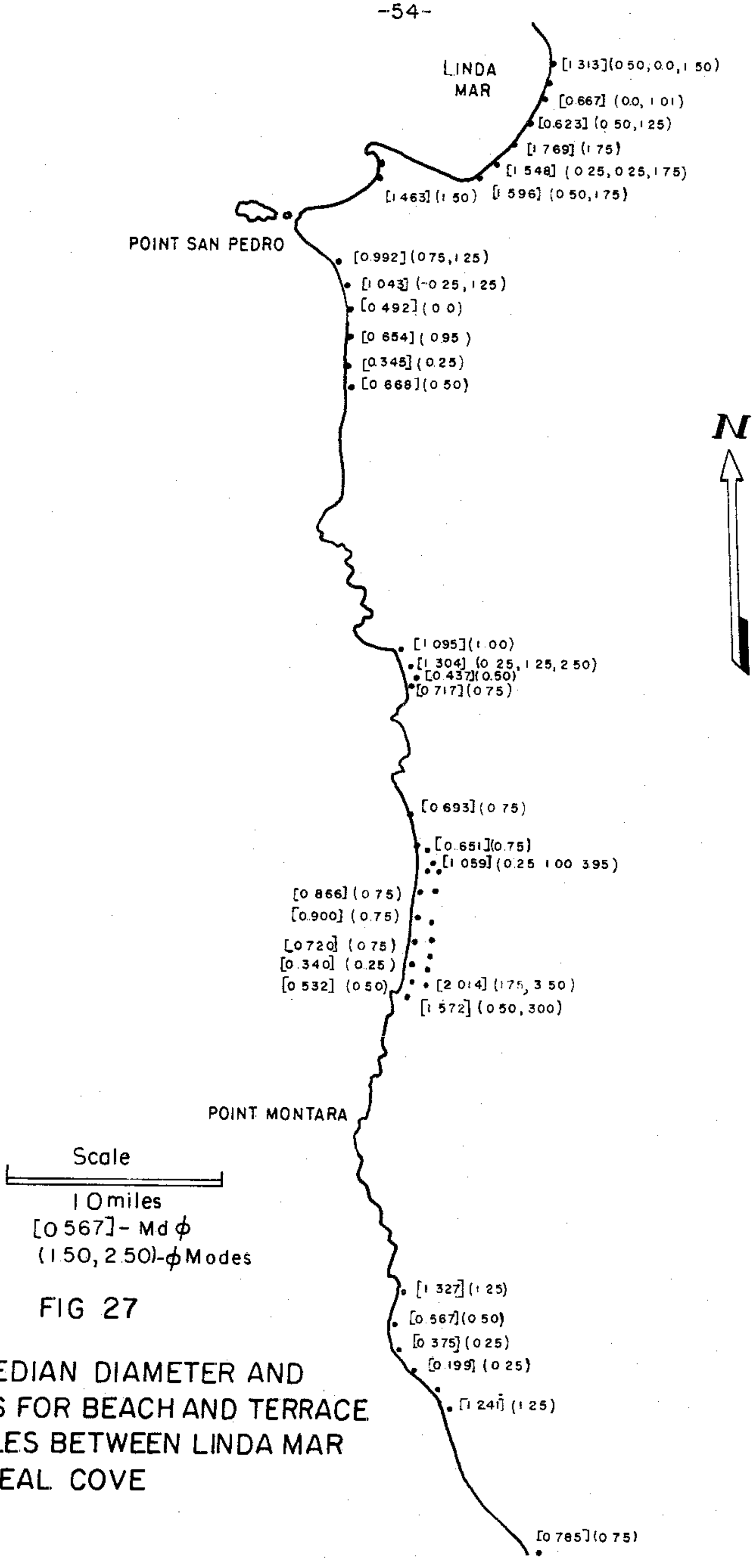


FIG 27

PHI MEDIAN DIAMETER AND MODES FOR BEACH AND TERRACE SAMPLES BETWEEN LINDA MAR AND SEAL COVE

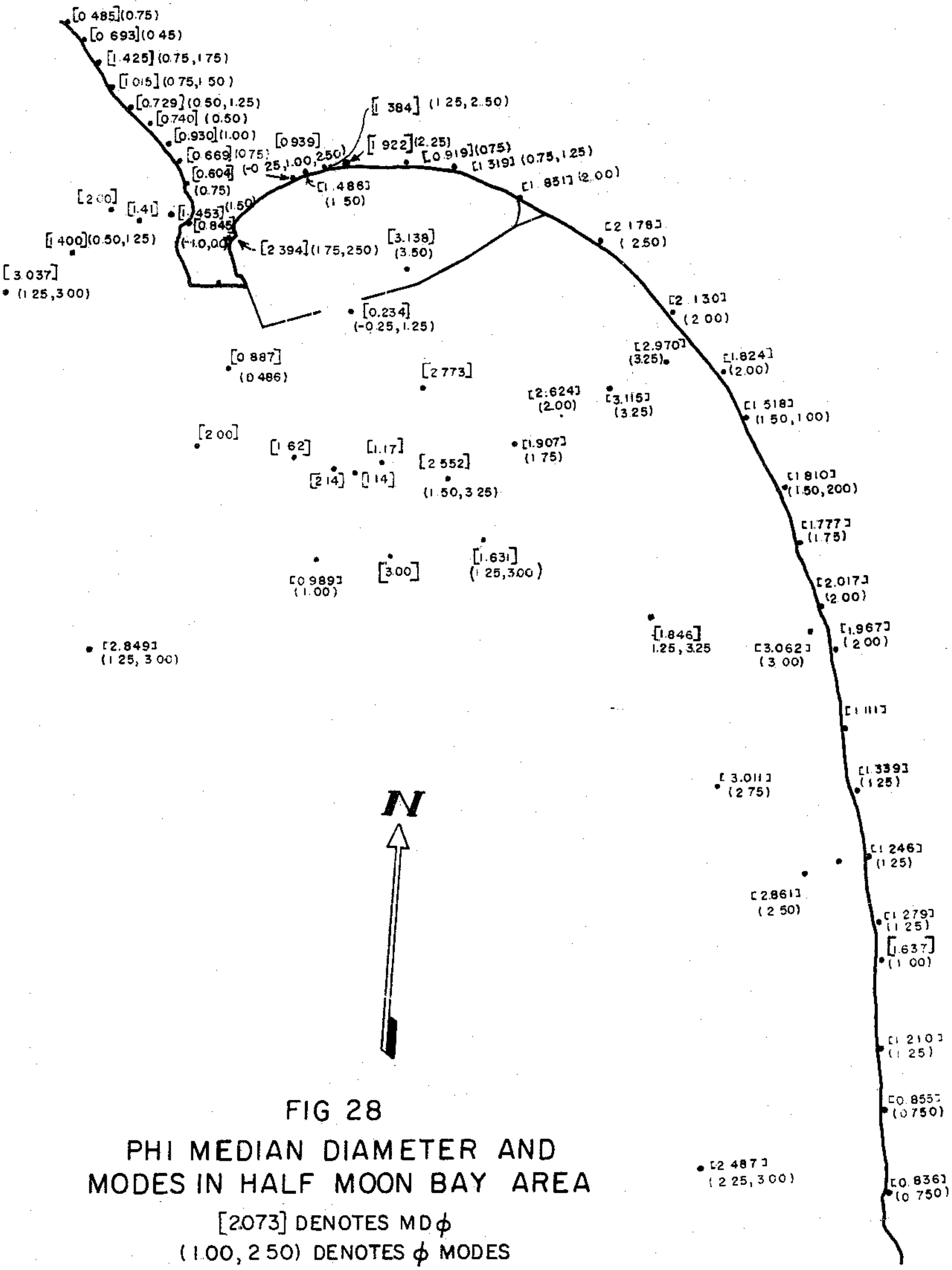


FIG 28
PHI MEDIAN DIAMETER AND MODES IN HALF MOON BAY AREA

[2.073] DENOTES MDϕ

(1.00, 2.50) DENOTES ϕ MODES

Scale

1 0 miles

There are two possible explanations of these very coarse, poorly sorted samples. The deposit may result from the breakdown of bedrock in the immediate vicinity of the sample stations through wave erosion or more probably the action of boring clams which are common throughout the reef area. This seems possible in the case of samples 1438 and 1439 as hydrographic surveys show the bottom to be rocky in this area. This may be the case for sample 1461 and 1462 as the bottom in this area is ambiguously listed as "hard." Fathometer reflections did not indicate a rocky bottom when the samples were collected however. The area where samples 1451 and 1452 were collected has a sandy bottom according to hydrographic surveys. This explanation (bedrock disintegration) does not fit the data for samples 1451 and 1452 and is probably not applicable to the case of samples 1461 and 1462.

The second possibility is that these represent a relic deposit of a lower stand of sea level. The relatively linear character and conformity to depth contours support this hypothesis, and such relic deposits are common at this depth (Curray, 1960). Such an origin indicates that the area has not yet reached equilibrium under present conditions or that these deposits lie beyond the range of transporting processes (Moore, D. G., and J. R. Curray, 1964). In areas which have reached equilibrium, grain-size generally decreases with the depth (Moore, D. G., and J. R. Curray, 1964). This is generally true of the traverses north of Pillar Point. The traverse from Pillar Point, however, indicates coarser grain-size with increasing depth. This is probably an area which has not yet reached equilibrium under present conditions. This is to be expected in areas of little sediment supply which is the case in this area as will be shown in following sections.

The data are insufficient to determine whether or not this zone is one produced by the breakdown of the reef or represents a relic deposit. Evidence favors the latter. It is not possible to draw any definite conclusion on the basis of grain-size data as to whether preservation of the deposit is a result of its being beyond the range of the local transporting processes or is a result of the area not having reached a state of equilibrium since the establishment of the present sea level. In the preceding section it was noted that the outward influence of sand derived from the terraces at Montara Beach and Half Moon Bay (vector 1493) was limited to depths of less than 90 feet. This strongly suggests that the preservation of the deposit if it is a relic sand is due to its position beyond the range of transport processes; this does not rule out the possibility of the area being one which has not yet reached equilibrium. Both may well be true.

The grain-size data can be utilized in verifying some of the hydraulic predictions made in the section on general analysis. The refraction of waves in Half Moon Bay is considerable, and large variations in the energy of the waves incident upon the shores of the bay are indicated by the refraction diagram (Figure 12). Where waves of high energy reach the shore the grain-size of the beach samples at that point should be coarse relative to samples from areas of lower energy. The agreement between grain-size distribution and energy predictions indicates that the general pattern of waves as shown by the refraction diagram is the predominant one.

The southern-most samples collected along the beaches of Half Moon Bay are the coarsest. On the basis of the refraction diagram one would not be led to this conclusion. The energy of the incident waves as indicated by the spacing of the orthogonals is considerably lower at the extreme southern end of the bay than at points farther north along the shore. Inspection of the offshore topography relative to the incident waves shows that the increase in grain-size occurs where the incident waves are no longer affected by the southern-most extension of the reef. Wave refraction diagrams apparently cannot accurately predict the loss of energy that occurs as waves pass over massive offshore topographic irregularities such as the extensive reef at Half Moon Bay. Predictions for the entire area affected by the reef are in excellent agreement with grain-size data. The predictions are also in agreement with grain-size data for areas not affected by the reef. Correlation of energy predictions between these two different environments (areas shadowed by the reef versus areas with waves unaffected by the reef) fails, however.

ORIGINS OF THE PROVINCES

Source

Province 1 covers a vast majority of the area studied but commonly grades into other provinces towards the shore (Figures 16 and 24). It extends seaward past the limit of sampling and extends north and south beyond the limits of the present investigation. It is highly unlikely that a province extending to such depths (greater than 220 feet) is a product of deposition under present conditions. Rather, it is probably inactive now and the product of conditions and processes extant during a lower stand of sea level. Geological relationships from several different aspects provide strong evidence in support of this. At present there is no significant source of hypersthene or augite in the area studied. The sands of province 1 are characterized by the presence of both of these minerals which, combined, comprise approximately 20-25% of the heavy mineral content. Consideration of the composition of offshore sands north of the Golden Gate (Cherry, 1964) and of the San Francisco Bay sediments from drill cores (A. M. Sarna-Wojcicki; personal communication, 1965) indicates that the assemblage of province 1 (represented by vector 1412) can be produced by a mixture of pre-modern sediment from these two sources. There is no other apparent source for this heavy mineral association. At present there is no net transport of sand along the coast north of the Golden Gate (Cherry, 1964; D. Moore; personal communication, 1965). The influence of sands coming through the Golden Gate today is of local extent only and does not extend south of Point San Pedro. At present there is no source for the sands of province 1. With a lower stand of sea level, however, it is reasonable to expect littoral transport of both the sediment lying on the continental shelf north of the Golden Gate and the sediment pouring out of the Golden Gate under these conditions. This is evident from the fact that the coast would be devoid of any rocky promontories (which now characterize it) as shown by hydrographic surveys; such a relatively straight, unobstructed, sandy shoreline would present optimum conditions for littoral transport.

Lower stands of sea level are an accepted fact of the Pleistocene (Shepard, 1963; Curray, 1964; and others). On the basis of the aforementioned conditions of source alone it is not unreasonable to call the sands of province 1 pre-modern; however, evidence of a stratigraphic nature provides strong evidence in support of this hypothesis also. Samples 1502 and 1543 are taken from a cross-bedded layer in the pre-modern terraces backing Montara Beach. The compositions of these samples correspond closely to that of province 1. The cross-bedding is steeply inclined and closely resembles that usually associated with sand dunes. The bed is overlain and underlain by granodioritic deposits with little intermixing of the two types. This is indicative of an abrupt change in conditions involving the cessation of the deposition of the granodioritic material and influx of different sand in the form of sand dunes. This provides strong evidence that the sands of province 1 do represent pre-modern deposits and have resulted from the mixing of sediment from the San Francisco Bay drainage and areas to the north of the Golden Gate.

Provinces 2 and 3 are both characterized by the presence of vector 1493. Sample 1493 was taken from the terrace deposits at Montara Beach. The characteristics and source of these deposits and those backing Half Moon Bay have been discussed (pages 7 and 8). The similarilty of composition of the terraces in these two areas is a result of their having been derived from the same source (samples 1551, 1561, 1562 are basically composed of the hornblende suite of vector 1493). Deposits derived from them should be very similar or even indistinguishable (compare the compositions of samples from Montara Beach with those from the Half Moon Bay beaches). Provinces 2 and 3 are backed by these terrace deposits and are, in general, limited to the areas adjacent to them or the granodiorite. Province 2 must have been derived from the granodiorite or terrace deposits in the Montara area (primarily the latter) and province 3 from the Half Moon Bay terrace deposits.

The assemblage characterizing province 4 has no apparent source in the area studied. The Merced formation which backs much of the shoreline in the areas north of Linda Mar contains hypersthene, augite and hornblende in roughly the proportions of vector 1474 (T. Hall; personal communication, 1965). The beach and nearshore deposits in the areas backed by the Merced formation also have a heavy mineral content similar to that of vector 1474. Province 4 appears to be the southern-most region of a province which extends northward along the San Francisco beaches.

There is a very close relationship between the geographic occurrence of the supplying formation (Figure 2) and the location of the province. With the exception of province 1, the provinces are limited almost entirely to an area contiguous with their sources. The longshore spread is limited and in each case is more pronounced to the south (especially province 2). These provinces (other than province 1) undoubtedly represent Holocene erosion and deposition. Province 1, on the other hand, represents transport and deposition during the last regression and transgression of the Pleistocene and post-pleistocene. It is not contiguous with its source but has been transported considerable distances along the coast.

Supply, Transport and Deposition

The provinces exist as separate and discrete entities. The Holocene provinces are contiguous with their sources. Such a distribution may only arise under one of two conditions: 1) littoral transport occurs, but local supply is large and far outweighs sediment introduced by the former, resulting in a flooding out and complete masking of the latter,[1] or 2) transport is not significant and locally supplied detritus is locally deposited.

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[1] The condition of case 1 may appear to hold true when only relatively small amounts of local sediment are introduced if these sediments contain a much higher percentage of heavy minerals (on the order of 10 versus .01 per cent). Such is not the case here; the sands of province 2 and 3 have a heavy mineral content of about 5.8% versus 1.4% for provinces 1 and 4.

The first possibility hinges upon the existence of a large local supply of sand to the littoral transport system. Without this the existence of distinct provinces is impossible in the presence of net littoral transport. Sand may be supplied by streams, mass-wasting processes, and wave erosion. Inspection of the streams in the area studied has shown that the beach berms block them during most of the year. All but one of these are only open during brief periods following exceptionally heavy rains, perhaps for only a total of one month during the year. The one exception is Pilarcitos Creek which is open for longer periods but is closed during at least eight months of the year. None of these streams are large. The quantity of sand introduced by the streams is minor. Mass-wasting processes are active in the area north of Montara Beach but have little significance in the remainder of the area (except possibly at Pillar Point). Figure 6 provides ample evidence of the prominence of sliding and gullying in the Point San Pedro area. Slides have forced the closing of Highway 1 on numerous occasions during the rainy months of January, February, and March. Pillar Point is affected by slope wash and minor sliding. Wave erosion is difficult to evaluate directly and varies with the resistance of the rock. It is the only significant agent of supply in the Montara Beach and Half Moon Bay area. Provinces 2 and 3 are primarily products of wave erosion. Due to the equlibrium or near-equilibrium orientations of these areas, the present rate of supply is probably low.

The supply of sand to the littoral system from the areas other than Montara Beach and Half Moon Bay may be analyzed by its effect on the adjacent beach and nearshore deposits. If the supply from mass-wasting and wave erosion is significant, it should be strongly reflected in the composition of the adjacent beach and shallow water deposits. In the areas around Point San Pedro, Devils Slide and Pillar Point there is little or no masking of the pre-modern sands of province 1. The local contributions of sand in these areas are negligible despite the apparent activity of erosional processes.

Local supply of sand is very small; what significant addition there is arises from wave erosion of the poorly consolidated terraces. The hypothesis of transport masked by large local supply is untenable. The limited supply indicates that there must be no net, long-term littoral transport of sand in this area.

More detail of the dispersal pattern and hence long-term littoral transport may be obtained from the distribution of vector 1493 (Figure 18). The two areas of high proportions of vector 1493 reflect distribution of sand from two discrete sources: the terraces and granodiorite at Montara and the terraces at Half Moon Bay. The abrupt northern terminations and attenuated southern boundaries of these areas indicate that transport tends towards the south, but the two zones are not continuous and transport between them is not significant. On the basis of this distribution pattern and the refraction diagram (Figure 11) which indicates a strong southward component in the incident waves and resulting currents in the area south of Montara Beach, it is probable that the absence of transport in this area results primarily from a lack of sufficient supply of sand.

Origins

The lowering of sea level during the Wisconsin glaciation made extensive littoral transport possible by exposing the flat, featureless continental shelf off this position of the California coast. It caused sediments previously deposited in San Francisco Bay to be deposited directly on the coast. The river sediments were mixed with those being transported from the north in the littoral system and the resulting suite of heavy minerals is similar to that of vector 1412. This mixture was transported to the south and through the area presently under study throughout the period of regression and transgression. During this low stand of sea level, sand dunes formed on the flat coastal plain and are preserved in terraces in several local areas (Minard, 1964). The composition of the sands in the littoral transport system may have been altered slightly in the area studied by the addition of granodiorite material as the hornblende content of the sands in province 1 is generally slightly higher than that of samples collected north of this area (D. Moore; personal communication, 1965).

The retreat and advance of the shoreline and littoral zone spread the sands of province 1 over the entire area covered in this study. The deposits of this sand in depths less than approximately 60 feet are probably thin and discontinuous because present day headlands began to cut off the hitherto unrestricted littoral transport when sea level reached this point.

Continued rise cut off the supply of sand coming from the area to the north completely and initiated erosion of the formations exposed along the coast today. Erosion in the past as in the present was primarily by wave attack. The waves had little effect upon the well indurated formations but readily eroded the poorly consolidated terrace deposits. A complete lack of net littoral transport of sand since the establishment of the present sea level has been the major factor in the formation of several different provinces along the coast, while the older, pre-modern deposits throughout the area are relatively homogeneous due to unrestricted transport during the period of their deposition.

Changes Since the Pleistocene

The above presents a general picture of the manner in which the provinces originated and the role of littoral transport in determining the pattern occurring in the sedimentary record. There has, however, been at least one major change in supply that complicates the above picture and should be noted. Evidence of this change is found in the terrace deposits at the south end of Half Moon Bay.

The lower portion of the terrace at Miramontes Point is commonly cross-bedded on a small scale, well sorted, and composed largely of vector 1412 (samples 1554, 1557, 1559, 1560). The cross-bedding and occasional coarse layers indicate a nearshore environment of deposition. These beds are overlain by silty and clayey sands (sample 1558) which are cut by conglomeratic lenses (sample 1561) that are probably channel fillings. Toward the top of the terrace and to the north the conglomerate becomes predominant. The silty and clayey sands are a mixture of vectors 1493 and 1412. The channel fill is primarily granodioritic (vector 1493) in the sand fraction but also contains abundant pebbles of tuff, basalt and sedimentary rocks.

The presence of sands with a composition similar to vector 1412 in this location indicates conditions at the time of deposition completely unlike those found today. The influence of the Montara granodiorite which characterizes the area so strongly at present must have been absent. The channel fill which cuts into the silty and clayey sands probably represents the influx of the granodioritic material. From this period on the hornblende-rich assemblage gained ascendance as seen in the deposits that overlie the channel fill to the north. Here the beds rapidly became composed entirely of granodioritic material (sample 1551 is representative of the entire terrace exposure of this sample station). It is probable that the cutting of the channels into the silty sands represents, stratigraphically, the beginning of the uplift of Montara Mountain to its present position. Since this time sediments with a granodioritic suite of heavy minerals have predominated throughout most of the area on the shore and out to depths of less than 90 feet. Unfortunately the data available at present are not sufficient to correlate the terraces of Half Moon Bay with those at Montara

Beach or to place the uplift in its position in time relative to the Wisconsin regression and transgression. Further work with these terraces may well provide the data necessary for putting these events in proper order.

SUMMARY AND CONCLUSIONS

Wave refraction diagrams can be used to predict that little net, long-term littoral transport of sand occurs in the area studied. Both Montara Beach and Half Moon Bay represent stable equilibrium configurations and little transport of sand past these areas is expected. Lack of significant transport past Montara Beach precludes any movement of sand in the high energy area to the south through lack of supply of sand for transport. The absence of any build-up of sand at the north end of Montara Beach indicates that there is no appreciable quantity of sand being supplied from the area to the north. The refraction of waves in the Point San Pedro area as seen in aerial photographs is such that the point must act as a barrier to transport.

The field study has shown the distribution of sediments in this area to be characterized by three genetically different types of sand distributed into four sedimentary petrological provinces. Considerations of the dispersal patterns of locally derived sediment have shown that there is no net, long-term littoral transport of sand in this area. The conclusions of the general analysis based upon hydrodynamic considerations have been substantiated by the results of the field study and enumerated in some detail.

During the last lower stand of sea level, littoral sediment transport was unrestricted due to the straight, unobstructed character of the coastline. A homogeneous mixture of sand which blanketed the entire area resulted from the regression and transgression of the littoral zone across the the continental shelf. A complete change in the littoral transport and consequently dispersal pattern was produced by the rise in sea level to its present position. The irregularities of the present coastline effectively blocked any net littoral transport. Under these conditions locally derived sand predominated, and where supplied in sufficient quantities it blanketed the older deposits on a local scale. The net result of this has been the production of a series of Holocene deposits on the pre-modern sand of province 1 and, consequently, a coastal sedimentation pattern characterized by a series of provinces.

The limitation of recently derived sand particles to depths less than approximately 90 feet (the outer edge of the mixing zones) indicates that conditions of turbulence necessary for transport of sand do not exist at depths greater than 90 feet under the hydrodynamic conditions extant in this area. Grain-size data substantiate this approximation. This is on the basis of general conditions over a long period of time as it is predicated upon data from long-term sediment movement considerations. Turbulence from storm waves is undoubtedly not limited to such depths.

Littoral sediment transport plays a key role in producing a particular sediment dispersal pattern, and through its effect upon transport, coastal configuration does also. During the existence of a straight, sandy coastline in the area studied, distribution of sand along the coast was characterized by one relatively homogeneous assemblage (province 1) which reflected the mixing of two major sources. With the rise in sea level and resulting irregular, rocky coastline characterized by numerous promontories, an entirely different distribution pattern resulted. Under these conditions a pattern of varied assemblages was produced. The coastal sands at present reflect local sources and no mixing. Each type is generally of limited areal extent and occurrs contiguously with its source area. This basic change in sediment distribution pattern can be attributed primarily to changes in littoral transport patterns.

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APPENDIX I

Heavy Mineral Composition of
Terrace, Beach and Offshore Samples

Province 1

(New)	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1407	56	08	17	03	00	00	04	02	00	01	00	07	00	00	02	00	00	00
1410	54	09	15	01	01	00	08	04	01	01	00	04	01	01	00	00	00	00
1412	49	11	18	02	00	00	14	02	01	00	00	01	01	01	00	00	00	00
1414	57	10	15	00	01	02	05	01	02	01	00	04	00	01	01	00	00	00
1415	56	07	15	01	01	02	06	00	01	01	00	08	01	01	00	00	00	00
1416	55	07	19	03	00	01	07	02	01	00	00	05	00	00	00	00	00	00
1417	57	05	15	03	00	00	06	02	00	02	00	06	00	04	00	00	00	00
1420	56	08	13	01	01	00	05	03	01	04	00	07	00	00	00	00	00	01
1422	53	07	19	03	00	01	06	01	00	01	00	06	00	01	02	00	00	00
1424	56	09	15	05	00	00	07	03	01	00	00	03	01	00	00	00	00	00
1432	62	08	14	07	00	00	06	01	00	00	00	00	01	00	00	01	00	00
1433	61	06	16	04	00	02	06	03	00	00	00	01	01	00	00	00	00	00
1435	61	09	17	04	00	02	02	02	00	00	01	00	01	00	01	00	00	00
1436	59	07	16	04	00	00	05	02	01	01	00	04	00	00	01	00	00	00
1437	57	11	15	01	00	00	05	04	00	01	00	06	00	00	00	00	00	00
1438	49	09	18	00	10	04	05	01	02	00	01	00	00	01	00	00	00	00
1439	61	08	15	05	00	00	03	04	01	01	00	02	00	00	00	00	00	00
1440	59	12	15	03	01	02	01	00	01	01	01	04	00	00	00	00	00	00
1442	60	10	20	00	00	02	03	01	01	00	01	01	00	00	00	01	00	00
1444	56	12	16	01	00	03	02	02	01	01	00	04	01	00	01	00	00	00
1445	52	08	22	01	00	00	06	01	01	00	01	01	02	00	01	03	00	01
1447	49	08	19	04	00	05	04	02	01	01	01	03	01	00	01	00	00	00
1449	53	17	18	02	00	02	02	00	02	00	00	02	00	00	01	01	00	00
1450	53	09	15	07	00	00	06	03	03	00	00	00	00	01	01	02	00	00

Province 1 (Con't)

(New)	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1451	56	09	20	02	00	02	05	00	01	01	00	02	00	00	01	00	00	00
1452	58	08	13	03	00	05	06	03	00	00	00	02	01	00	01	00	00	00
1461	60	09	18	02	00	01	00	00	04	03	00	03	00	00	00	00	00	00
1462	61	12	17	02	00	02	04	00	00	00	00	00	01	00	00	00	00	01
1478	52	08	14	00	03	09	03	04	04	00	01	01	00	00	00	00	00	01
1479	50	08	22	02	03	03	03	03	04	00	00	00	00	00	00	00	00	02
1480	43	13	16	00	06	04	04	02	11	00	01	00	00	00	00	00	00	00
1482	51	09	13	01	00	03	04	04	03	00	06	01	00	00	04	00	00	01
1483	48	09	21	01	01	06	01	01	08	00	02	00	00	00	00	01	00	01
1484	56	08	15	00	01	06	04	03	02	00	03	00	00	00	01	01	00	00
1485	62	04	10	00	01	07	04	01	02	00	07	00	00	00	00	01	00	01
1510	45	07	08	00	29	01	02	05	01	00	02	00	00	00	00	00	00	00
1512	62	07	04	00	18	00	06	02	00	00	00	00	00	00	01	00	00	00
1513	52	07	14	00	13	01	03	07	02	00	01	00	00	00	00	00	00	00
1514	48	11	14	00	17	04	00	00	05	00	00	00	00	00	00	01	00	00
1515	39	03	04	00	44	03	02	01	01	00	01	02	00	00	00	00	00	00
1518	68	03	09	00	12	01	02	01	01	00	02	00	00	00	01	00	00	00
1570	44	10	10	01	27	05	02	00	00	00	00	00	00	00	00	01	00	00
1571	43	12	11	02	14	03	04	02	04	00	04	01	00	00	00	00	00	00
1572	54	04	10	04	07	05	03	03	03	00	04	01	00	00	01	01	00	00
1574	61	05	06	03	09	02	05	01	00	00	01	00	04	00	03	00	00	00

Samples inspected but not counted

1408	1413	1421	1434	1446	1511
1409	1418	1423	1441	1448	1516
1411	1419	1425	1443	1481	

Province 2

	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1428	86	01	05	01	00	02	01	01	00	01	00	00	00	00	00	00	00	00
1429	83	04	05	00	01	03	01	01	00	00	01	01	00	00	00	00	00	00
1486	91	04	01	00	00	02	01	00	00	00	00	01	00	00	00	00	00	00
1488	83	02	06	00	00	04	01	01	01	00	00	00	00	00	01	00	01	00
1489	90	01	00	00	00	00	07	00	01	00	00	01	00	00	00	00	00	00
1490	88	03	02	00	00	02	01	01	03	00	00	00	00	00	00	00	00	00
1492	69	04	06	00	00	13	00	03	02	00	03	00	00	00	00	00	00	00
1494	91	04	00	00	01	00	00	01	03	00	00	00	00	00	00	00	00	00
1495	84	04	04	00	00	01	01	05	01	00	00	00	00	00	00	00	00	00
1497	77	04	04	00	00	08	00	04	03	00	00	00	00	00	00	00	00	00
1498	81	05	03	00	00	00	04	00	01	02	04	00	00	00	00	00	00	00
1499	79	04	09	00	00	04	00	01	01	00	01	01	00	00	00	00	00	00

Samples inspected but not counted

1430
1487
1491

Province 3

	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1453	68	03	12	01	00	04	02	05	01	00	00	00	01	00	02	01	00	00
1454	74	01	09	01	00	02	04	02	01	00	00	01	01	00	03	00	00	01
1455	73	02	08	03	01	01	05	04	02	00	00	00	00	00	00	00	00	01
1456	77	02	04	00	00	06	05	03	00	00	02	00	00	00	01	00	00	00
1457	73	04	04	01	05	04	01	02	04	00	00	00	00	00	00	02	00	00
1458	81	00	05	02	00	03	05	01	00	00	01	00	00	00	00	02	00	00
1459	77	07	04	02	00	04	04	01	00	00	00	00	01	00	00	00	00	00
1463	83	03	04	00	00	00	03	02	00	00	01	01	01	00	01	00	00	01
1464	79	03	04	01	02	04	04	02	00	00	00	00	00	00	00	01	00	00
1465	73	06	05	02	01	03	06	02	01	00	00	01	00	00	00	00	00	00
1466	81	04	03	02	02	01	03	02	00	00	00	00	01	00	00	01	00	00
1467	77	03	08	06	00	00	03	01	00	00	01	00	00	00	00	01	00	00
1468	84	01	06	03	00	00	02	02	00	00	00	00	00	00	02	00	00	00
1469	93	01	01	00	00	01	01	01	00	00	01	00	00	00	01	00	00	00
1470	82	01	04	03	00	00	03	03	01	03	00	00	00	00	00	00	00	00
1519	75	08	10	00	01	01	01	00	01	00	01	01	00	00	01	00	00	00
1520	57	02	04	00	00	04	01	05	00	01	22	01	00	00	00	03	00	00
1521	63	02	04	00	00	03	00	05	00	01	20	00	00	00	02	00	00	00
1522	29	02	03	00	00	07	01	02	03	01	51	00	00	00	01	00	00	00
1523	81	04	07	00	01	01	01	02	00	00	02	00	00	00	01	00	00	00
1524	66	07	04	00	00	06	01	03	01	01	08	01	00	00	02	00	00	00
1525	64	09	08	00	00	12	01	02	01	02	01	00	00	00	00	00	00	00
1527	74	05	07	00	01	08	02	01	01	00	01	00	00	00	00	00	00	00

Province 3 (Con't)

	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1529	74	06	09	00	01	06	00	01	02	01	00	00	00	00	00	00	00	00
1531	79	04	04	00	03	07	00	02	00	00	01	00	00	00	00	00	00	00
1534	77	06	04	01	02	03	01	03	02	01	00	00	00	00	00	00	00	00
1535	72	04	06	00	00	09	01	04	00	00	04	00	00	00	00	00	00	00
1536	75	03	08	01	01	09	00	01	00	00	02	00	00	00	00	00	00	00
1537	67	04	06	01	00	09	00	06	01	02	02	00	00	00	01	01	00	00
1538	76	04	07	00	00	10	00	00	00	00	00	00	00	00	01	02	00	00
1539	67	07	07	00	00	13	00	00	03	01	01	00	00	00	00	01	00	00
1540	76	06	07	00	02	03	00	03	00	00	02	00	01	00	00	00	00	00
1542	83	03	07	01	01	03	01	00	00	00	00	01	00	00	00	00	00	00
1568	78	04	11	00	01	00	04	01	00	00	00	00	00	00	00	01	00	00
1578	71	04	11	03	03	02	00	02	02	00	00	00	00	00	00	02	00	00

Samples inspected but not counted

1526
1528
1530
1533
1541
1579

Province 4

	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1400	46	22	14	00	00	08	01	05	01	01	01	01	00	00	00	00	00	00
1471	49	26	16	01	00	02	00	02	02	01	00	00	00	00	00	00	01	00
1472	45	26	21	00	00	05	00	02	01	00	00	00	00	00	00	00	00	00
1473	36	28	27	00	00	07	00	01	01	00	00	00	00	00	00	00	00	00
1474	45	28	14	00	00	02	02	03	03	02	01	00	00	00	00	00	00	00
1476	45	27	18	02	00	02	00	03	01	00	00	00	00	00	00	02	00	00
1477	44	24	20	00	00	05	04	01	01	00	00	00	00	00	00	00	01	00

Samples inspected but not counted

1475

Mixing Zone Provinces 1 and 2

	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1426	70	04	12	02	01	01	03	03	00	01	00	03	00	00	00	00	00	00
1427	66	09	11	03	00	02	03	03	01	00	00	01	01	00	00	00	00	00
1431	58	08	12	06	00	02	06	01	02	00	00	01	00	00	00	02	00	00
1503	63	04	06	00	00	06	01	06	05	00	08	00	00	00	00	01	00	00
1504	72	05	07	00	01	04	00	03	01	01	06	00	00	00	00	00	00	00
1505	58	09	11	00	06	04	03	02	04	00	03	00	00	00	00	00	00	00
1506	72	03	09	01	08	01	02	03	00	00	01	00	00	00	00	00	00	00
1508	66	06	13	00	02	06	00	04	00	00	03	00	00	00	00	00	00	00
1509	63	03	01	00	23	01	03	03	00	02	01	00	00	00	00	00	00	00

Samples inspected but not counted

1507

Mixing Zone Provinces 1 and 3

	Hornblende	Hypersthene	Augite	Oxihornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1460	68	08	15	01	00	04	02	00	00	00	01	00	00	00	01	00	00	00
1517	57	05	09	01	12	05	05	00	02	00	04	00	00	00	00	00	00	00
1569	43	14	20	02	08	05	02	03	02	00	00	00	00	00	01	00	00	00
1573	58	03	12	03	07	03	06	02	02	01	01	00	00	00	01	01	00	00
1574	61	05	06	03	09	02	05	01	00	00	01	00	04	00	00	03	00	00
1575	55	05	09	00	19	04	03	00	01	00	02	00	00	00	00	02	00	00
1576	57	09	13	02	08	04	02	01	00	00	02	01	01	00	00	00	00	00
1577	72	05	12	00	03	02	01	01	00	00	02	00	00	00	00	02	00	00

Samples inspected but not counted

1516

Mixing Zone Provinces 1 and 4

	Hornblende	Hypersthene	Augite	Oxihornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1401	54	16	11	00	00	01	09	01	01	00	01	01	02	00	00	01	00	02
1402	61	12	12	01	02	01	02	03	00	00	00	01	03	00	00	00	00	02
1403	60	07	14	03	01	01	08	02	01	00	00	01	01	00	01	00	00	00
1404	47	20	17	02	00	01	06	03	00	00	00	02	01	00	00	00	00	01
1405	55	16	11	03	01	03	05	02	01	01	00	02	00	00	00	00	00	00
1406	52	16	12	01	00	01	07	02	01	04	01	01	01	00	01	00	00	00

Terrace and Stream Samples

	Hornblende	Hypersthene	Augite	Oxyhornblende	Carbonate	Sphene	Tremolite Actinolite	Epidote	Garnet	Zoisite	Zircon	Enstatite	Glaucophane	Lawsonite	Apatite	Clinozoisite	Andalusite	Indeterminate
1493	93	00	00	00	00	02	01	01	00	01	02	00	00	00	00	00	00	00
1500	83	00	02	00	00	00	04	04	00	00	07	00	00	00	00	00	00	00
1501	68	04	02	00	00	11	03	04	04	01	03	00	00	00	00	00	00	00
1502	57	09	22	00	00	08	02	01	01	00	00	00	00	00	00	00	00	00
1543	50	11	21	00	00	08	01	02	03	00	01	03	00	00	00	00	00	00
1544	76	02	02	00	00	10	02	04	02	00	02	00	00	00	00	00	00	00
1545	74	02	02	00	00	14	00	04	02	00	02	00	00	00	00	00	00	00
1547	32	04	11	00	00	16	00	07	04	04	07	00	02	02	07	03	00	01
1548	68	04	04	00	19	01	03	00	01	00	00	00	00	00	00	00	00	00
1551	86	01	05	00	00	01	03	00	00	00	00	00	00	00	04	00	00	00
1554	61	08	16	03	00	00	05	02	00	00	00	00	01	00	02	01	01	00
1555	54	12	15	03	00	02	09	03	00	00	00	00	00	00	00	01	01	00
1556	64	05	19	01	00	02	08	01	00	00	00	00	00	00	00	00	00	00
1557	59	10	17	01	00	04	06	03	00	00	00	00	00	00	00	00	00	00
1558	65	07	14	02	00	03	04	02	00	00	01	00	01	00	01	00	00	00
1559	55	15	19	00	00	03	05	01	01	00	00	00	00	00	00	01	00	00
1560	56	05	22	00	00	06	05	03	00	00	02	00	00	00	00	01	00	00
1561	58	01	05	00	00	09	02	02	02	00	15	00	01	00	02	01	00	02
1563*	68	05	13	00	00	07	01	02	01	00	01	00	00	00	02	00	00	00
1564*	93	01	04	00	00	00	00	01	00	00	00	00	00	00	00	01	00	00
1565*	98	00	01	00	00	01	00	00	00	00	00	00	00	00	00	00	00	00
1566*	87	02	03	00	00	02	01	01	02	00	02	00	00	00	00	00	00	00
1567*	70	04	05	00	00	03	05	03	03	00	06	00	01	00	00	00	00	00

Samples inspected but not counted

*Stream samples

1496	1546	1550	1553
1506	1549	1552	1562

APPENDIX II

Vector Analysis of Terrace,
Beach and Offshore Samples

PROVINCE 1

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1407	.77687	.23279	-.00774	-.03206	.08471	-.04248
1410	.73159	.23655	.02102	-.01466	.03582	.01886
1412	1.00000	.00000	.00000	.00000	.00000	.00000
1414	.54798	.29090	.02023	-.03992	.11432	.10071
1415	.71065	.28499	.01782	-.03481	.10141	-.06028
1416	.91360	.13951	-.00447	-.03663	.12654	.12997
1417	.79590	.32994	-.00608	-.02429	.06263	-.14998
1420	.60912	.35736	.01780	-.01802	.03322	.02722
1422	.93527	.11355	-.00740	-.04047	.13871	-.13597
1424	.72482	.27602	-.00381	-.01610	.02604	.01453
1432	.62031	.40490	-.00420	-.01916	.01234	.00485
1433	.67532	.34533	-.00341	-.04049	.12779	-.08633
1435	.55028	.31405	-.00487	-.03418	.14839	.05709
1436	.72748	.31320	-.00501	-.02940	.07320	-.06189
1437	.60573	.28873	-.00470	-.01965	.03108	.12382
1438	.63872	-.02737	.24716	-.04474	.23543	.03691
1439	.58668	.37651	-.00444	-.03158	.07345	.02183
1440	.43090	.31864	.01625	.02575	.09627	.20574
1442	.63561	.19656	-.00258	-.03989	.17987	.05886
1444	.46750	.25386	-.00452	-.05439	.16619	.19913
1445	.98468	-.00223	-.00351	-.02543	.16356	-.10747
1447	.78430	.03888	-.00578	-.05146	.30141	-.04703
1449	.46737	.10023	-.00355	.04846	.12235	.38358
1450	.71571	.23693	-.00210	-.02301	.06533	.02603
1451	.78024	.13169	-.00419	-.05413	.17750	-.01739
1452	.47510	.38561	-.00281	-.05015	.17622	.04290
1461	.56836	.27948	-.00344	-.05826	.17137	.05991
1462	.51450	.29008	-.00323	-.04419	.10402	.16556
1478	.30499	.24605	.07485	-.07798	.40779	.09848
1479	.83170	-.05832	.07131	-.08085	.32058	-.06231
1480	.44313	-.09307	.17196	-.04691	.28924	.29566
1482	.46018	.26220	-.00093	.08274	.16759	.11393
1483	.63808	-.06102	.02791	-.06694	.44951	.03752
1484	.43042	.28527	.02302	-.01354	.27546	.06058
1485	.26873	.52934	.02220	.06439	.21830	-.02210
1510	.15399	.09420	.71058	.02350	.00349	.12995
1512	.12599	.56635	.37103	.00231	-.10506	.13484
1513	.48151	.17048	.31026	-.02001	.13136	.02849
1514	.23858	.04365	.42270	-.07146	.21844	.25265
1515	.00000	.00000	1.00000	.00000	.00000	.00000
1518	.27885	.56888	.23052	-.00071	.04875	-.04169
1570	.10622	.00790	.67315	-.05089	.12118	.24374
1571	.29514	.01768	.38775	.06438	.07377	.31403
1572	.36210	.39741	.16665	.02562	.20455	-.05505

Samples inspected but not run on vector analysis

1408	1413	1421	1434	1446	1511
1409	1418	1423	1441	1448	
1411	1419	1425	1443	1481	

PROVINCE 2

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1428	.13393	.87668	-.00085	-.03449	.05477	-.03011
1429	.07809	.84034	.01539	.00000	.04900	.05845
1486	-.01992	.96110	-.00023	-.02416	-.01276	.09536
1488	.11218	.83767	-.00008	-.04732	.10891	-.00706
1489	.12386	.96929	.00164	.00363	-.07780	-.02196
1490	.00678	.93599	.00177	-.02491	.02281	.06306
1492	-.10992	.73458	.00167	-.04845	.36198	.08975
1494	-.04924	.97935	.01637	-.01820	-.03836	.11237
1495	.06613	.87669	.00053	-.02618	.02028	.07019
1497	-.07874	.84642	.00226	-.06525	.20633	.09830
1498	.10451	.86140	.00034	.04895	-.06821	.08740
1499	.17010	.73445	-.00093	-.03834	.13060	.02346

Samples inspected but not run on vector analysis

1430
1487
1491

PROVINCE 3

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1453	.35808	.58304	-.00119	-.06113	.21210	-.07568
1454	.36009	.71172	-.00128	-.03883	.09988	-.12549
1455	.35325	.71100	.01857	.02539	.04743	-.08946
1456	.09755	.83449	.00092	-.01149	.11223	-.01420
1457	.01428	.79463	.09386	-.04318	.10132	.07637
1458	.22741	.84221	.00000	-.01534	.04994	-.09888
1459	.05393	.81892	-.00021	-.02860	.02877	.14384
1463	.15308	.87058	-.00069	-.00253	-.02601	.01629
1464	.10112	.83801	.03428	-.03303	.05840	.01866
1465	.16980	.76057	.01882	-.02123	.01557	.08014
1466	.09616	.87105	.03268	-.01725	-.02429	.05790
1467	.33809	.73977	-.00284	-.00574	-.00456	-.05116
1468	.23767	.84154	-.00193	-.02517	.01322	-.06584
1469	.02872	.97803	-.00019	-.01051	-.01113	.01313
1470	.19475	.87821	-.00089	-.01782	-.00775	-.04748
1519	.21987	.65382	.01617	-.01934	.03978	.12431
1520	.09662	.61908	-.00135	.39361	.04102	-.00527
1521	.07623	.69046	-.00203	.32604	.03094	.00754
1522	.00000	.00000	.00000	1.00000	.00000	.00000
1523	.16699	.78415	.01538	-.00243	.03097	.03361
1524	-.05885	.74039	-.00054	.09382	.11230	.19312
1525	-.09241	.61710	.00029	-.07589	.33774	.24340
1527	.04984	.73357	.01858	-.04939	.19729	.07836
1529	.09501	.68566	.01817	-.04851	.18286	.09862
1531	-.05475	.83714	.05062	-.04184	.14601	.09202
1534	.00754	.82544	.03539	-.03407	.05261	.13868
1535	-.00399	.75359	.00008	-.00543	.22793	.06879
1536	.06954	.72882	.01661	-.04630	.24523	.01362
1537	-.02521	.73757	-.00020	-.04307	.28308	.07600
1538	-.00497	.76880	-.00047	-.08095	.26307	.06249
1539	-.13081	.68283	.00195	-.08437	.36551	.18651
1540	.08424	.74518	.03401	-.01061	.07569	.11332
1542	.16249	.80090	.01468	.04113	.07205	.00239
1568	.37393	.66371	.01617	-.02812	.03086	-.03791
1578	.30469	.61484	.05454	-.04981	.12466	-.01837

Samples inspected but not run on vector analysis

1526	1533
1528	1541
1530	1579

PROVINCE 4

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1400	-.02960	.06775	-.00140	-.05355	.26562	.77164
1471	.09543	.04430	-.00235	-.03714	.05049	.85159
1472	.23592	-.20789	-.00325	-.07212	.22016	.80327
1473	.43032	-.64164	-.00473	-.10238	37273	.83640
1474	.00000	.00000	.00000	00000	.00000	1.00000
1476	.18167	-.11326	-.00363	-.03911	.07114	.88528
1477	.35756	-.20926	-.00185	-.05961	.18603	.71167

Samples inspected but not run on vector analysis

1475

MIXING ZONE

PROVINCES 1 and 2

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1426	.45219	.57827	01552	-.03498	.07762	-.06733
1427	.31647	.54716	-.00193	-.03427	.06941	.13277
1431	.52789	.41917	-.00187	-.02787	.06673	.04042
1503	.04675	.67331	.00390	.08735	.20172	.06493
1504	.08776	.71741	.17850	.05020	.10621	.08594
1505	.23909	.39752	.13583	.00754	.14718	.16900
1506	.28272	.63587	.14570	-.01699	.05024	-.03849
1508	.25038	.49793	.03772	-.02224	.24347	.04953
1509	-.01730	.65165	.45982	.00971	-.06571	.05617

Samples inspected but not run on vector analysis

1507

MIXING ZONE

PROVINCES 1 and 3

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1460	.38168	.46136	-.00273	-.04365	.17025	.06449
1517	.27589	.40860	.27123	.03234	.12540	.00716
1569	.56977	-.23948	.20991	-.08612	.32552	.27538
1573	.54221	.39401	.15574	-.02386	.14537	-.14714
1574	-.24842	.60083	.19196	.00075	-.00066	.03297
1575	.22055	.33933	.43062	-.00673	.11149	.02528
1576	.34319	.31455	.17604	-.01492	.14323	.13106
1577	.31639	.58277	.05333	-.01441	.10376	.00652

MIXING ZONE

PROVINCES 1 and 4

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1401	.36736	.32281	.00064	.02107	-.06624	.39512
1402	.29463	.44354	.03924	-.03066	.04159	.25654
1403	.64450	.37000	.01981	-.02394	.05750	-.03921
1404	.52506	-.02414	-.00378	-.01646	.00971	.52100
1405	.24936	.34613	.02078	-.02361	.02796	.42243
1406	.37312	.27123	.00000	.01293	-.02351	.40967

TERRACE AND STREAM SAMPLES

Sample Number	Vector 1412	Vector 1493	Vector 1515	Vector 1522	Vector 1547	Vector 1474
1493	.00000	1.0000	.00000	.00000	.00000	.00000
1500	.14735	.90382	.00046	.08928	-.04926	-.05403
1501	-.15782	.82747	.00447	-.02072	.26265	.11417
1502	.58141	.09926	-.00231	-.10797	.41453	.02299
1543	.55854	-.01988	-.00213	-.09139	.44739	.12239
1544	-.10580	.88563	.00257	-.03564	.22211	.04598
1545	-.22298	.87819	.00249	-.06152	.34612	.07221
1547	.00000	.00000	.00000	.00000	1.00000	.00000
1548	.08479	.64111	.36111	-.01981	-.03576	.05134
1551	.18303	.86964	-.00100	-.02849	.02529	-.05083
1554	.63664	.34548	-.00370	-.03205	.07426	.00102
1555	.61891	.21952	-.00133	-.02125	.05575	.15483
1556	.77476	.29245	-.00167	-.04569	.14999	-.15899
1557	.55513	.26153	-.00154	-.05356	.18300	.08201
1558	.45490	.45695	-.00253	-.03040	.13666	.01709
1559	.54252	.10630	-.00124	-.05154	.15710	.27075
1560	.79871	.08762	-.00228	-.05114	.36468	-.17806
1561	.05414	.64261	.00071	.21917	.24743	-.05353
1563*	.26806	.53943	-.00124	-.06414	.28002	.00411
1564*	.10769	.92334	-.00060	-.02659	.00206	-.01091
1565*	.02546	.99670	-.00024	-.02632	-.00439	-.00365
1566*	.05344	.91133	.00095	-.00356	.02708	.02322
1567*	.16297	.74630	.00266	.07387	.04161	.03225

Samples inspected but not run on vector analysis

1496
1506
1546
1549
1550
1552
1553
1562

*Stream samples

APPENDIX III

Grain-size Distribution of
terrace, beach and offshore samples

Province 1

Sample	Median (ϕ)	Mean (ϕ)	Standard Deviation	Modes (frequency) (ϕ)
1407	3.1216	3.1340	.30165	3.00(126.888)
1410	3.3446	3.3220	.30988	3.50(122.861)
1412	3.3823	3.3458	.32860	3.50(127.882)
1414	3.3413	3.3030	.35090	3.25(130.777)
1415	3.3962	3.3679	.32207	3.50(142.641)
1417	3.2462	3.2443	.41123	3.25(100.988)
1421	3.2322	3.2408	.39084	3.00(103.403)
1422	3.2295	3.2325	.38365	3.00(88.556)
1423	3.1891	3.1798	.38427	3.25(116.866)
1424	3.0608	3.0727	.26755	3.00(142.088)
1425	3.0652	3.0495	.30509	3.00(117.737)
1432	3.0755	3.0737	.41011	3.00(122.542)
1433	3.1493	3.1276	.29681	3.25(131.720)
1435	3.1120	3.1153	.31464	3.00(139.209)
1437	2.9713	2.9276	.36778	3.00(111.782)
1438	1.3999	1.4603	.42408	.50(5.157); 1.25(122.564)
1439	2.9885	2.9285	.46263	1.25(5.550); 3.00(116.225)
1440	2.6141	2.4468	.89821	1.25(27.362); 2.25(32.175); 3.25(55.483)
1441	2.3466	2.4037	.60106	2.25(79.357); 3.25(43.456)
1443	2.0724	2.1151	.49950	2.00(93.674)
1444	2.1243	2.1027	.57586	2.25(78.994)
1445	3.1493	3.0718	.52735	3.25(75.111)
1447	2.9313	2.9421	.27679	3.00(128.142)
1449	2.6383	2.6641	.46551	2.50(101.856)
1451	2.7789	2.6878	.69197	1.25(11.075); 2.75(85.350)
1452	2.7769	2.4582	.93066	.50(13.007); 1.25(12.557); 3.00(74.339)
1461	2.8469	2.6878	.57120	1.25(8.490); 3.00(93.745)
1462	1.8736	1.9331	.87713	.25(11.147); 1.50(50.758)
1478	1.4501	1.4658	.45996	1.50(89.268)
1479	1.4633	1.4671	.43157	1.50(99.621)
1480	.99223	.98536	.52086	.75(69.198); 1.25(71.589)
1481	1.0433	.89777	.68696	-.25(20.820); 1.25(81.509)
1482	.47200	.54999	.61980	0.0(60.580)
1483	.65441	.69375	.59916	.756(79.689)
1484	.34536	.38842	.49929	.25(98.717)
1485	.66846	.74939	.48202	.50(119.708)
1510	.67270	.71245	.55347	.75(91.168)
1511	1.4252	1.3794	.74891	.75(41.704); 1.75(48.931)
1512	.72885	.86605	.66434	.50(76.934); 1.25(65.717)

Province 1 (Con't)

Sample	Median (ϕ)	Mean (ϕ)	Standard Deviation	Modes (frequency) (ϕ)
1513	.73986	.84115	.63402	.50(77.589)
1514	.92977	.97439	.34666	1.00(140.007)
1515	.66917	.70330	.38812	.75(134.678)
1516	.08454	.11192	.30628	-1.00(5.976); 0.0(156.957)
1518	.60421	.56965	.39369	.75(131.720)
1570	1.4531	1.4956	.46918	1.50(94.073)
1571*	.773			
1572*	2.00			

*Samples analyzed by sieve techniques

Samples not analyzed

1408		
1409	1420	1448
1411	1434	1474
1413	1436	1574
1416	1442	
1418	1446	

Province 2

Sample	Median (ϕ)	Mean (ϕ)	Standard Deviation	Modes (frequency) (ϕ)
1428	2.0984	2.1526	.46153	2.00(93.458)
1429	2.0305	2.0307	.44130	2.00(88.590)
1430	2.1340	2.1728	.38445	2.00(107.464)
1486	1.0945	1.0816	.50399	1.00(75.218)
1487	.43697	.52242	55709	.50(93.930)
1488	.71684	.74865	.50530	.75(72.093)
1489	1.3035	1.4573	1.2232	.25(32.630); 1.25(28.820); 2.50(22.753)
1490	.68258	.69275	.50901	.75(85.261)
1491	.65082	.65540	.47120	.75(86.831)
1492	.86566	.86286	.51553	.75(81.437)
1494	.89954	.90754	.51048	.75(91.281)
1495	.71964	.76972	.46078	.75(120.036)
1497	.69939	.79386	.41323	75(106.114)
1498	.23997	23628	.45628	.25(92.870)
1499	.53239	.49466	.41927	.50(124.350)

Province 3

Sample	Median (φ)	Mean (φ)	Standard Deviation	Modes (frequency) (φ)
1453	2.4870	2.3648	.79882	2.25(48.324); 3.00(52.052)
1454	2.8614	2.8739	.47318	2.50(74.596)
1455	3.0114	3.0164	.45817	2.75 (91.771)
1456	3.0625	3.0419	.34568	3.00(112.370)
1457	1.8581	2.0360	.75746	1.50(70.272); 3.00(30.435)
1459	1.6317	1.8618	.80756	1.25(74.176); 3.00(32.804)
1463	2.5518	2.3852	.96800	1.50(38.605); 3.25(48.062)
1464	1.9071	1.9406	.55528	1.75(78.474)
1465	2.6237	2.5954	.62272	2.00(51.104); 3.00(55.083)
1466	3.1150	3.0483	.51870	3.25(88.491)
1467	2.9790	2.8585	.62325	3.25(82.793)
1468	2.7732	2.5864	.81288	2.25(39.464); 3.25(60.747)
1469	.23401	.20061	.61830	-.25(93.653); 1.25(19.008)
1470	3.1378	3.0194	.59442	3.50(81.053)
1519	2.3942	2.2779	.60273	1.75(37.118); 2.50(95.694)
1520	.93872	.97978	.94622	-.25(31.763); 1.00(44.183); 2.50(17.129)
1521	.44062	.51048	.67628	.50(71.133)
1522	1.9216	1.8723	.60160	2.25(63.014)
1523	1.4864	1.5881	.68035	1.50(76.667)
1524	.91694	1.0457	.72937	.75(70.070)
1525	.83566	.85258	.6200	.75(65.390)
1526	.85460	.89275	.61460	.75(71.109)
1527	1.2101	1.2403	.47920	1.25(91.822)
1528	1.0365	1.0905	.51441	1.00(84.825)
1529	1.2794	1.2513	.45170	1.25(83.743)
1530	1.2463	1.2146	.52825	1.25(80.242)
1531	1.3388	1.3433	.41571	1.25(97.018)
1533	1.1105	1.1923	.80805	1.25(86.850); 3.25(11.209)
1534	1.9667	1.9692	.40129	2.00(117.725)
1535	2.0170	2.0113	.37063	2.00(100.584)
1536	1.7772	1.7468	.57731	1.75(73.313)
1537	1.8096	1.8105	.42887	1.50(80.908); 2.00(82.897)
1538	1.5179	1.4894	.60966	1.50(60.167); 2.00(58.811)
1539	1.8236	1.7832	.48972	2.00(89.055)
1540	2.1289	2.1341	.35215	2.00(120.203)
1541	2.1776	2.1076	.55513	2.50(77.188)
1542	1.8512	1.7722	.59123	2.00(74.529)
1568*	3.00			
1578*	1.14			

*Samples analyzed by sieve techniques

Samples not analyzed

1458

1579

Province 4

Sample	Median (ϕ)	Mean (ϕ)	Standard Deviation	Modes (frequency) (ϕ)
1471	1.3128	1.0326	.88444	-.50(22.139); 0.0(23.681); 1.50(72.484)
1472	-.15792	.01891	.62842	-.25(93.034); 1.50(13.550)
1473	.66666	.61413	.74915	0.0(37.621); 1.00(49.136)
1474	.62270	.65044	.73050	.50(44.079); 1.25(46.766)
1475	1.7690	1.7934	.32220	1.75(139.911)
1476	1.5478	1.2832	.83782	-.25(17.234); 25(18.645); 1.75(82.491)
1477	1.5964	1.3699	.82864	.50(22.009); 1.75(67.022)

Samples not analyzed

1400

Mixing Zone 1-2

Sample	Median (ϕ)	Mean (ϕ)	Standard Deviation	Modes (frequency) (ϕ)
1426	3.0910	3.0737	.45157	3.00(97.640)
1427	2.9247	2.9044	.36196	3.00(97.395)
1503	1.3265	1.3417	.33722	1.25(141.494)
1504	.56746	.61231	.53624	.50(106.136)
1505	.37500	.31056	.51615	.25(88.819)
1506	.19756	.24078	.33225	.25(126.993)
1508	1.2411	1.2173	.45188	0.0(8.860); 1.25(117.792)
1509	.78475	.79642	.58600	0.0(40.057); .75(92.565)

Samples not analyzed

1431
1507

Mixing Zone 1-3

Sample	Median (Φ)	Mean (Φ)	Standard Deviation	Modes (frequency) (Φ)
1516	.08454	.11192	.30628	-1.00(5.976); 0.0(156.957)
1569	.98889	1.0120	.38583	1.00(129.774)
1573*	2.00			
1574*	.887			
1575*	.486			
1576*	1.62			
1577*	2.17			

*Samples analyzed by sieve techniques

Samples not analyzed

1517
1460

Mixing Zone 1-4

1401	2.7641	2.7855	.40148	2.75(100.616)
1402	2.8220	2.7974	.33562	2.75(137.276)
1403	3.0257	3.0235	.32185	3.00(110.188)
1404	3.0248	3.0312	.28660	3.00(119.973)
1405	3.0989	3.0758	.24586	3.00(141.775)

Samples not analyzed

1406

Terrace and Stream Samples

Sample	Median (φ)	Mean (φ)	Standard Deviation	Modes (frequency) (φ)
1493	1.0587	1.2711	1.1222	.25(38.335); 1.00(36.072); 3.75(12.815)
1496	1.0286	1.3133	1.1648	.50(41.804); 2.50(19.373)
1500	1.5725	1.6821	1.1867	.50(37.010); 3.00(27.178)
1501	2.0137	2.1554	.65922	1.75(91.533); 3.50(13.648)
1502	1.8158	1.8341	.43816	1.75(97.332)
1506	.19768	.24078	.33225	.25(126.993)
1543	1.8351	1.8544	.41265	1.75(96.461)
1544	1.9261	2.0438	.72330	1.75(71.819)
1545	1.9477	1.9737	.42185	2.00(104.998)
1546	1.4707	1.5631	1.1253	.25(35.255); 1.50(33.296); 3.25(17.184)
1548	1.5657	1.5580	.56308	1.25(66.561); 175(63.912)
1549	1.5592	1.6422	1.0777	.25(27.388); .75(28.168); 1.50(36.975); 2.50(25.232)
1552	.72282	.88731	.83288	.50(54.644)
1554	2.3536	2.3845	.29762	2.25(142.151)
1555	2.3472	2.3749	.29125	2.25(146.389)
1556	2.3731	2.3799	.32068	2.25(137.821)

Samples not analyzed

1542
1547
1550
1551
1553
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567