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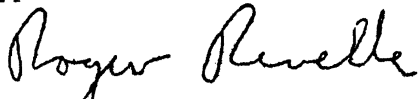
THE MARINE GEOLOGY OF THE
SAN NICOLAS ISLAND REGION, CALIFORNIA

Robert M. Norris

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Robert M. Norris

ABSTRACT

San Nicolas Island is an anticline, modified by folding, faulting and marine terrace cutting. Terracing is believed to have taken place during the Pleistocene. Total submergence of the island is considered probable. Wave erosion along the present coastline has developed a series of sandy pocket beaches separated by rocky promontories. East-flowing longshore currents, particularly along the northern coast, have deposited a large, pointed sand spit at the southeastern end of the island. The shape of the spit was found to have changed considerably during historic time.

The shelf north of the island is broad and flat and is mostly rocky, being covered locally with patches of shelly sand and gravel. This northern shelf is very similar in character to the shelf north of Santa Catalina Island, although the San Nicolas shelf is larger. The shelf south of San Nicolas is narrow and sloping and is covered for the most part by terrigenous sand and sandy mud.

Eocene Foraminifera have been recovered from a number of submarine outcrops near the island. Several outcrops on the outer edge of the northern shelf have yielded siliceous casts of what may be Miocene Foraminifera. Recent Foraminifera from the shelf sediments have been investigated and show depth zonation in general agreement with that established by Natland (1933) and more recently by Butcher (1951).

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INTRODUCTION

San Nicolas Island, sixty miles off the Southern California coast, is the exposed central portion of an elongate submarine ridge extending from Santa Rosa Island on the northwest to Cortes Bank on the southeast, a distance of 130 miles.

Over 250 bottom samples were taken on a grid pattern surrounding San Nicolas Island. All sampling was carried on from the University of California's research vessel E. W. SCRIPPS in 1950 and 1951. In addition to the sampling, a continuous echo-sounding profile was made whenever the vessel was under way. Shoreline processes, general island geology, and nearshore currents were observed on the island itself during several visits in 1950 and 1951.

Laboratory treatment of the samples was divided into four main parts: (1) Microscopical examination and description of all samples of sand-size or greater; (2) Mechanical analyses of a representative group of sand and sandy-mud sediments; (3) Carbonate determination of beach and bottom sands; (4) Examination of rocks and Recent sediments for contained Foraminifera.

Acknowledgements

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PREVIOUS LITERATURE

Few papers have been published which are specifically concerned with the geology of San Nicolas Island. Howers' brief report (1890) is the longest published description of island geology. Kemnitzer (1933) made a more complete investigation, but has published only a very short abstract (1936).

GEOLOGY OF THE ISLAND

STRATIGRAPHY

Eocene

More than 2000 feet of Middle and Late Eocene sandstone and shale are exposed on the island. Conglomerate occurs only as scattered small lenses in the sandstone. Age of the rocks was determined by Laiming (personal communication) from Foraminifera collected by the author. Laiming places the strata in his "A-2 Zone" (Laiming, 1941).

Miocene (tentative)

No rocks definitely known to be Miocene occur on San Nicolas Island, but three small igneous dikes on the south side of the island are tentatively assigned to the Miocene although field evidence indicates only that they cut the Eocene and are covered by Pleistocene deposits. Igneous activity was very widespread in Southern California during the Middle Miocene, however, and Miocene volcanics are found on all the other Channel Islands.

Pleistocene

Unconsolidated marine and non-marine terrace deposits lie unconformably above the Eocene. The marine portion consists of broken shells, sand, and pebbles; the non-marine part is mainly dune sand. The age of the marine deposits was determined by George Kanakoff of the Los Angeles County Museum on the basis of a molluscan fauna collected by the author.

STRUCTURE

San Nicolas Island is an eroded asymmetrical anticline with an axis trending approximately N 60° W. The south limb has an average dip of 15° SW; the north limb an average dip of 11° NE. The anticline plunges slightly toward the southeast, but not appreciably toward the northwest insofar as can be determined from the island.

Small-scale, high-angle normal faults have modified the anticlinal fold. The displacement is less than 200 feet at most places. Most of the faults belong to two conjugate systems which cross the anticlinal axis at nearly 45°. Both systems of faults displace each other and are therefore approximately the same age. The faulting probably represents structural adjustment to folding stress because of its consistent relationship to the axis of folding. None of the faults have been active since the formation of the terraces and are therefore pre-Pleistocene. Smith (1900, p. 185) expressed the belief that the steep southern side of the island was a fault scarp. Detailed field examination by Kemnitzer (1933) and by the author reveals no evidence of major faulting along the southern

side of the island. It is possible that the escarpment is a fault-line scarp eroded back by marine agencies from a fault some distance off the coast of the island.

GEOMORPHIC FEATURES

Terraces

The six well-developed terraces which occur on San Nicolas Island are best preserved on the north and east sides. The terraces are buried by sand on the west and have been largely destroyed by erosion on the south. Elsewhere in Southern California more terraces occur in some localities. Usually the greater number is the result of terracing to elevations higher than the highest point on San Nicolas Island (907 feet). Development of many terraces above 900 feet in the Southern California region plus the subdued character of the upper part of the island, suggest that San Nicolas Island was totally submerged during the Pleistocene.

Beaches

Sandy beaches occur along most of the coast except in the extreme western part where beaches, when present, are composed of cobbles and boulders. Most beaches are only a few hundred yards long and are separated by rocky promontories.

One or more sand samples were collected from each beach on the island. All were taken at the highest point reached by waves at the time of collection in order to avoid errors introduced by wind, animal footprints, etc. The foreshore slope was measured with an inclinometer as close to the sampling site as possible. All sand samples were mechanically analyzed in the Emery settling tube (Emery, 1938). A fair correlation* was found between beach slope and medium diameter; i.e., coarse-grained beaches were the steeper. The beach sands were analyzed also for calcium carbonate content, most of which was comminuted shell material. Most of this shell material plus an unknown amount of terrigenous sand must be derived from below half tide, because most shell-bearing mollusks in the San Nicolas area live below this level.

The Sand Spit

A triangular spit about one mile long is located at the southeastern end of the island. At present, the spit has a submerged continuation approximately one mile beyond the exposed part. Previous records show that the spit is neither a permanent nor a stable feature. The following historical summary will illustrate this:

*The coefficient of correlation is +0.51.

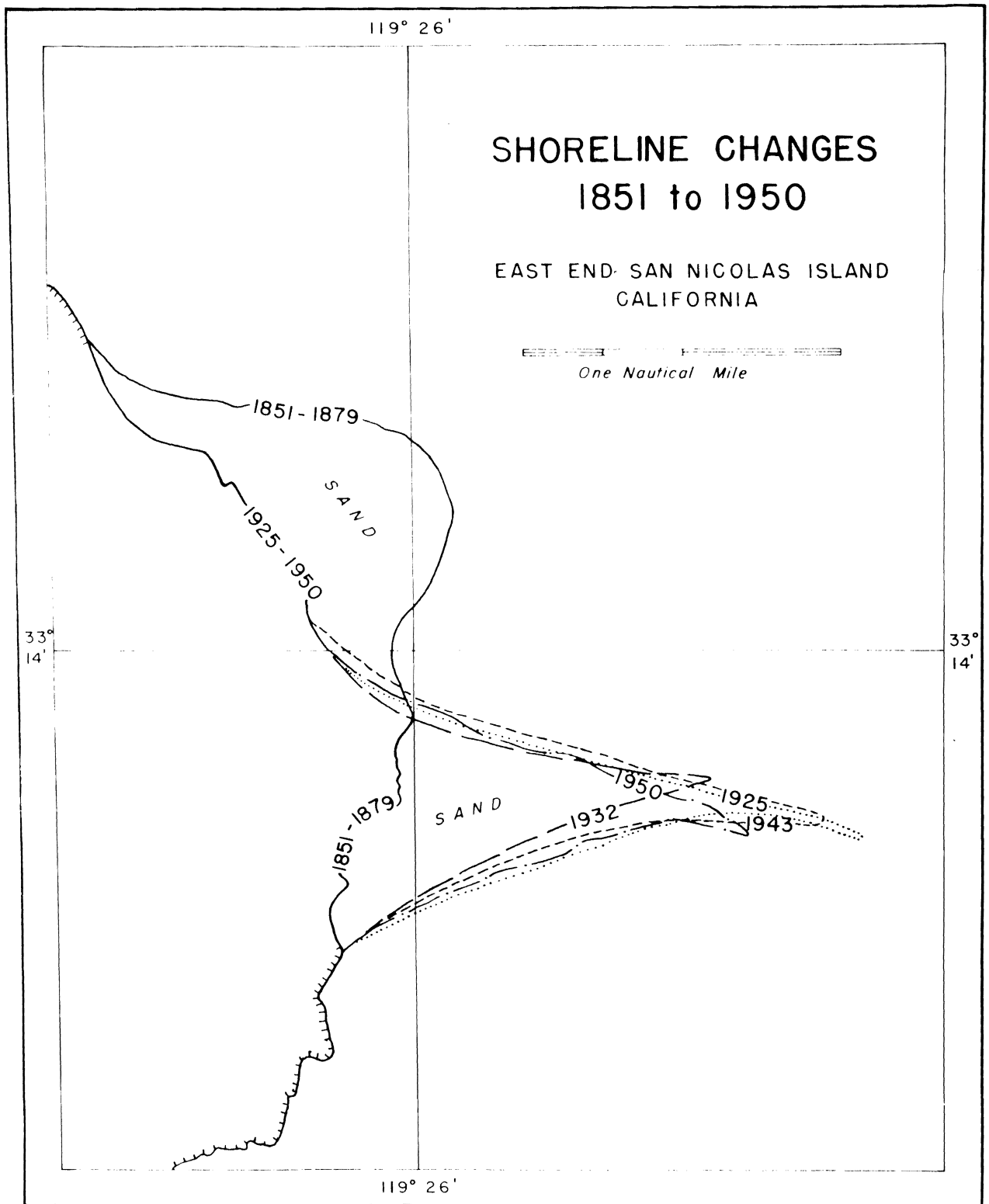


Figure 1. Changes in outline of the sand spit.

Kellett, writing in 1847, described a line of breakers extending a mile and three-quarters from the eastern end of the island. It therefore appears probable that the spit had, at that time, a configuration similar to that which it has today.

In 1851 the U. S. Coast and Geodetic Survey published the first accurate chart of the area. This chart does not show a spit, but rather a rounded sandy area to the northwest of the present location (see figure 1). Despite the fact that the original survey was published on a scale of 1: 380,000, it is unlikely that a feature as prominent as the spit could have been missed.

The first detailed survey of the island was made by the U. S. Coast and Geodetic Survey in 1879. The modern spit was not then existent, but the large rounded sandy protruberance, first indicated by the 1851 survey, is shown in detail. In 1879 several sounding lines across the area occupied by the present day spit show depths of two to seven and one-half fathoms. The striking change, which evidently occurred between 1847 and 1851, caused Davidson (1889) to remark:

"...(Kellett)...also lays down breakers for a mile and three-quarters from the eastern point. It is probable that he has been misled by heavy current rips conflicting with the westerly swell; or it is possible there may be some hidden dangers in the kelp field off the eastern end of the island..."

Davidson, in the 1889 edition of the Pacific Coast Pilot, describes conditions as of that date:

"...The eastern end of the island is one and one-quarter miles broad, high and bold, except at the northeast point, where there is a low sand spit stretching out one-third of a mile, and around which the currents run at times with great force..."

Doubtless, Davidson referred to a spit like that shown in the 1879 chart (see fig. 1), for the modern spit is not located at the northeastern extremity of island, is longer than a third of a mile and the currents do not run "around" it. Holder (1910) mentions: "...the long attenuated sand spit...", indicating that the present-day configuration had been attained by 1910. Subsequent surveys made by the U. S. Coast and Geodetic Survey show smaller changes, which are illustrated in figure 1.

San Nicolas Island is so oriented that the prevailing northwesterly winds blow parallel to the northern shore or approach it at a slight angle. In either case, the winds produce a more or less continuous longshore drift on the northern shore. The southern coast, on the other hand, is parallel to wind-direction only in its western half; the eastern half normally lies in the lee and longshore drift is therefore apt to be weaker. Current measurements along the northern coast confirm the existence of a strong longshore drift toward the spit (0.2 to 0.3 knot during a period of

low waves). However, on one occasion (March 1951), near the outer end of the spit, waves approached from the east at an angle which should have developed a northwest-flowing current in opposition to the wind. The fact that this did not occur indicates that longshore drift established along the northern coast of the island had sufficient velocity to overcome opposing wave-approach near the end of the spit. During a period of southern swell (March 1951), currents measured along the south side of the spit moved westward toward the island, turning seaward near the mid-point of the spit.

For the following reasons, the sand spit is believed to be primarily the product of longshore drift along the northern coast:

- (1) An easterly longshore drift is well-developed along the northern coast. Further, the northern side of the spit is more or less a continuation of north coast beaches whereas the southern side of the spit is separated from southern coast beaches by a large rocky headland.
- (2) Longshore drift along the southern coast is less strongly developed and has been observed to move toward the island along the south side of the spit.
- (3) Sand transported by wind across the top of the island is of minor importance.
- (4) The position of the sand spit from 1851 to 1879 shows an even closer relation to the north coast than at present.

In summary, it may be said that the northern side of the spit is a zone of wave-deposition and wind-erosion, while the southern side is a zone of wind-deposition and wave-erosion.

GEOLOGY OF THE SHELF AND SLOPE

PHYSIOGRAPHY

San Nicolas Island is situated on a nose or salient of the submerged Santa Rosa-Cortes Ridge. The island is surrounded by a sloping shelf whose outer edge has an average depth of 58 fathoms. The shelf north of the island is six miles across and has a slope of $0^{\circ}40'$; south of the island the shelf is only one mile across and steeper, having a slope of $3^{\circ}40'$. The slope beyond the shelf is likewise steepest on the south, about 11° , whereas the northern slope into the Santa Cruz Basin has a slope of $6^{\circ}30'$.

Shoal Areas

Inside the 50-fathom contour surrounding the island are two shoal areas, both of which are igneous rock. One shoal, eight miles northwest of the island, is capped by Begg Rock. Kemnitzer (1933) examined a sample from Begg Rock and reports it to be a fine-grained rhyolite with vague flow structure. He suggests that Begg Rock may be an eroded volcanic neck. Three miles off the middle of the northern coast is a shoal area nearly two miles long and about 100 yards wide. This shoal is oriented nearly parallel to the long axis of the island. Sounding lines obtained on the E.W. SCRIPPS cruise of February 1951 have extended the shoal a quarter-mile east of the extremity shown on the 1949 edition of the U. S. Coast and Geodetic Survey chart. The extension had a minimum depth of 11 fathoms and dropped off abruptly on three sides to 30 fathoms. A number of samples were obtained from this shoal. All are a dark-colored, coarse-grained diabase. Many of the samples are freshly broken, establishing the igneous nature of the shoal beyond reasonable doubt. The shape of the shoal suggests a large dike rather than a volcanic neck like Begg Rock.

Submarine Terraces

An examination of echo-sounding profiles obtained in the San Nicolas area shows many small terrace-like benches interrupting the submarine slope. Average depths of the more persistent benches are given in Table I where they are compared to similar benches from other parts of the world. Locations of several benches in the San Nicolas area are shown in figure 2.

TABLE I

San Nicolas Area	Common World-wide benches (Shepard & Wrath)	World-wide low sea-levels (Zeuner)
55 to 65 feet	45 feet	---
110 to 130 feet	95 feet	100 feet
160 to 180 feet	155 feet	---
230 feet	210 to 225 feet	230 feet
---	270 feet	---
330 to 340 feet	300 to 330 feet	330 feet
---	---	660 feet

Submarine Canyons

Concentrated at the eastern end of the insular platform are nine submarine canyons. Two of these cut the slope into San Nicolas Basin, and seven enter the Santa Cruz Basin. Echo-sounding profiles along the slopes show smaller gully-like features between the canyons. The San Nicolas group of canyons have V-shaped cross-sections and possess longitudinal profiles closely similar to those of the larger canyons on the island. All dimensions, however, are on a much grander scale (see figure 3).

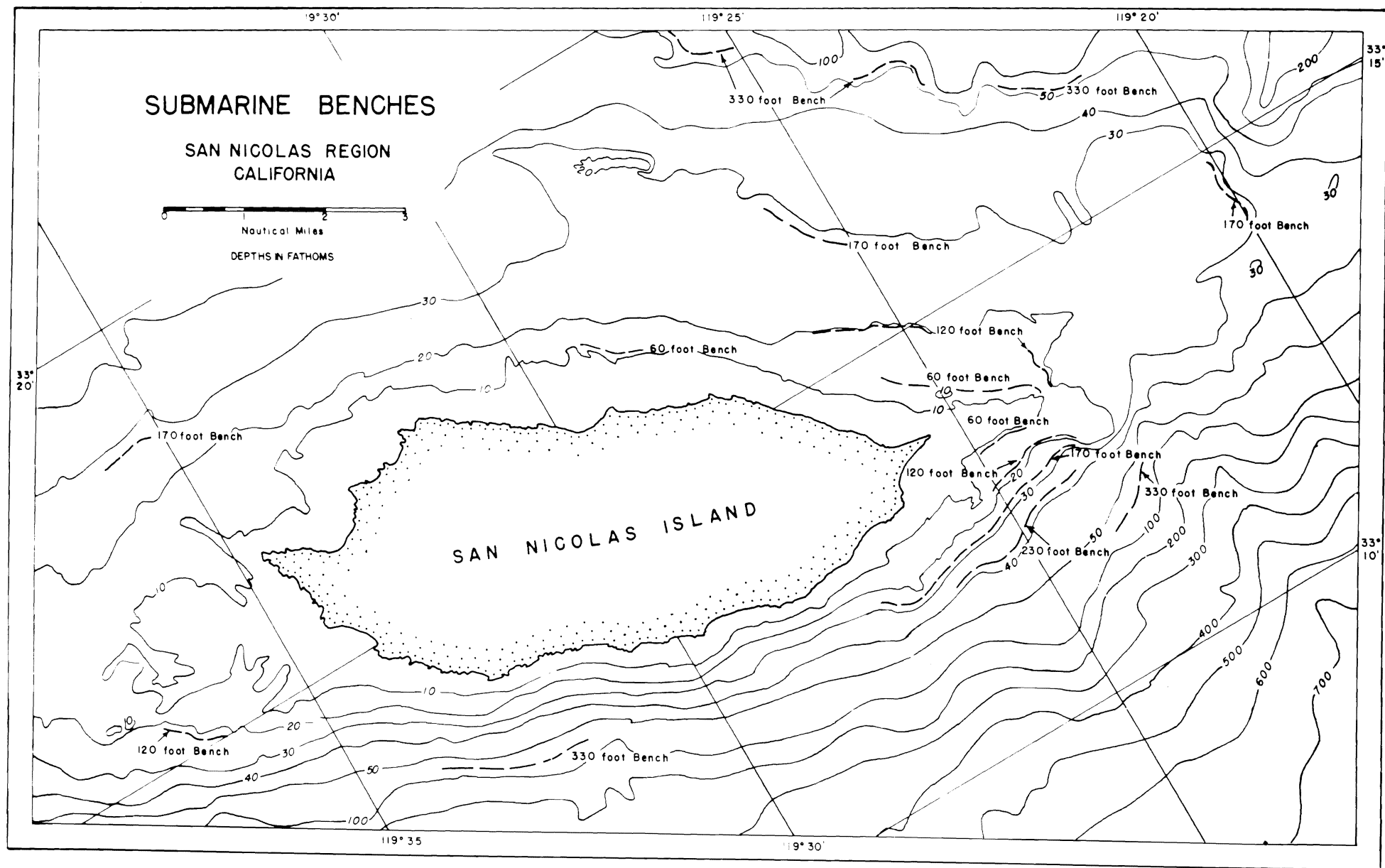


Figure 2. Location chart of the submarine benches.

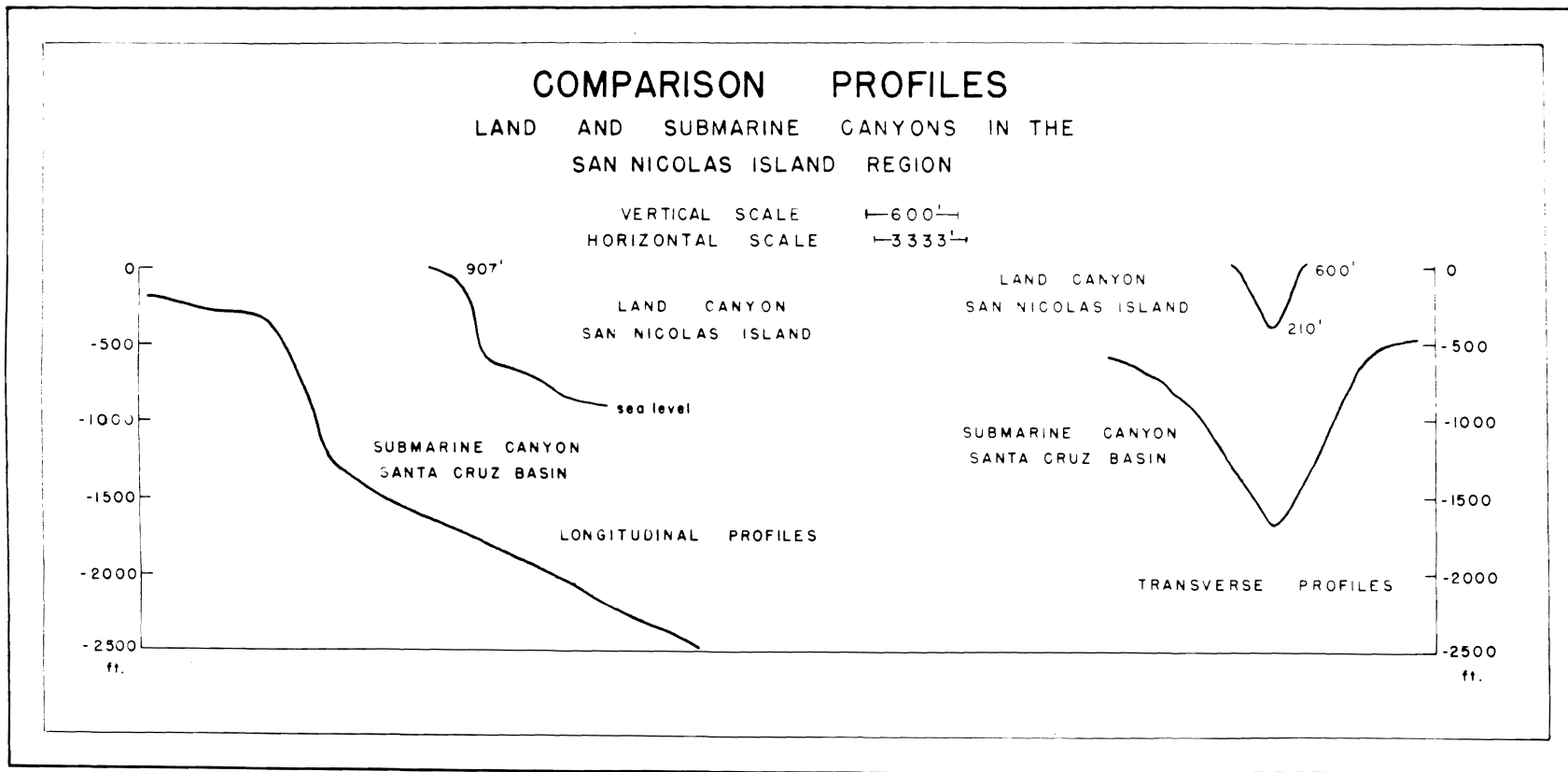


Figure 3. Submarine and land canyon profiles.

DISTRIBUTION OF BOTTOM TYPES

Areal distribution of various types of bottom is shown on the bottom sediment chart (figure 4). Data on which this chart is based are derived from the following sources:

- 923 U. S. Coast and Geodetic Survey bottom notations.
- 72 U. S. Navy Electronics Laboratory bottom photographs.
- 285 E. W. Scripps sample stations.

1280 total stations

Rock areas are doubtless more extensive than indicated on the chart; sampling devices frequently failed to obtain a representative sample of the bottom. Bottom photographs commonly show rocky areas with local accumulations of sand. Snapper samplers seldom are able to break off fragments of rock, and when used in such an area are very apt to recover only loose shell material, which is abundant in these samples.

Rocks freshly broken from submarine outcrops are principally sandstone and shale. The great majority of these rocks are lithologically very similar to sandstone and shale found on the island. Some shale fragments broken loose from the sea floor contain Eocene Foraminifera. However, dredging near the break in slope north of the island has provided samples of sandy shale, laminated cherty shale and fine-grained, thin-bedded sandstone. These rocks are unlike the Eocene of the island and are probably late Miocene since they contain siliceous casts of Foraminifera which, according to M. N. Bramlette (personal communication) are probably late Miocene.

Areas indicated as sandy on the bottom sediment chart (figure 4) include bottoms covered with terrigenous sand, shell sand, and broken shell gravel. Early in the sampling program it was found that the shell content of bottom sands varied greatly, even in short distances. Accordingly, differentiation was not practical without greatly increasing sample coverage. Sand is most extensive in the relatively featureless area northeast of the island between 20 and 35 fathoms depth. Other more restricted sandy areas occur near the sand spit, between sandy beaches and the 10-fathom curve, and as isolated patches on bottoms otherwise rocky. Many of the sandy patches shown west of the island are doubtless small accumulations between rocks or on rock surfaces. Many of these sand patches are based on two or three samples, often obtained with devices incapable of bringing up rock. Bottom photography and samples obtained by a chain-bag dredge have confirmed the joint occurrence of rock and sand.

Calcareous material in the sand-size shelf sediments is composed mostly of comminuted mollusk and echinoid shells, echinoid spines, bryozoa, and Foraminifera, in that order. Fifty-one shelf sediments were analyzed for calcium carbonate and showed a range from 11 to 100 percent. The average content of all bottom samples (which included some muddy sands) was 44 percent. The sands averaged 49 percent, over three times as high as the beach sands. Highest percentages were found in the shelly sands

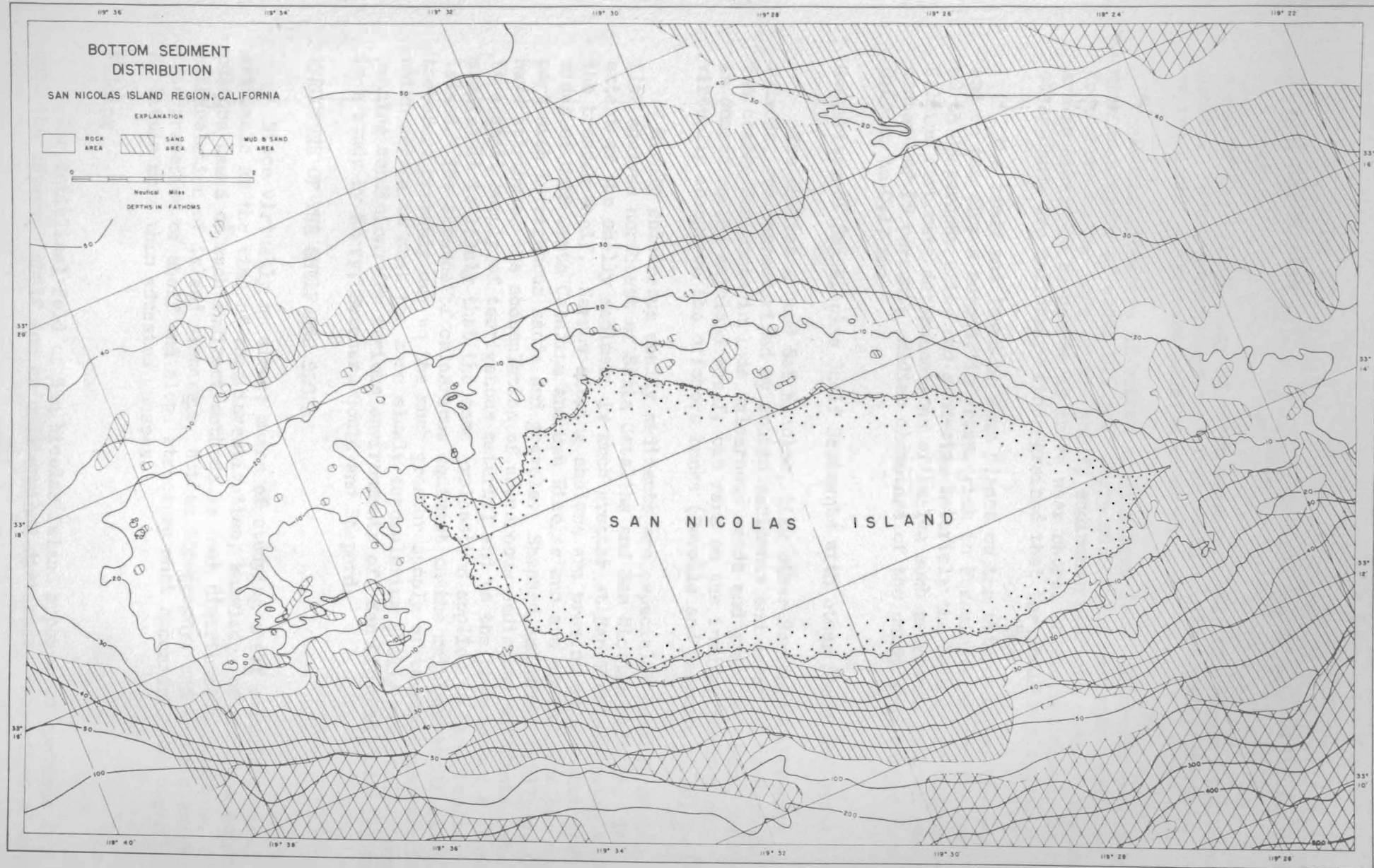


Figure 4. Bottom sediment chart

north of the island, many of which were more than 80 percent calcium carbonate. Lowest percentages came from south of the island, where the sands averaged only 28 percent calcium carbonate.

Median diameters of bottom sands ranged from 0.09 mm. to over 2.0 mm, with an average of about 0.5 mm. There was no uniform size gradation from shore to the edge of the shelf; sediments near the edge of the shelf are as likely to be coarse as those near shore. Slope sediments, on the other hand, are uniformly finer-grained than the shelf sediments.

The sandy mud found at some places on the outer edge of the shelf and on the slopes beyond, is green, rich in Foraminifera, and includes 60 to 85 percent silt- and sand-size material; the balance is clay-size. Calcium carbonate determinations of twelve such sediments gave an average content of 29 percent. Median diameters of the sandy muds ranged from 0.09 mm to 0.17 mm.

Comparison of San Nicolas Shelf Sediments with other Shelf Sediments

The shelves around San Nicolas, like other Southern California islands, are characterized by coarse sediments and areas of bare rock. The coarse sediments include calcareous sands and gravels. Sandy mud is common on the mainland shelf, but rare on the insular shelves and virtually absent on the offshore banks (Revelle and Shepard, 1939, p. 248).

Highly calcareous shelly sediments are especially notable on the flat shelves northeast of Santa Catalina and San Nicolas Islands. The extent of the shelly sediment is much greater at San Nicolas, owing to the broader shelf. Narrow sloping shelves are present on the southwest sides of both Santa Catalina and San Nicolas and are covered for the most part with terrigenous sands and gravels. Shepard and Wrath (1937, p. 42) have attributed the accumulation of calcareous sediments off Santa Catalina to a small supply of terrigenous material and to the presence of a flat shelf. It is likely that the same explanation applies to San Nicolas Island. The absence of calcareous sediment on the mainland shelf is therefore probably due to the much greater supply of terrigenous material which serves to mask the more slowly accumulating shelly material. Corresponding conditions for various environments off San Diego will be treated in a study by Emery, Butcher, Gould and Shepard.

STRUCTURE OF THE SHELF AND SLOPE

Since virtually no direct means of studying shelf structure were available at the time of this investigation, knowledge of shelf structure must be based on such indirect methods as rock distribution patterns, extrapolation of island structure, bottom topography, and seismic surveys. Interpretation of shelf and slope structure must necessarily be regarded as little more than educated guesses.

Folding

The anticlinal fold of San Nicolas Island appears to continue out onto the adjacent shelf for an undetermined distance. Projection of dips

measured at the coastline shows that a bed outcropping there would not reappear either on the shelf or the slope beyond (see figure 5). If dips remain constant across the shelf, progressively younger rocks would outcrop away from the island and down the slopes into the deep basins. Some substantiation of this hypothesis is provided by the occurrence of possible Miocene rocks near the edge of the northern shelf.

Faulting

Shepard (1948, pp. 193-194) lists evidence for the fault origin of continental slopes which is useful for recognizing submarine fault scarps in general. These criteria can be applied as follows: the slope from the insular shelf into the Santa Cruz Basin is steep ($6^{\circ}40'$), straight, and has abundant rock outcrops. Further, the topography of the Santa Cruz Basin resembles that of some structural basins in eastern California (e.g., Saline Valley, Inyo County), which suggests a fault origin for the slope. The slope on the south side of the island also shows evidence of fault origin. It not only is steeper (11°), but is the site of seismic activity (Clements and Emery, 1947, Plate I). The steep, eroded southern face of the island may therefore be a resequent fault line scarp eroded back from the original fault by combined wave and stream attack. The slopes may, however, be dip slopes of the asymmetrical anticlinal island, modified by erosion, but without important faulting.

FORAMINIFERA ECOLOGY

Foraminifera population counts were made on 29 bottom samples, 25 of which were located along three traverses. Two of the traverses on the south side of the island extended from the 10-fathom contour out into deep water in the San Nicolas Basin (600+ fathoms). The third traverse was confined to the shelf north of the island from 10 to 50 fathoms depth. The other four samples were not on any traverse.

In general, samples nearest shore and therefore in shoalest water had the smallest populations per gram of sample (dry weight). This fact may be due to a more rapid sedimentation rate near shore and to the more common destruction of delicate Foraminifera tests in shallow water. Wave action undoubtedly stirs and shifts shallow-water sediments more vigorously and more often than it does the deep-water sediments. The presence of the shoal water form Discorbis rosacea (d'Orbigny) in water over 500 fathoms suggests a down-slope movement of sediment.

The ratio of benthonic individuals to planktonic individuals is not constant along any of the traverses, which suggests that population density is also dependent upon depth and/or the type of bottom. As a rule, benthonic individuals outnumber planktonic individuals in shallow water, whereas the reverse is true in deep water. The benthonic population in the San Nicolas region is dominated by four species:

A HYPOTHETICAL STRUCTURE SECTION ACROSS SAN NICOLAS ISLAND AND THE ADJACENT PLATFORM

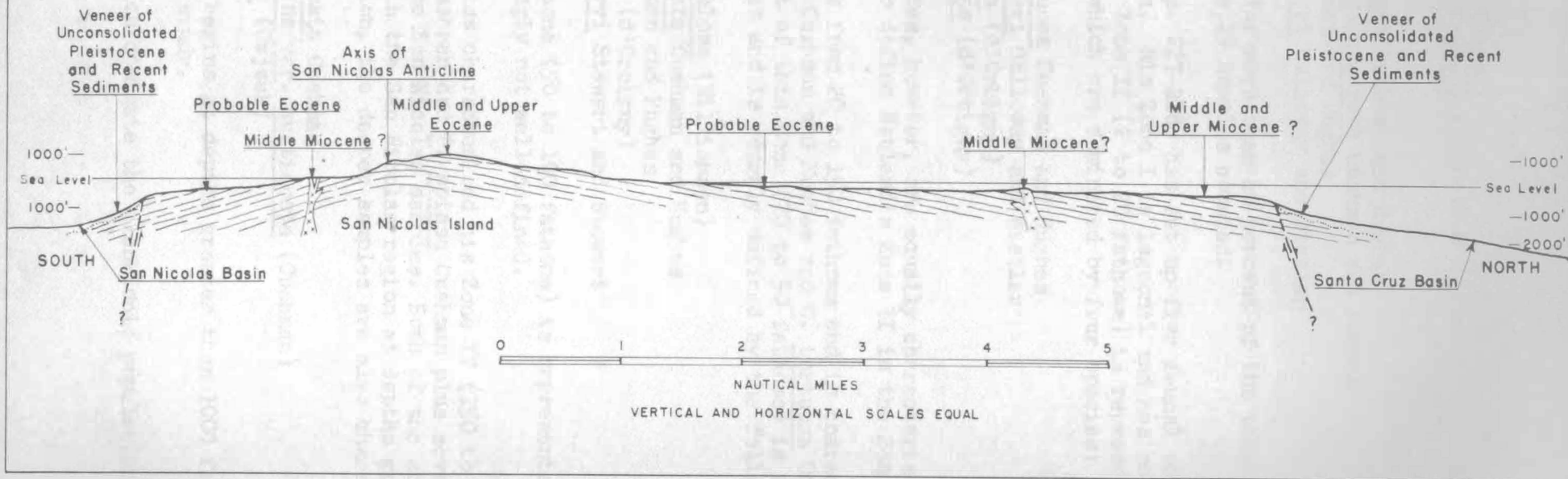


Figure 5. Structure section across island and adjacent shelf.

Cassidulina limbata Cushman and Hughes
C. subglobosa var. quadrata Cushman and Hughes
C. tortuosa Cushman and Hughes
Cibicides fletcheri Galloway and Wissler

These species account for more than 40 percent of the total benthonic population in 22 of the 29 samples counted.

Natland (1933, pp. 227-228) has set up five faunal zones for Southern California Foraminifera. His Zone I is lagoonal and has no equivalent in the San Nicolas area. Zone II (2 to 20 fathoms) is represented in this study by four samples which are dominated by four species:

Cassidulina tortuosa Cushman and Hughes
Cibicides fletcheri Galloway and Wissler
Discorbis rosacea (d'Orbigny)
Hoplundina elegans (d'Orbigny)

All the foregoing species, however, are equally characteristic of deeper water and cannot be said to define Natland's Zone II in the San Nicolas region.

Zone III extends from 20 to 150 fathoms and is characterized here by Cassidulina limbata Cushman and Hughes and C. tortuosa Cushman and Hughes. The upper part of this zone (20 to 50 fathoms) is represented in this study by 20 samples and is roughly defined by the following species:

Angulogerina angulosa (Williamson)
Cassidulina limbata Cushman and Hughes
C. tortuosa Cushman and Hughes
Planulina ornata (d'Orbigny)
Pullenia salisburyi Stewart and Stewart

The lower part of the zone (50 to 100 fathoms) is represented by only four samples and is accordingly not well-defined.

Natland (ibid.) has characterized his Zone IV (150 to 1080 fathoms) by Bolivina argentea Cushman and B. spissa Cushman plus several other species not noted in the San Nicolas samples. Both of the above species, however, are abundant in the San Nicolas region at depths greater than 150 fathoms. In addition, the deeper samples are also characterized by:

Cassidulina delicata Cushman
Uvigerina peregrina var. curticosta (Cushman)
Sigmoilina tenuis (Czjzek)

Natland's Zone V begins at depths greater than 1000 fathoms and has no counterpart in this study.

Three species which dominate the planktonic population in nearly all the samples are:

Globigerina bulloides d'Orbigny

G. eggeri Rhumbler

Orbulina universa d'Orbigny

In 20 of the 29 samples G. eggeri Rhumbler was the most abundant planktonic form; in the rest, G. bulloides D'Orbigny was the commonest.

GEOLOGIC AND GEOMORPHIC HISTORY

EOCENE

The first known event in the San Nicolas region is the deposition of more than 2000 feet of marine sandstone and shale during middle and late Eocene time. Source of this material is unknown, although Reed (1933, p. 143) has suggested the possibility of a Catalinian land-mass east of San Nicolas. Reed and Hollister (1936, p. 28) point out that there is evidence of folding activity at the close of the Eocene. The San Nicolas anticline may have come into existence at this time.

OLIGOCENE

No rocks of this age are known from either the island or the adjacent sea floor. If the San Nicolas anticline was not developed during the Eocene, it could have been formed during the orogenic period at the close of the Oligocene.

MIOCENE

No Miocene sedimentary rocks occur on the island, but, as mentioned earlier, may be present near the edge of the insular shelf (see Emery and Shepard, 1945, p. 444).

Volcanic activity was very widespread in Southern California during the Middle Miocene, more so than at any time since the opening of the Tertiary. For this reason, volcanic activity which gave rise to the diabase dikes on the island and shelf and to the rhyolitic Begg Rock is tentatively assigned to the Middle Miocene.

PLIOCENE

Little is known of Pliocene history because no rocks of that age have been found on the island or adjacent shelf. It has been supposed, however, that the San Nicolas area was above sea-level during the Pliocene and was being eroded (Reed, 1933, p. 252).

PLEISTOCENE

Probable total submergence of San Nicolas occurred during the Middle Pleistocene. Marine terrace deposits of this age occur on the 750-foot terrace, although they have not definitely been found on the 835-foot terrace. San Nicolas Island terrace levels do not correspond

well with world-wide levels and only to a limited degree with other Southern California terraces. It is therefore suggested that the San Nicolas terraces are at least partly the result of diastrophic movements of the insular block.

The submerged terraces seem much more closely related to world-wide features of this nature and are probably due to eustatic sea-level changes rather than diastrophic movements of the insular block (Zeuner, 1945, p. 252).

SUMMARY AND CONCLUSIONS

Calcium carbonate in beach sands suggests an origin of considerable beach material below half-tide. An average of 13 percent of island beach sands was shell material, nearly all of which comes from below half-tide. The sand spit at the southeastern end of the island has been built by sand moved easterly along the northern shore of the island by longshore currents. Considerable sand deposited on the north side of the spit is eventually blown across to the southern side where it is redistributed by a west-flowing longshore current. A study of the history of the spit has shown that on at least one occasion it had shifted a considerable distance north of its present position. In recent years only slight changes have occurred.

Study of the island terraces indicates total submergence took place during the Middle Pleistocene. Development of terraces is attributed to a combination of diastrophic movements of the insular block and eustatic sea-level changes which have shifted the plane of wave-erosion.

The broad shelf north of the island is for the most part an area of Eocene rock thinly covered with patches of shelly-sands and -gravels. An elongate dike-like diabase outcrop occurs near the outer edge of the northern shelf. Rocks from the edge of the northern shelf bear a resemblance to parts of the Middle and Late Miocene Monterey formation of the mainland. The presence of rounded cobbles and pebbles which show no evidence of recent transport, plus the presence of glauconite and phosphorite grains, indicates that the shelf is primarily a nondepositional environment. The shelf on the south side of the island is much narrower and steeper and lacks the shell sands which are common north of the island.

Submarine benches found at a number of places around the island show a remarkable agreement with other submarine benches in the world. This correspondence suggests that they may have been formed during eustatic sea-level shifts of the Pleistocene.

Recent Foraminifera from the San Nicolas region show a depth zonation in general agreement with depth zones established by Natland in the Santa Catalina region and by Butcher (1951) in the San Diego area.

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