A PEBBLE-COBBLE DEPOSIT IN MONTEREY BAY, CALIFORNIA

by

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United States
Naval Postgraduate School

THESIS

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Lieutenant (Junior Grade), United States Navy
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ABSTRACT

A deposit of pebbles and cobbles was discovered in approximately 60 fm of water on the continental shelf in Monterey Bay, California. Samples were taken in the area and the extent of the deposit was determined. The material was characterized as well rounded, moderately well sorted coarse pebbles derived mainly from the granites of the Santa Lucia Formation with lesser amounts of alluvium from the Salinas Drainage Basin which flows into Monterey Bay. It was established that the deposit probably represents a marine terrace of Pleistocene Age, indicating a relative lowering of sea level of about 330 to 360 ft. This appears to be the first reported evidence of submerged marine terraces in Northern California.

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ACKNOWLEDGEMENTS

The author wishes to express his sincere appreciation to all those individuals and groups whose generous assistance aided in the completion of this report. Special thanks are due to my advisor, Professor Robert S. Andrews, for his patience, guidance, and time, especially the petrographic analysis; to my wife, Pat, who typed several drafts of this report and supplied invaluable moral support; to the technicians of the Department of Oceanography, especially Wendall Ayers, who helped in so many ways; and to Gary Greene, U. S. Geological Survey, Marine Geology Division, Menlo Park, California, for discussions concerning seismic and bathymetric profiles in Monterey Bay and their interpretation.

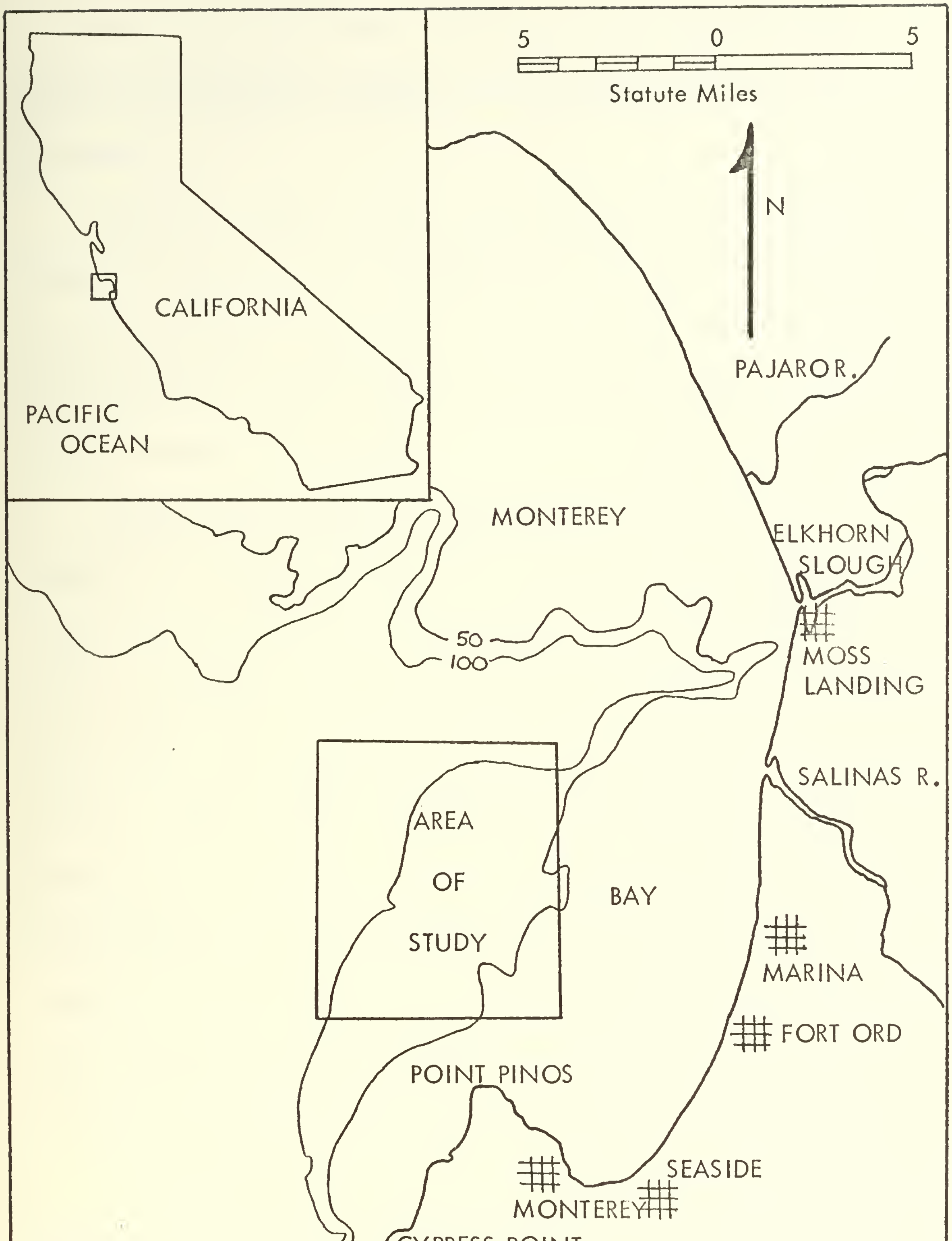
I. INTRODUCTION

A. PURPOSE

The purpose of this study was to investigate the occurrence of pebbles and cobbles discovered in significant quantities (J. Geary, personal communication) on the outer edge of the continental shelf in southern Monterey Bay, California (Fig. 1). Since this portion of the continental shelf is characterized generally by green sand and silt, the occurrence of these large particles, collectively referred to as the pebble-cobble deposit for the remainder of this report, can be considered anomalous. The approach of the study was to attempt to establish the possibility that this deposit represents an ancient marine terrace. Bathymetric profiles were recorded, bottom samples were collected, and the texture, lithology, and distribution of the deposit were determined.

B. PREVIOUS WORK

Galliher (1932) studied the general nature of the sedimentary cover on the continental shelf in Monterey Bay and reported a wide band of gravel (particle diameters of 2-10 mm) with a few pebbles (particle diameters greater than 10 mm) over the area of the present study. However, the largest pebbles according to histograms included in his report were less than 14 mm in size, corresponding to a maximum size of approximately -4 Ø and comparing in size to only the smaller material



Adapted by Dorman (1968)

Figure 1. Monterey Bay Area

reported in the present study. Galliher concluded that the coarse material represented a reworked alluvial deposit from the Salinas Drainage Basin.

Monteath (1965) reported on the depositional environments of the bottom sediments on the continental shelf in southern Monterey Bay. His results differed significantly from Galliher's in that he found that the wide band of gravel did not exist, but rather that the area contained silty sand with a few pebbles.

Yancey (1968) described the sediment cover in Monterey Bay, primarily the northern half, and reported sediment types aligned in bands approximately parallel to the submarine contours. The outermost band, on the edge of the continental shelf, consisted predominantly of coarse sand, including some cobbles. Yancey concluded that this band is a "relict deposit" of Pleistocene Age and based his estimate of the age on two factors. The first was the discovery, in a sample containing coarse sand, of shallow water gastropods which could have been found during the Pleistocene, and a cold water Pleistocene gastropod. The second factor was his assumption that coarse sediments are not being accumulated in this area under present conditions.

This paper apparently presents the first report of a significant pebble-cobble deposit in this area and it is the first report on the nature of the material comprising the deposit.

II. DESCRIPTION OF AREA

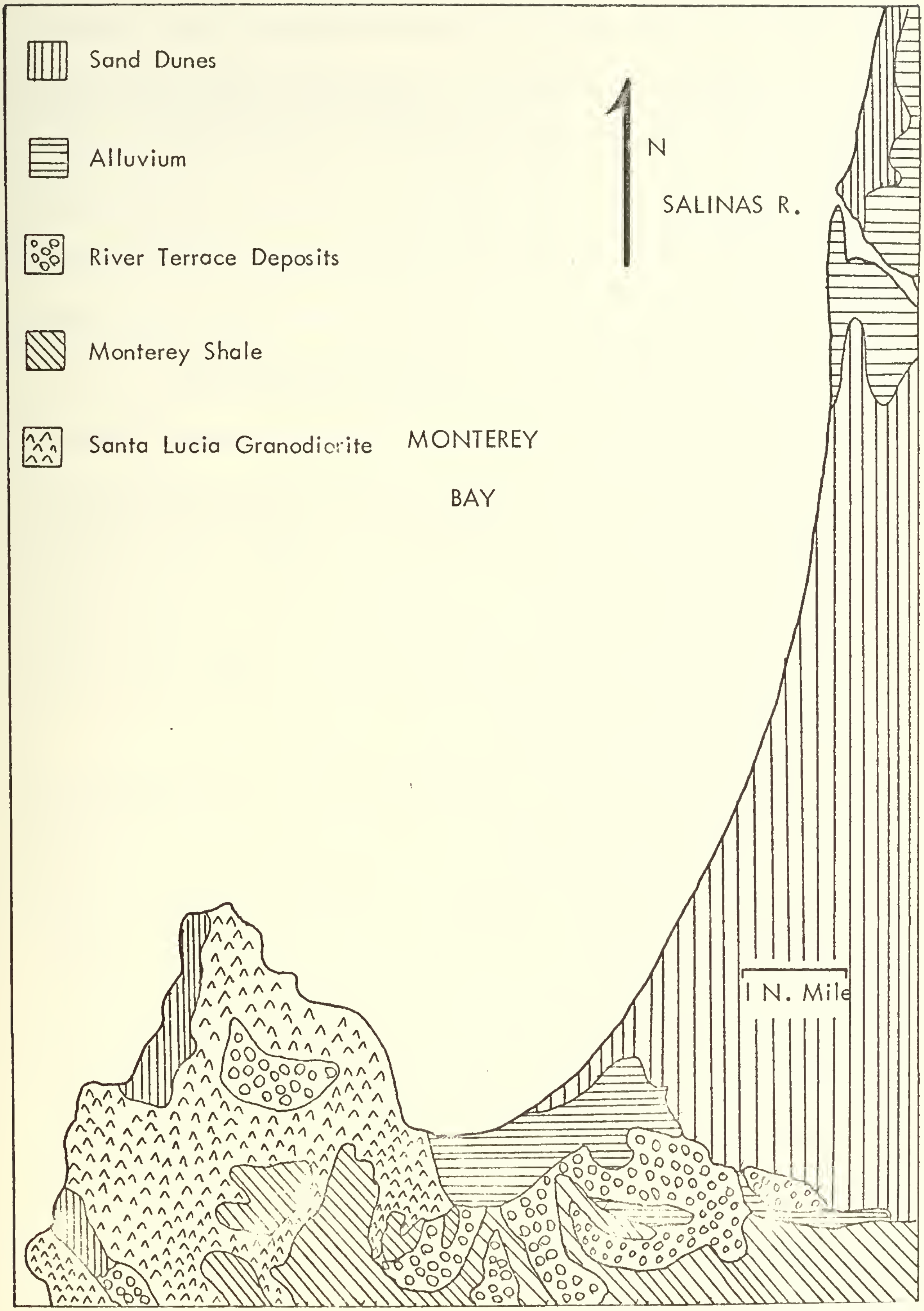
A. SUBMARINE TOPOGRAPHY

The dominant topographical feature in Monterey Bay is the Monterey Submarine Canyon, described in detail by Martin and Emery (1967). The canyon extends to within 100 yards of the shoreline at Moss Landing and divides the continental shelf in the bay into two halves. The canyon is adjacent to the area where the pebble-cobble deposit is located. In this area the transition between the continental shelf and the continental slope, represented by the sides of the canyon, is quite abrupt and the slope of the canyon approaches 45° immediately to the west of the area studied. The shelf-slope transition, which was used to define the western edge of the area studied, occurs at depths ranging from about 90 m at the northern end to about 135 m at the southern end. The general bathymetry of the continental shelf in Monterey Bay is quite smooth and gently sloping with some rock outcropings or reefs occurring.

B. GEOLOGIC SKETCH OF SURROUNDING AREA

1. Coastal Geology

The southern half of Monterey Bay is bordered on the south by the Monterey Peninsula and on the east by sand dunes extending from the city of Seaside to Elkhorn Slough (Fig. 2). The Santa Lucia Formation of Cretaceous Age forms the northern and western end of the



Adapted by Monteath (1965)

Figure 2. Coastal Geology

peninsula. This formation is exposed continuously along the shoreline from Cypress Point to Monterey, and also outcrops offshore to the north and west of Point Pinos. The formation contains granitic rocks which occur throughout the Santa Lucia and Gabilan Mountains and ranges in composition from quartz diorite to granodiorite and granite, including various porphyritic and pegmatitic facies (Hart, 1966).

The Monterey Formation of Middle and Upper Miocene Age overlies the Santa Lucia Formation on the peninsula. It is basically a siliceous shale with porcellanite and chert. The Monterey Formation outcrops almost continuously throughout the entire Santa Lucia Range and, although it does not actually occur along the shoreline in Monterey Bay, it does outcrop in the bay (Dorman, 1968).

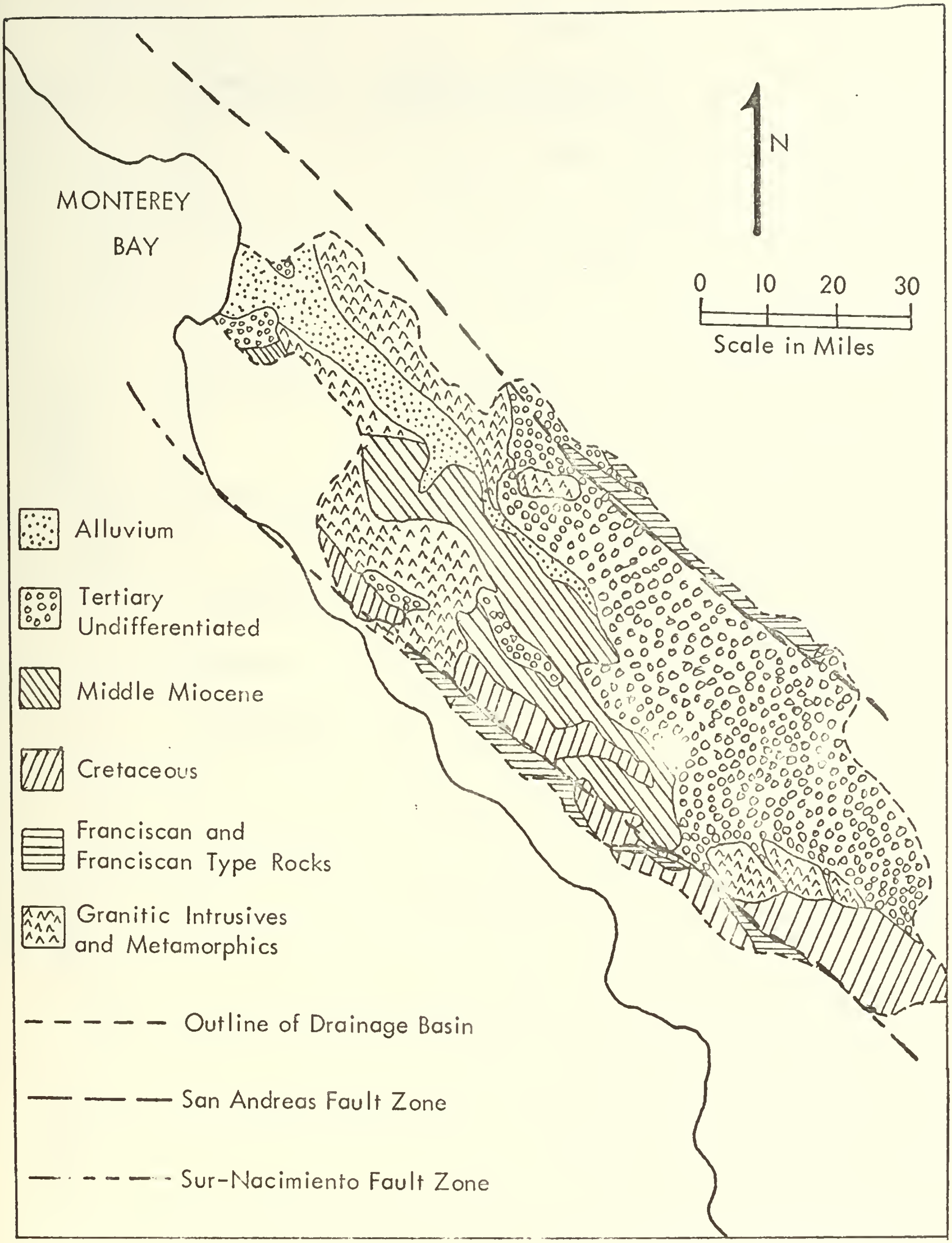
From Monterey to Moss Landing, the shoreline is backed by unconsolidated Quaternary deposits. Recent sand dunes fringe the shoreline, and areas of older sand dunes are found in the Fort Ord area. Gravel, sand, silt, and clay of the stream channel and flood plain deposits are also widely distributed. Another distinctive unit forming the low hills bordering the lowlands of the bay is the Aromas Red Sands, consisting typically of coarse red sands and some "gravel" and clay (Hart, 1966).

2. Salinas Drainage Basin

The geology of the Salinas Drainage Basin can be characterized by its complexity. Basement rocks of the basin are divided into two mutually exclusive provinces by the San Andreas and Sur-Nacimiento

Fault zones (Page, 1966) and the rocks found range in age from Paleozoic to Recent. The geology is summarized in Fig. 3 and Table 1 based on reports by Bailey, Irwin, and Jones (1964), Hart (1966), and Page (1966).

Fault zones (Page, 1966) and the rocks found range in age from Paleozoic to Recent. The geology is summarized in Fig. 7 and Table I based on reports by Bailey, Irwin, and Jones (1964), Dorr (1962), and Page (1966).



Adapted from Yancey (1968) and Page (1970)

Figure 3. Generalized Geology of the Salinas Drainage Basin

Geologic Age			Formation
CENOZOIC	Quaternary	Recent	Dune and beach sand
			Older dune sand
		Pleistocene	Alluvial sand, gravel, and clay
			Stream terrace and fan deposits
			Aromas Red Sands
			Paso Robles
	Tertiary	Pliocene	Etchgoin, Etchgoin-Jacalitos, Pancho Rico
		Miocene	Santa Margarita
			Monterey
			Sandholdt, Temblor, Vaqueros
		Oligocene	Berry Conglomerate
		Eocene	The Rocks Sandstone, Lucia Shale, Junipero Sandstone
		Paleocene	Carmelo
MESOZOIC	Cretaceous		Asuncion
			Santa Lucia
	Jurassic		Franciscan
PALEOZOIC	Undivided		Sur

Adapted from Hart (1966)

Table 1. Stratigraphy of Surrounding Area

III. PROCEDURE

A. COLLECTION OF DATA

The primary vessel used for the collection of data for this study was U.S.N.S. BARTLETT (T-AGOR-13). This ship was used on two occasions: November 3 to November 5, 1969, for the bathymetric survey and collection of bottom samples, and April 27 to April 29, 1970, also for the collection of bottom samples. The Naval Postgraduate School's 63-ft research boat was used for additional bottom sampling.

1. Bathymetric Profiles

Bathymetric profiles were recorded in the area (Fig. 4) using a Precision Graphic Recorder. Eighteen profiles were taken between the 50-fm and 100-fm contours, normal to the contours, and spaced one-half mile apart. Additionally, two long profiles were recorded to align the short profiles and to show features parallel to the short profiles.

The purpose of the bathymetric survey was to determine bottom topography of the area in greater detail than is possible with available navigational charts. The track spacing, although not close enough to reveal all details of bathymetry, was considered sufficient to reveal all major features and significant trends of bathymetry with dimensions greater than one-half mile.

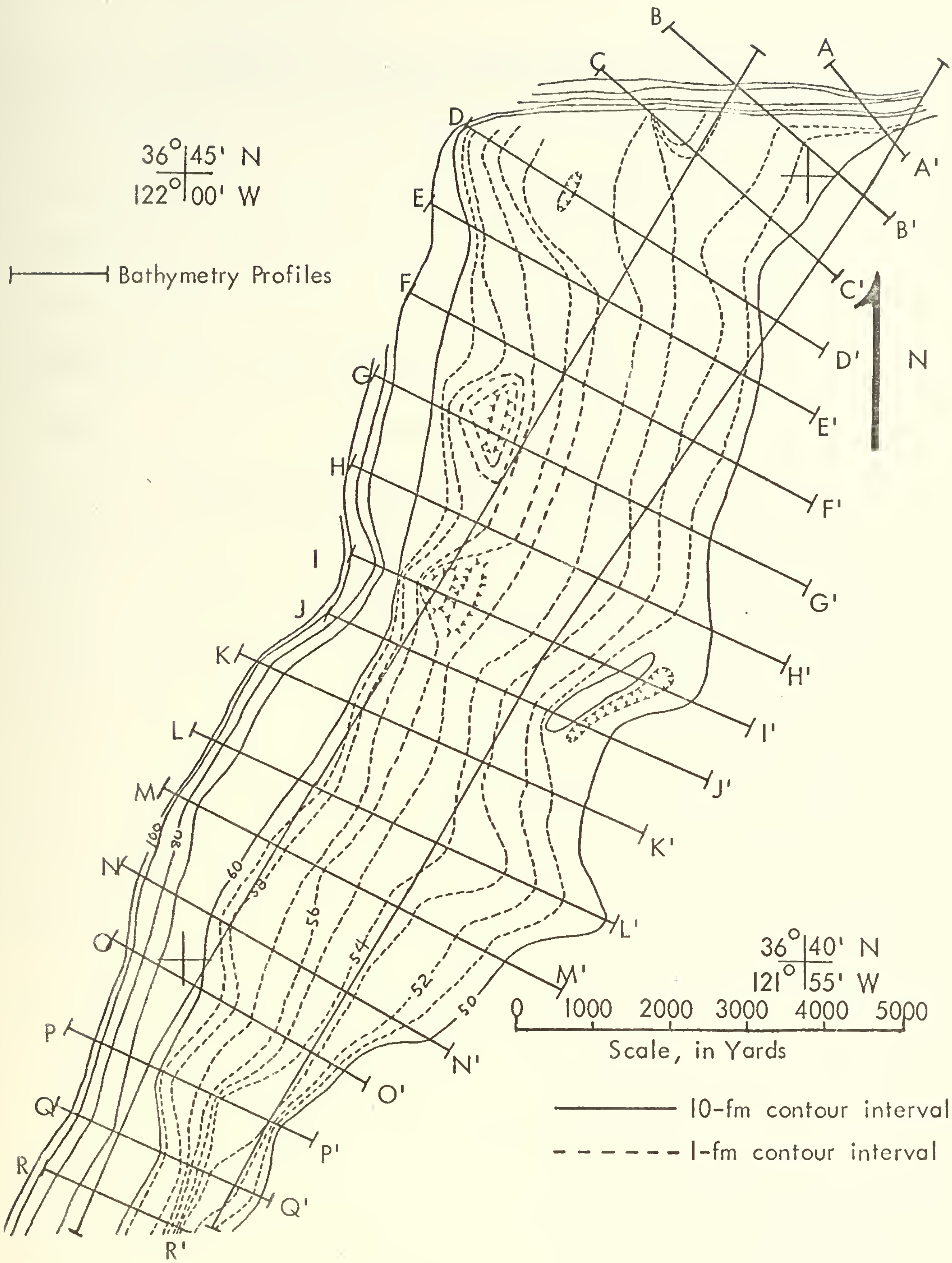


Figure 4. Tracks of Bathymetric Profiles

2. Bottom Samples

Twenty-one dredge samples (Fig. 5) were collected with a 12-inch diameter, 4-ft long pipe dredge. Two factors were considered in sampling; collecting a large enough quantity of pebbles and cobbles with which to effectively work, and determining, as well as possible, the distribution of the pebble-cobble deposit. Thus, samples were first collected in the immediate area of the initial discovery (Fig. 5) and then around the area to determine the extent of pebble-cobble deposit.

Dredge hauls were conducted by towing the dredge for approximately 0.5 mile at a speed of from 1 to 2 knots with from 350 to 400 m of cable out. This provided a scope of from 3:1 to 4:1. This dredging distance was reduced to about 0.3 mile after some experience with the equipment.

In order to better define the distribution of the pebble-cobble deposit, grab samples were collected in the region of the dredge hauls.

B. ANALYSIS OF DATA

1. Roundness and Shape

During the collection of samples it was observed that the pebbles and cobbles in the samples appeared quite rounded and spherical. Therefore, a single sample, D-5, which was considered quite representative of all samples was selected for roundness and shape

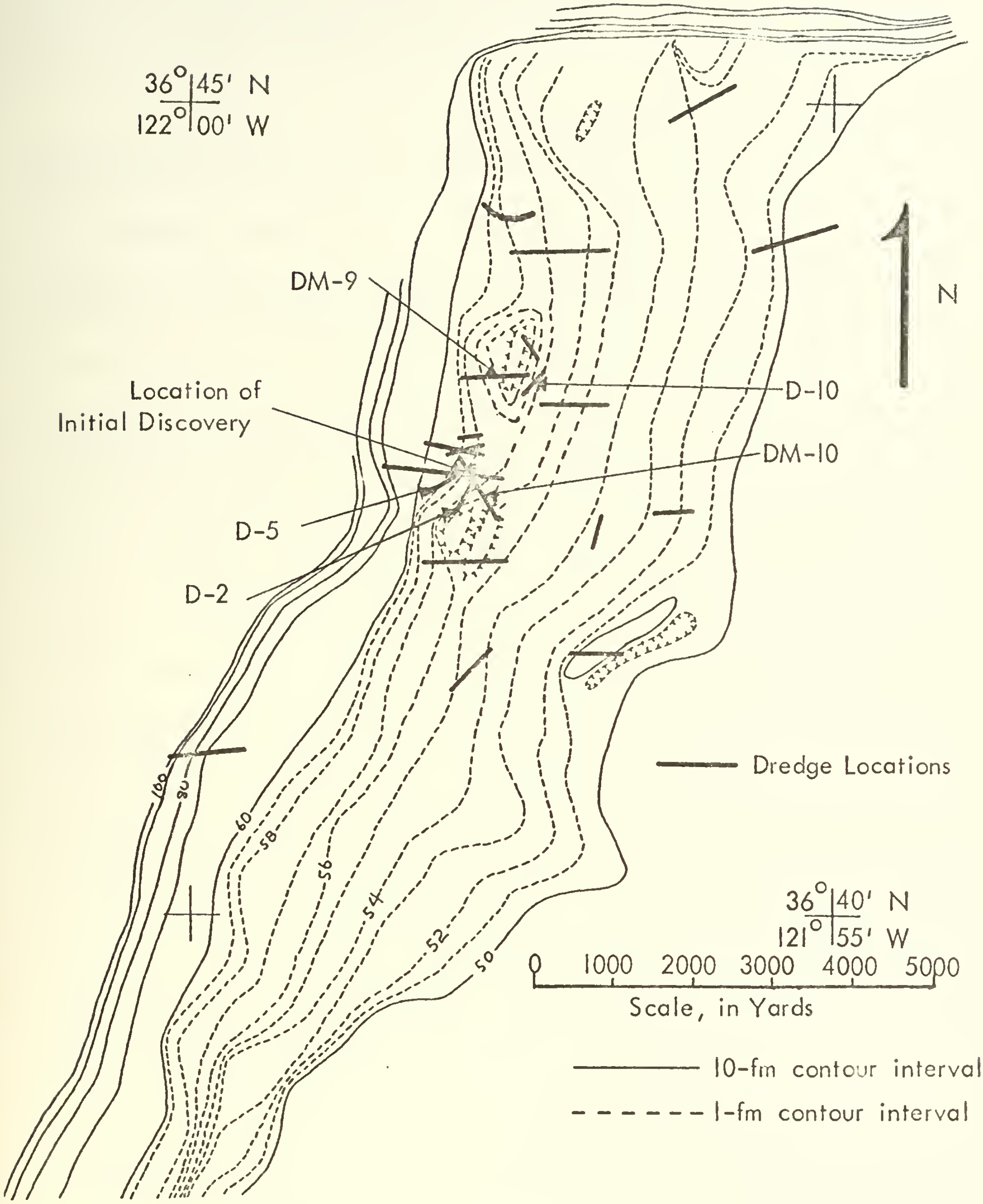


Figure 5. Sample Locations

analysis. This was done to get a quantitative measure of the roundness and shape of the particles, and the method of analysis followed that discussed by Krumbein (1941).

The roundness of a particle is defined by Krumbein as a measure of curvature of the corners and edges expressed as a ratio to the average curvature of the particle as a whole, where, for practical purposes, the average curvature is expressed in terms of the inscribed circle drawn on a projection of the particles in a plane. The procedure for determining roundness was to compare the particle with a set of visual images of known roundness, included in Krumbein's paper, and then to assign a value of roundness to the particle.

The shape of a particle is fundamentally the ratio of its surface area to its volume. For practical purposes, the shape is expressed as the ratio of the volume of the particle to the volume of its circumscribing sphere. The cube root of this ratio is known as the sphericity and is used as the quantitative measure of shape. The determination of sphericity involved the measurement of three mutually perpendicular diameters; a long axis, intermediate axis, and short axis. Using a plot of the sphericity vs. the ratios of the intermediate to the long axis and the short to the intermediate axis (Krumbein, 1941), sphericity could be read directly to an accuracy of 0.02.

2. Size Analysis

The size distribution of the samples was determined at half-phi intervals. For sample number D-5, the sample analyzed for

shape and roundness, the intermediate axis length was used as the particle diameter. Emery (1955) showed that the intermediate diameter is a valid criterion for size of a particle. For the other samples containing pebbles and cobbles, the author analyzed the size of the particles with a set of square holes cut in metal plates. The decision to use square holes was arbitrary but considered the fact that sieves or screens used for analysis of finer material are composed of square holes. These holes corresponded to particle diameters from -3 Ø to -7.5 Ø, inclusive, in half-phi increments. The sizing plates greatly facilitated the measurement of particle diameter and made it possible to measure a large number of particles in a short period of time.

The frequency distribution of the samples was determined in two ways. For the samples collected in November 1969, the number of particles in each half-phi increment was multiplied by the cube of the geometric mean of the limiting diameters of the size class to determine a volume frequency. For the samples collected in April 1970, the actual weight of the particles in each size interval was measured to determine a weight frequency. Emery (1955) showed that the results of either method of analysis are similar and that either may be used.

Weight and volume cumulative frequencies were plotted and statistical parameters computed. This was done for each individual sample containing more than 50 particles, and total volume and weight curves and statistics were compiled from a consideration of all pebbles and cobbles from every dredge haul containing any coarse material.

The weight and volume curves were combined by converting volume to weight by assuming a constant rock density of 2.67 gm/cm^3 for the samples.

3. Lithology

The general lithological character of the samples was determined by breaking each rock except the smallest ones to expose a fresh surface and grouping the rocks according to types based on a macroscopic analysis. A petrographic analysis was done on 15 thin sections that represented examples of all rock types found, placing emphasis on the more unusual rocks and those difficult to define by macroscopic techniques.

IV. RESULTS

A. BATHYMETRIC SURVEY

The bathymetric survey (Fig. 4 and 6) in general showed the gently sloping nature of the continental shelf and the abrupt transition from the shelf to the slope of the canyon adjacent to the area studied. However, several interesting features were noted. In the southeastern corner of the area there is an area of positive relief. This knoll is indicated on navigation charts, but this survey showed it to be considerably greater in extent and magnitude of relief than is indicated on these charts. Additionally, a dredge haul made over the knoll with the fathometer operating showed that the magnitude of the knoll's vertical relief is greater (as much as 10 fm) than shown in the two profiles crossing it in this survey. Also, on the landward side of the knoll, there is a slight linear depression paralleling the knoll.

Several profiles in the northern half of the area showed a feature with positive relief adjacent to the shelf-slope transition. This feature is especially apparent on profile G-G' (Fig. 6) and suggests a low ridge at the edge of the continental shelf. Because the depth of the ridge is not constant, it is obscured in Fig. 4. There is a linear bathymetric feature of negative relief extending in from the canyon and passing to the south of the knoll toward Monterey Harbor. Results of seismic work currently being analyzed by the U. S. Geological Survey, Marine

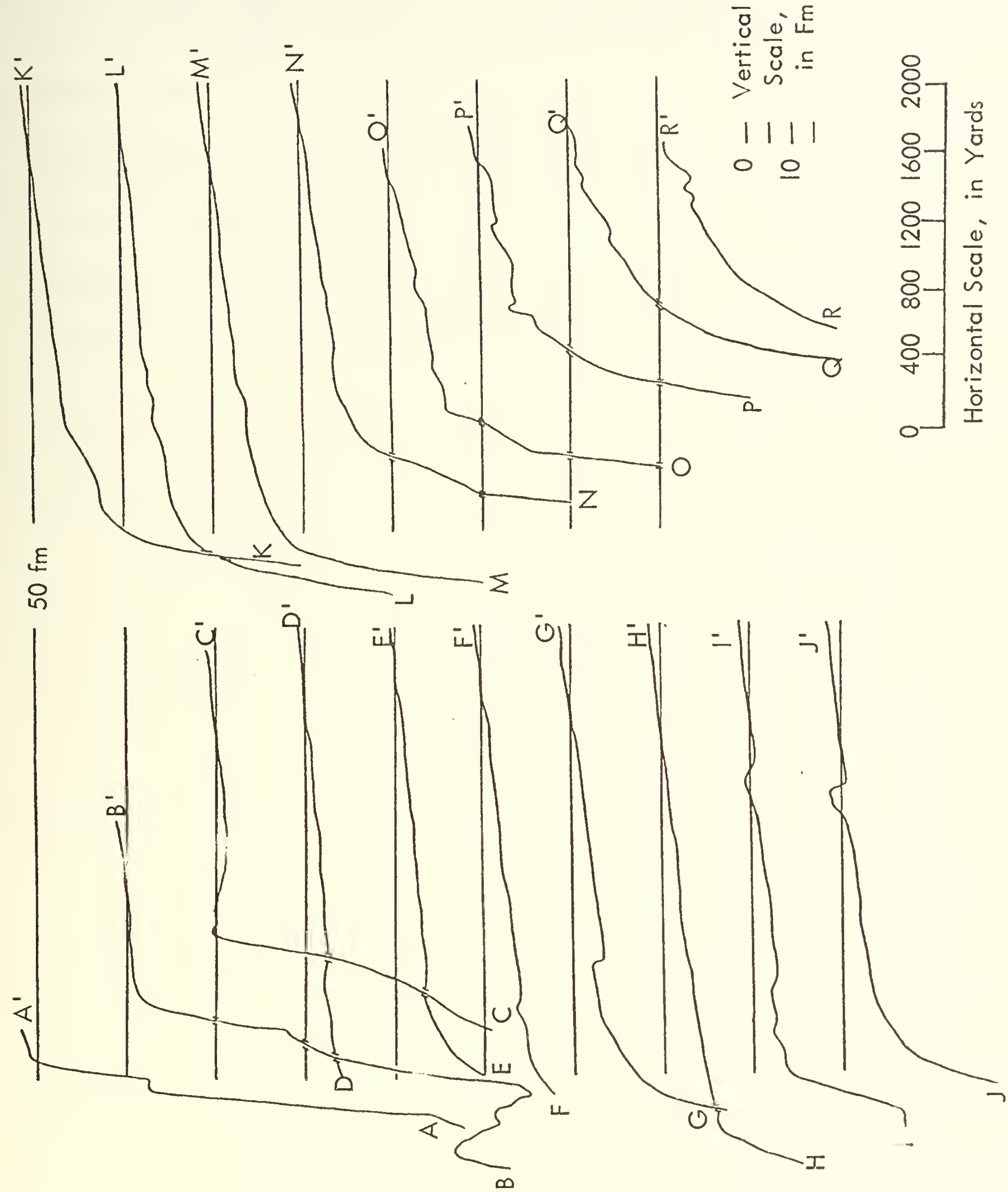


Figure 6. Bathymetric Profiles
(Reference level 50 fm)

Geology Division, Menlo Park, California, (G. Greene, personal communication) indicate that this linear depression represents the surficial evidence of a buried channel, with some evidence that a fault is associated with the channel. The channel could represent an ancient drainage system for the northern half of the Monterey Peninsula, and faulting evidence substantiates Martin's and Emery's (1967) inference of the seaward projection of the Tularcitos Fault. Additionally, the profiles in the southern part of the area showed much irregularity of the bottom west of Point Pinos.

B. BOTTOM SAMPLES

Ten of the dredge hauls recovered material from the pebble-cobble deposit. One dredge haul in the area of the knoll recovered freshly broken segments of a fairly well cemented pebble conglomerate. This conglomerate, along with more of the material recovered from the knoll (J. Geary, personal communication) appeared to be similar in composition to the material comprising the pebble-cobble deposit. The grab samples, with a maximum penetration of 5 inches, recovered no pebbles or cobbles. However, it might be noted that the initial discovery of the deposit was made with a Shipek grab which has a maximum penetration of 4 inches.

Only the pebbles and cobbles were analyzed in this study; the finer material was disposed of, except for a small sample from each dredge which was saved for later analysis. Some of the pebbles

recovered had marine growths, brachiopods and coral, on them and appeared free of the matrix material on one side. These were apparently surficial particles. However, most of the particles had no growth on them and had the matrix material adhering to all sides, indicating that the majority of the material was buried.

1. Roundness and Shape

The roundness of the particles analyzed had values ranging from 0.35 to 0.95 with an average of 0.68. The sphericity of the particles had values ranging from 0.47 to 0.99 with an average of 0.74. Based on a scale value of 1.0 indicating perfect sphericity and roundness, these results indicate that the particles had a high degree of sphericity and roundness.

A plot of sphericity vs. roundness was made and no relationship between them was observed. However, the average values of sphericity and roundness were computed for the particles in each half-phi increment of particle diameter. These values were plotted against particle diameter and a slight but definite increase in sphericity and roundness with size was noted (Fig. 7).

2. Size

During initial sampling it was observed that there was a sharp break rather than a gradual transition between the coarse particles that are the subject of this report and the matrix material of fine sand and silt. This break was found to be at -3 Ø, a value used as the

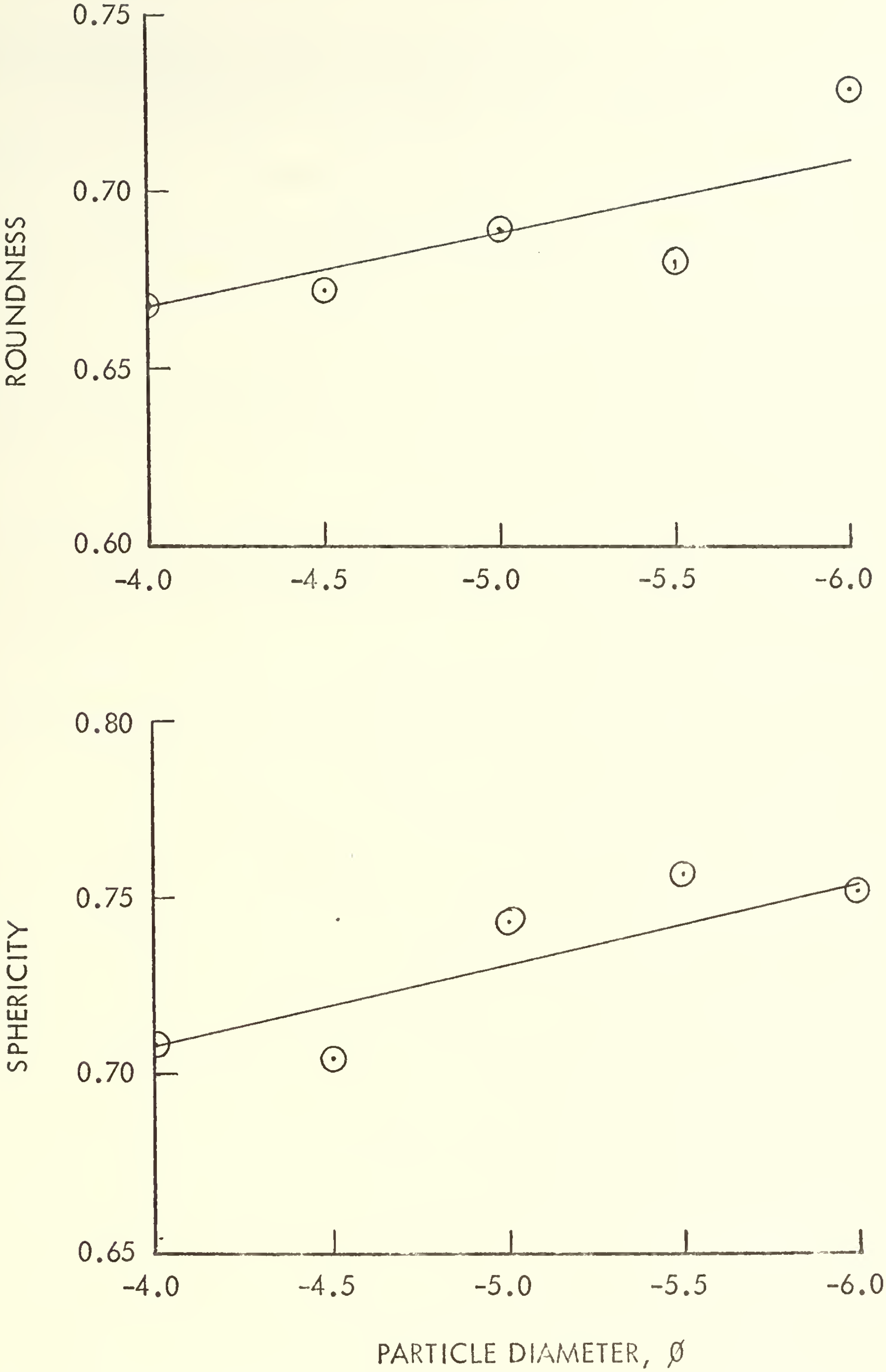


Figure 7. Roundness and Sphericity vs. Particle Diameter

lower limit of particle diameter considered in this study. The largest particle recovered was slightly greater than -7 Ø.

In ignoring the fine portion of the samples and treating only the coarse fraction, the present investigator was aware of the fact that cumulative percent curves and statistical parameters derived from the coarse fraction would be completely different from those that would be determined from a treatment of the complete sample. However, if one recognizes that the presence of two unique types of deposits in the same sample, in this case the pebble-cobble deposit and the matrix material, implies two different sedimentation processes and/or sources, then the separate treatment of the coarse fraction should be expected to reveal information of the conditions of its deposition.

The cumulative frequency curves plotted on arithmetic probability paper are shown in Fig. 8 and 9 and those statistical parameters computed, Inman median, mean, and sorting, Folk and Ward mean and sorting, and Trask sorting, are shown in Table 2. Individual samples are identified by sample numbers. In Fig. 8 and 9, the combination of all samples analyzed by volume is "Total V," a volume cumulative frequency curve, and those analyzed by weight is "Total M," a weight cumulative frequency curve. The total of all the samples, combined by converting volume frequencies to weight is identified as "Total" and is a weight cumulative frequency curve. Observed data points are connected by solid lines and extrapolations used to determine percentiles are represented by dashed lines. It can

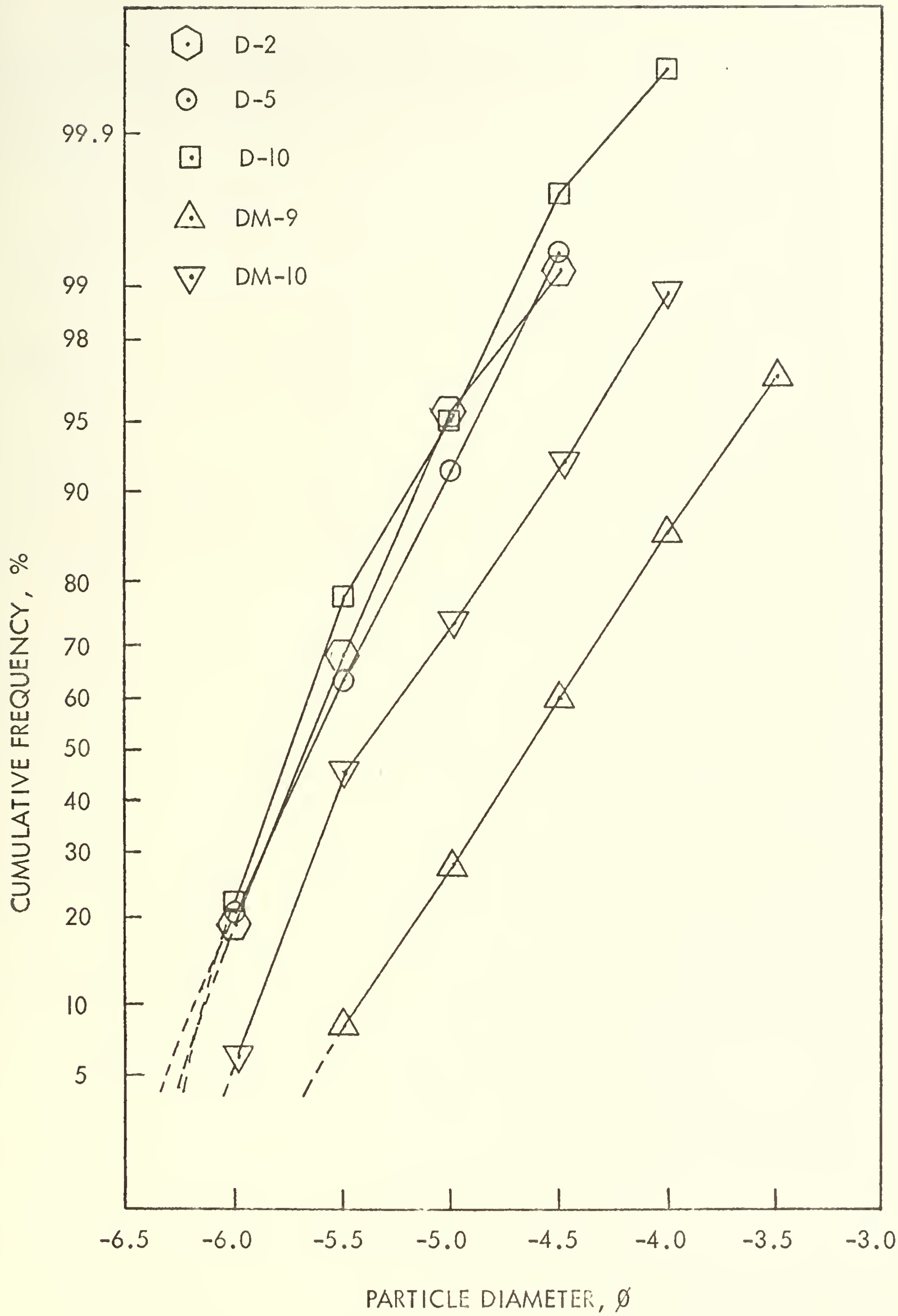


Figure 8. Cumulative Percent of Samples

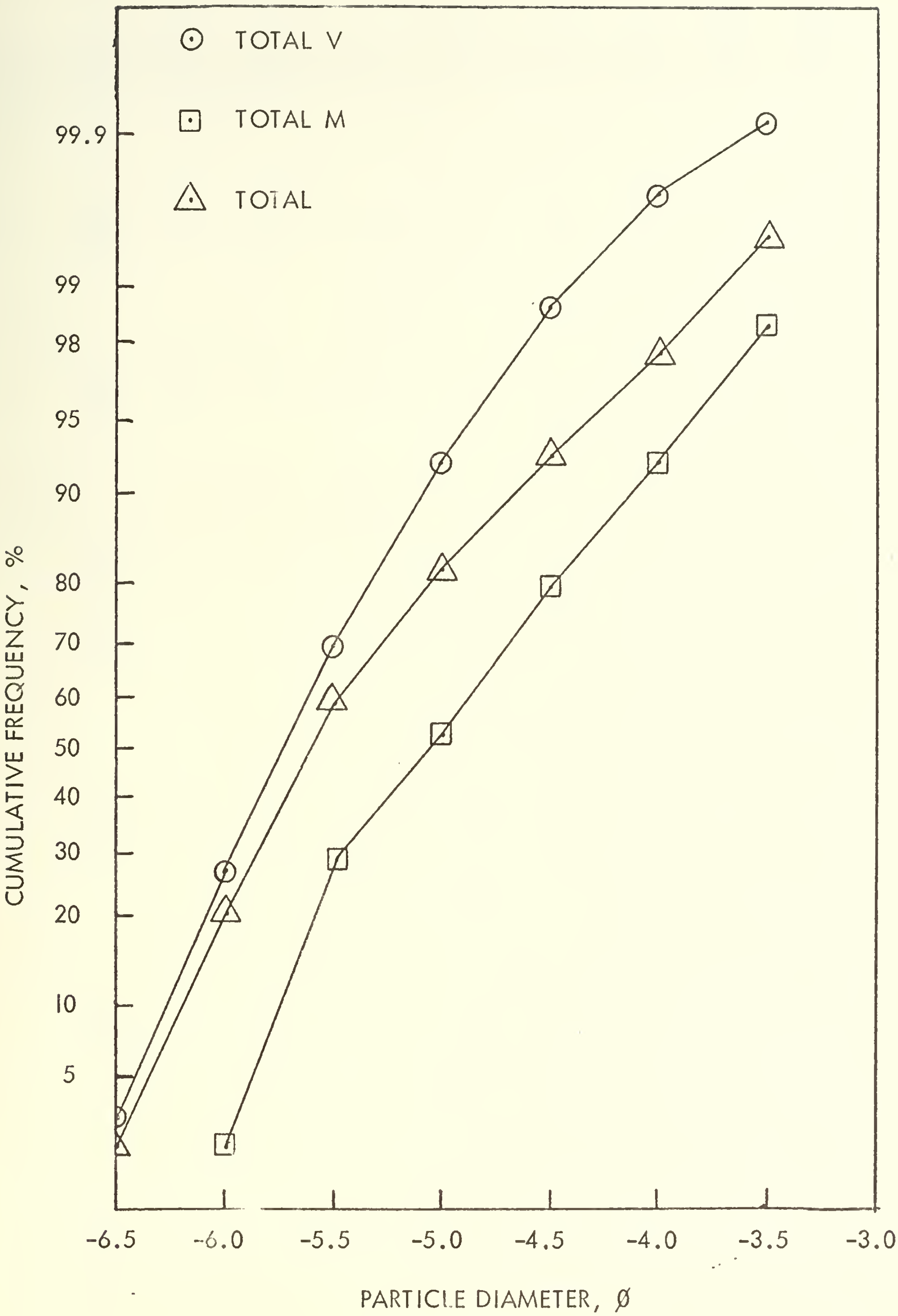


Figure 9. Cumulative Percent of Combined Samples

Coefficient Sample	Inman Median	Inman Mean	Folk and Ward Mean	Trask Sorting	Inman Sorting	Folk and Ward Sorting
D-2	-5.67	-5.66	-5.66	1.21	0.39	0.38
D-5	-5.65	-5.64	-5.64	1.23	0.46	0.43
D-10	-5.75	-5.71	-5.73	1.16	0.35	0.34
DM-9	-4.66	-4.67	-4.66	1.32	0.62	0.60
DM-10	-5.42	-5.29	-5.33	1.29	0.52	0.51
Total V	-5.74	-5.70	-5.71	1.24	0.46	0.47
Total M	-5.06	-5.00	-5.02	1.39	0.65	0.63
Total	-5.61	-5.50	-5.33	1.30	0.59	0.60

Table 2. Statistical Parameters of Pebble-Cobble Deposit

be seen that the samples can be generally characterized as well to moderately well sorted coarse pebbles (mean size of about -5.5 Ø). Samples DM-9 and DM-10 contained smaller pebbles and were not as well sorted. Although the effect of adding samples with different mean sizes is to increase the sorting coefficient, the total of all samples considered as one yields moderately well sorted pebbles.

3. Lithology

The results of the petrographic analysis are shown in Table 3. Using these results as a guide, the samples were estimated to be 70% derived from the Santa Lucia Formation and 30% miscellaneous rock types representing a cross section of those rock types found in the Salinas Basin, including rocks from the Franciscan Formation. The occurrence of these rock types correlates with Galliher's (1932) results which showed the presence of Franciscan chert, granite, basalt, and Monterey shale, although Galliher did not indicate the dominance of the granite rock types derived from the Santa Lucia Formation.

Some interesting characteristics were noted on several of the rocks. Rock No. 243, the chert breccia, showed an interesting planar orientation of the fragments. The fossiliferous greywacke, Rock No. 353, has a very distinctive shape and appears to represent a flute or load cast as pictured by Krumbein and Sloss (1963, p. 131).

Specific gravity measurements on ten samples of chert showed that five had values ranging from 2.38 to 2.47 and the other five had values ranging from 2.58 to 2.67. Goldman (1959) reported

Rock No.	Rock Type
# 58	Dacite Porphyry
# 70	Granodiorite
# 85	Rhyolite
#106	Granite Gneiss
#173	Dacite Porphyry
#241	Well-Cemented Chert Breccia (angular fragments of chert, jasper, and recrystallized quartz; oriented somewhat along a plane)
#243	Granite Gneiss (identical to #106)
#247	Micaceous Granodiorite
#268	Granite
#271	Granite
#309	Rhyolite
#318	Granite
#338	Interbedded Ferruginous Chert and Slate
#352	Dacite
#353	Fossiliferous Greywacke (silty sand in texture)

Rock #241 appears to have been derived from other than the immediate area of Monterey Bay and may represent a Franciscan source.

(Petrographic analysis by R. S. Andrews)

Table 3. Results of Petrographic Analysis of Selected Rocks.

studies of Franciscan and Monterey chert which showed values of specific gravity ranging from 1.80 to 2.43 for Monterey chert and 2.6 to 2.8 for Franciscan chert. A comparison of these results with those of the present study indicates the presence of both types of chert.

The presence of Franciscan rocks and other rocks characteristic of the Salinas Basin and not of the Monterey Bay area indicates that the remaining 20% of the rocks, those not associated with the Santa Lucia or Monterey Formations, must have their source in the Salinas River Basin alluvial or shallow-water marine deposits.

C. DISTRIBUTION OF THE PEBBLE-COBBLE DEPOSIT

Based on results of sampling, the pebble-cobble deposit was determined to form a band approximately 2.5 miles long and 0.6 mile wide and in a depth ranging from 55 to 59 fm (Fig. 10). Examination of Fig. 6 and 10 shows that the distribution was approximately that of the ridge observed in the discussion of the bathymetry. This distribution corresponds to the distribution described by Galliher (1932) and Yancey (1968); that is, a band of coarse material aligned approximately parallel to the depth contours.

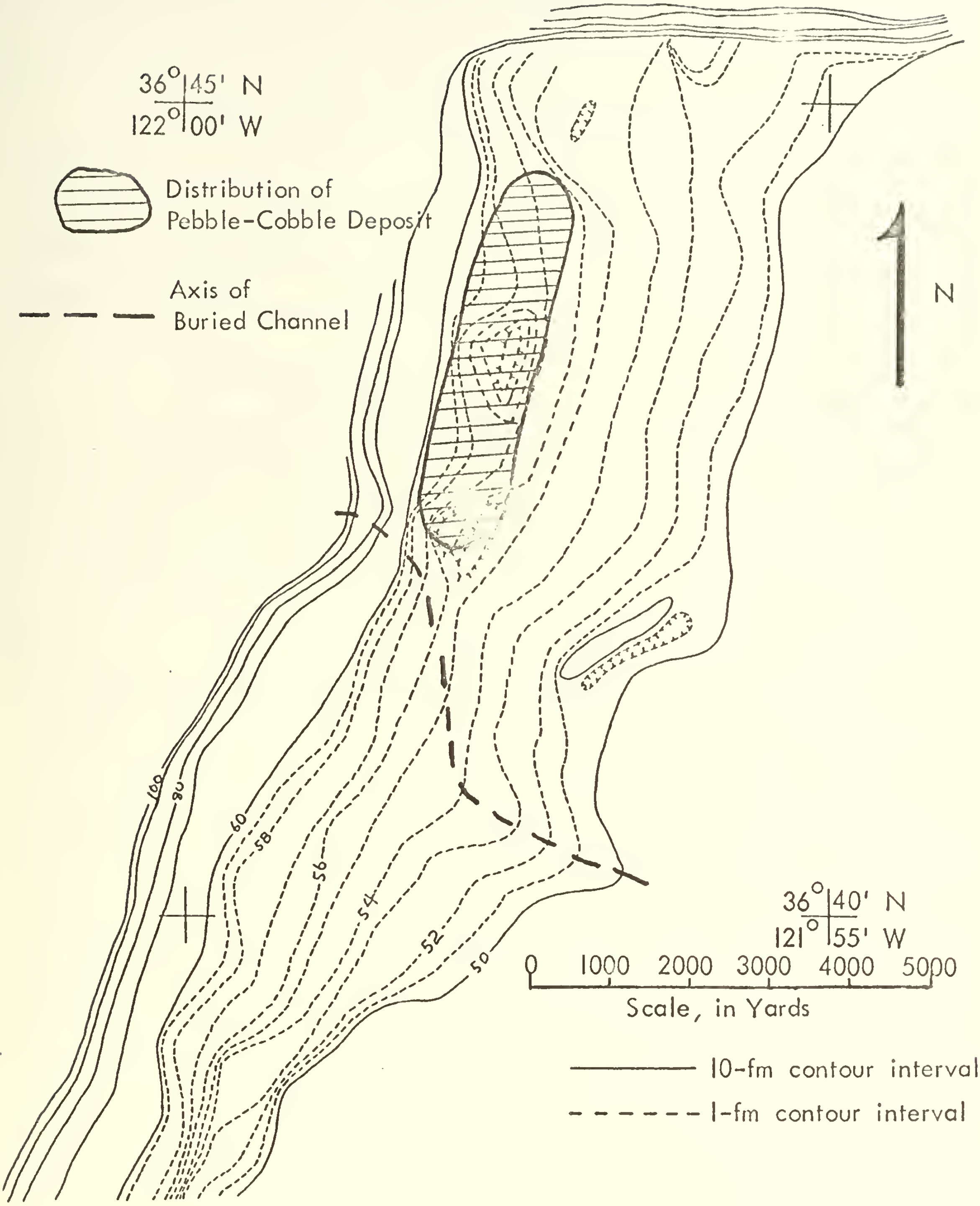


Figure 10. Present Distribution of Pebble-Cobble Deposit

V. CONCLUSIONS

A. ORIGIN OF PEBBLE-COBBLE DEPOSIT

An analysis of the previously listed results enables one to make a reasonable estimate of when the material was deposited, where it came from, the means by which it was transported to its present location, and the conditions under which it was deposited.

1. Time of Deposition

To make a reasonable estimate of when the pebbles and cobbles were deposited, several factors must be considered. The first is Yancey's (1968) discovery, in coarse sand in the northern part of the area studied in this report, of cold and shallow water fauna which were estimated to be of Pleistocene Age. The second factor is Yancey's statement, which the present author supports, that material this coarse is not being deposited under present conditions. This is primarily because the dynamic forces required to move the particles do not exist in the present depth of water on the outer edge of the continental shelf, since a current of more than 2.50 m/sec (4 knots) is the theoretical threshold velocity for material 32 mm (-5 Ø) in size (Shepard, 1963, p. 129). Also, as previously mentioned, the majority of the particles were not surficial but were buried und a cover of presently accumulating sediments. The fact that all of the particles are not yet buried does not mean that they could not presently be in the process of being covered. A consideration of all of these factors does indicate that the

individual pebbles and cobbles were deposited during the Pleistocene Age when sea level was greatly lowered.

2. Source Area

The results of the lithological analysis show that the primary original source of the pebble-cobble deposit is the Santa Lucia Formation. At a time of lowered sea level, the Santa Lucia would have extended almost to the southern limit of the area (Martin and Emery, 1967). Additionally, the southern bathymetric profiles (Fig. 6) show irregular topography that is hypothesized to be granitic sea cliffs at times of lower sea level. These sea cliffs would have provided a ready supply of granitic rocks to nearby areas. This in turn supports the concept of deposition at a time of lowered sea level because the closest source of granitic rocks at present is Point Pinos, 5 miles to the south of the study area. Those rocks not derived from the Santa Lucia Formation would have come from alluvial or shallow-water marine deposits of the Salinas River Basin. It might be pointed out that, during Mid-Pleistocene, the Pajaro and Salinas Rivers joined slightly below the present head of the canyon and drained down the canyon (Martin and Emery, 1967). Thus, deposits from this time could also have included debris from the Pajaro River. However, this does not affect the geological background since the geology of the Pajaro Basin is merely a continuation of that of the Salinas basin, with the exception that more of the Franciscan is present.

The pebble conglomerate discussed previously must also be considered as a possible source of the pebble-cobble deposit due to its nearby location and the fact that it appears to contain all the rock types found in the deposit. The linear depression landward of the knoll may represent a drainage scour channel at a time of lowered sea level.

3. Movement Into the Area

Two possibilities were considered for motion of the material into the area. If the knoll was the immediate source, the fine matrix of the conglomerate could have been eroded away, leaving the pebbles and cobbles as a lag deposit. Longshore movement under control of wave action and subaerial stream flow is a means by which the material could have been transported to its present location from more distant sources. This transport could have moved material directly from the base of sea cliffs and from Salinas Basin deposits or could have been working simultaneously with erosion of the knoll. Steers and Smith (1956) and Kidson, Carr, and Smith (1958) used radioactive tagging of particles to study motion of pebbles in the nearshore region. They showed that pebbles are moved in depths up to 25 ft when only moderate waves are running and the effect could be expected to be greater in heavy seas. Once again, conditions of lowered sea level would be required to find the distribution of material in this study.

B. CONDITIONS OF DEPOSITION

Three factors were considered in determining the depositional conditions of the pebble deposit. Roundness is a function of abrasion,

high roundness being associated with much abrasion. Abrasion can occur over long distances of transport or may be caused by wave action. The high degree of roundness of the samples must be due mainly to wave action since 80% of the material was transported only a short distance.

Analysis of the cumulative percent curves and the statistical parameters showed the most significant factors. The cumulative frequency curves (Fig. 8 and 9) are approximately straight lines, indicating a symmetrical distribution of grain sizes from which one may infer that the given samples were deposited in a condition of equilibrium with wave forces at a given time (Emery, 1955). Emery also prepared a table summarizing all available information, including results of his own study, on Trask sorting coefficients of coarse gravels (greater than 10 mm) for beaches, streams, and alluvial fans. Results of Emery's table show the following ranges of these coefficients: marine beaches ranged from 1.13 to 2.14 with a median of 1.25; streams ranged from 1.34 to 5.49 with a median of 3.18; and alluvial fans ranged from 2.50 to 8.95 with a median of 5.33. Most of these values were determined from samples selectively collected to include only coarse material which did not generally characterize the entire beach. This sampling technique is analogous to that of the present author. A comparison of these results with the results of the present study (Table 2), showing a range of Trask sorting of from 1.16 to 1.39, shows strong evidence that the pebble deposit at one time formed a marine beach. It was not necessary that this material form the actual beach; it would have been

possible for it to exist in the immediate nearshore area. Schupp (1953) reported that the material forming cobble beach cusps had a primary source area in a band immediately offshore in 20 to 30 ft of water and migrated between the beach and the source area under varying wave conditions.

C. SUMMARY

The pebble-cobble deposit in this study is probably a relict marine beach of Pleistocene Age. The beach would represent a relative lowering of sea level of about 330 to 360 ft. The author was unable to find any reference to submerged marine terraces in the immediate area but this lowering can be correlated with other marine terraces around the world and possibly off Southern California (Emery, 1958). The primary source of the material was marine sea cliffs of the Santa Lucia Formation, with lesser amounts of debris from the Salinas Drainage Basin.

D. FUTURE WORK

It can be seen that further work in the area is desirable. The analysis of the samples should be extended to include the matrix material. This analysis should be carried out along the continental shelf in Monterey Bay and an attempt should be made to relate the coarse and matrix materials.

The knoll in the southeastern corner of the area should be completely studied, including high and low resolution seismic reflection profiling, and its exact relationship to the pebble-cobble deposit determined.

The other positive-relief features in the study area may also yield some of the pebble conglomerate.

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13. ABSTRACT

A deposit of pebbles and cobbles was discovered in approximately 60 fm of water on the continental shelf in Monterey Bay, California. Samples were taken in the area and the extent of the deposit was determined. The material was characterized as well rounded, moderately well sorted coarse pebbles derived mainly from the granites of the Santa Lucia Formation with lesser amounts of alluvium from the Salinas Drainage Basin which flows into Monterey Bay. It was established that the deposit probably represents a marine terrace of Pleistocene Age, indicating a relative lowering of sea level of about 330 to 360 ft. This appears to be the first reported evidence of submerged marine terraces in Northern California.

14. KEY WORDS	LINK A		LINK B		LINK C	
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Pebble deposits						
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