Geologic Reconnaissance of San Clemente Island California

By F. H. OLMSTED

CONTRIBUTIONS TO GENERAL GEOLOGY

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CONTENTS

ILLUSTRATION

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By F. H. OLMSTED

ABSTRACT

San Clemente Island, which is the southernmost of the channel islands lying off the coast of southern California, is a gently arched and faulted block of the earth's crust composed principally of volcanic rocks. The volcanic rocks are chiefly pyroxene andesite flows and pyroclastic rocks which are overlain by relatively thin flows of dacite and rhyodacite or rhyolite. Overlying or interbedded with the upper part of the volcanic sequence are thin, discontinuous masses of marine sedimentary rocks which contain abundant fossils of probable middle Miocene age. The youngest deposits on the island are older sand deposits of probable Pleistocene age and younger sand deposits and alluvial-fan deposits of Recent age. Marine terrace deposits, soil, and landslide deposits are extensive but thin and generally were not mapped.

The San Clemente Island block is bounded on the northeast by a major fault—the San Clemente fault—on which the movement may have been chiefly horizontal. The volcanic rocks of the island are deformed by a gently domal or anticlinal structure whose axis is approximately parallel to the San Clemente fault. In addition, the rocks are cut by a system of relatively small faults that trend approximately north and also by a set trending N. 20°–30° W.

INTRODUCTION

PURPOSE AND SCOPE OF THE INVESTIGATION AND REPORT

At the request of the Department of the Navy, the United States Geological Survey made a geologic and hydrologic reconnaissance of San Clemente Island, Calif. The purpose of the present report is to make public the geologic information obtained during the investigation. In essence, this report refines the areal geology shown on the small-scale map included in an excellent paper by W. S. T. Smith (1898). The report also furnishes additional data on the age and lithology of the rocks and deposits described by Smith.

METHOD OF STUDY

The geology was studied by the writer under the immediate direction of Fred Kunkel, geologist in charge of the Long Beach area office of the Ground Water Branch, U. S. Geological Survey, and under the general supervision of G. F. Worts, Jr., district geologist in charge of ground-water investigations in California. The geologic fieldwork, which was done during a 3-month period largely in the autumn of 1955, consisted of a detailed reconnaissance of the northern part of the island and a somewhat more general reconnaissance of the southern part. The mapping was done on vertical aerial photographs provided by the Navy at a scale of about 1:24,000 and the geology subsequently was transferred to topographic maps of the U. S. Geological Survey at the same scale.

In addition to the field mapping, representative samples of the rocks were collected for study by the writer and by J. G. Vedder, geologist of the Fuels Branch, U. S. Geological Survey.

PREVIOUS INVESTIGATIONS

Three earlier geologic papers that contain references to San Clemente Island are listed at the end of this report. Of these papers the one by Smith (1898), which describes the geologic features of the island in considerable detail, was particularly useful.

GEOGRAPHIC SETTING

San Clemente Island is the southernmost of the group of channel islands off the coast of southern California. The center of the island, at about 32°50′ N. latitude and 118°30′ W. longitude, is about 80 miles slightly north of west from San Diego, and about 60 miles slightly west of south from San Pedro (pl. 1). The island is rather long and narrow, and the long axis trends approximately northwest—roughly parallel to the mainland coast between San Diego and San Pedro. The length of the island is slightly less than 21 miles; the width ranges from less than 1½ miles near the northern end to more than 4 miles in the relatively broad southern part. The area is approximately 56 square miles.

LOCATION-NUMBERING SYSTEM

A location number is used to describe the fossil-collecting localities and other sites on the island according to a system of latitude and longitude coordinates. The location number, which is enclosed in parentheses, consists of two parts separated by a hyphen. The first group of digits indicates the minutes and tenths of minutes of latitude north of 32° N. latitude; the group of digits following the hyphen indicates the minutes and tenths of minutes of longitude west of 118° W. longitude. For example, in the location number (56.6–31.8) for a fossil-collecting locality, the latitude is 32°56.6′ N., and the longitude is 118°31.8′ W.

PHYSIOGRAPHY

San Clemente Island may be described broadly as the upper part of a tilted and gently arched northwestward-trending block of the earth's crust that has a straight, steep northeastern slope and a more irregular and much gentler southwestern slope. The top of this block rises more than a mile above the adjacent ocean deeps, but only the upper 2,000 feet is above sea level (pl. 1). Transverse sections across the block (pl. 1) indicate clearly the asymmetrical shape. The steep northeastern slope, an eroded fault scarp, averages about 15° but locally is more than 30°, particularly in the part above sea level. On the other hand, the southwestern slope averages less than 5°, although it is somewhat steeper between sea level and an altitude of 1,500 feet because of the formation of wave-cut terraces during intermittent uplift of the island, probably during the Pleistocene epoch.

These marine terraces are some of the best examples of this feature to be found anywhere. Lawson (1893) and Smith (1898) recognized more than 20 distinct terraces below an altitude of about 1,500 feet, and careful study with good altitude control might reveal still more. Well-developed terraces do not occur above an altitude of 1,500 feet on the southwestern side of the island, and because of the steepness of the northeastern escarpment, terraces are poorly developed or absent on that side. Either the part of the island above 1,500 feet never was submerged, or it rose above sea level steadily rather than intermittently.

The terraces slope gently seaward, as does the similar offshore bench now being formed. The surfaces are mantled thinly and discontinuously by gravel and sand of marine origin, by gravel and rubble of alluvial and colluvial origin, and by soil that is characteristically high in clay content.

At most places the axial drainage divide of the island is close to the upper edge of the northeastern escarpment. The upper reaches of some of the stream courses draining to the northeast have relatively gentle gradients where they traverse the plateaulike upper part of the island, but the gradients become exceedingly steep once the escarpment is reached.

The southwestern slope of the island is notched by a series of rather steep-sided gullylike canyons. The upper reaches of most of these stream courses are ill defined, particularly those in the central and northern parts of the island. Farther downslope the streams have cut sharp V-shaped canyons that have steep walls of rock and bottoms floored either by rock or by a veneer of gravel. Dry cataracts and falls are common in many of these canyons; the plunge pools, or natural tanks, at the bases of some of these falls contain water throughout the year and afford a drinking-water supply to the several thousand goats and other animals on the island. The largest canyons are in the southern part of the island, where they reach depths of more than 500 feet. The geologic youthfulness of these canyons is indicated by the irregularity of their longitudinal profiles and by the virtual absence of integrated drainage patterns—each stream pursues a rather straight course in the direction of maximum slope of the general land surface, and branching tributaries are minor and scarce.

The island block is arched slightly not only along its long northwestward-trending axis but also in the transverse direction, so that from the northeast, as one might view the island from the direction of the mainland, the profile appears as a smooth, gradual slope downward toward both ends from the high point nearly 2,000 feet above sea level somewhat southeast of the center of the island. Submarine contours on the Coast and Geodetic Survey charts, reproduced in part on plate 1, indicate that these gradual slopes continue below sea level.

GEOLOGIC UNITS

Although San Clemente Island is composed principally of volcanic rocks of probable Miocene age, it contains some sedimentary rocks and unconsolidated sediments which range in age from Miocene to Recent. Seven unnamed geologic units are recognized, and, except for one minor sedimentary unit, they correspond generally to the units established by Smith (1898). Their distribution is shown on the geologic map (pl. 1) and their thickness and stratigraphic relations are shown in part on three geologic sections across the island (pl. 1).

The volcanic rocks, which constitute by far the bulk of the island, are chiefly lava flows and associated pyroclastic rocks that are predominantly andesitic but range in composition from andesite or basaltic andesite to rhyodacite or rhyolite. Smith (1898) mapped most of these rocks as andesite, but he assigned the youngest flows on the island to two additional units, dacite and rhyolite. The andesite, dacite, and rhyolite are readily mappable and, except for minor modifications, are shown on plate 1.

The sedimentary units are marine sedimentary rocks, equivalent to Smith's Miocene deposits; older sand deposits, roughly equivalent to Smith's later deposits; younger sand deposits, equivalent to Smith's aeolian sands; and alluvial-fan deposits, not mapped separately by Smith. Certain differences in the assignment of rocks to these units by Smith and the author are explained in the discussion of the individual units.

In addition to the mapped units, there are extensive but thin marine terrace deposits, alluvial and colluvial deposits, soil mantling the terraces and other relatively flat surfaces on the island, and landslide detritus along parts of the steep northeastern escarpment. Generally these materials are less than 10 feet thick, and except for the extensive landslides 2–3 miles southeast of Wilson Cove, and the relatively thick alluvial-fan deposits (*Qf*) on the lower terraces in the southern part of the island, they are not differentiated from the underlying rocks on the geologic map.

ANDESITE (MIOCENE)

Probably more than 95 percent of the bulk of San Clemente Island consists of a somewhat heterogeneous sequence of volcanic flows and pyroclastic rocks designated as andesite (*Ta*, *Tap* on pl. 1). These rocks attain a thickness of at least 2,000 feet and probably are considerably thicker, as is suggested by the "rocky" sea bottom at considerable depths as recorded by the U. S. Coast and Geodetic Survey on charts of San Clemente Island and vicinity.

The unit consists predominantly of pyroxene andesite in the form of flows, but pyroclastic rocks of similar composition, principally coarse breccia and tuff breccia, locally are abundant, particularly in the southern part of the island. Individual flow units range in thickness from a few feet to 50 feet or even more. Feeder dikes also are present but generally are not large or numerous. Much of the coarse breccia probably resulted from autobrecciation of flows, particularly near the margins where cooling facilitated solidification of the lava before movement ceased. Other beds of breccia and tuff breccia may have been deposited from eruptions of the peléan type or from mudflows. The flow rocks show great variety in structure and texture, but with few exceptions their composition appears to be that of pyroxene andesite. Several types of rock, each characterized by a more or less distinctive structure and texture, were identified in the field, but their relations are far too complex to permit delineating them adequately at the scale of the geologic map (pl. 1). One type, however, a porphyritic phase (*Tap* on pl. 1), was differentiated in a sizable area of outcrop in the northern part of the island. The various types of andesite are described briefly in the following paragraphs.

Possibly the most abundant phase of the andesite is a flow rock that is slightly to moderately porphyritic and irregularly to blockily jointed. Typically, the rock has a medium-gray to nearly black very fine-grained groundmass through which are scattered nearly euhedral phenocrysts of plagioclase averaging about 3 mm in diameter and smaller phenocrysts of pyroxene and altered dark minerals. In places the rock is highly vesicular, but generally vesicles are sparse or absent. Weathered surfaces are rough and pitted, and commonly this phase is brecciated. In thin section the rock has a hyalopilitic groundmass consisting of glass, scattered tiny laths of plagioclase, and fine magnetite dust. Flow banding is absent or inconspicuous. The phenocrysts, most of which are calcic andesine or sodic labradorite and some of which are zoned, constitute as much as half the volume. Both augite and hypersthene are present; the hypersthene generally is more abundant and shows better developed crystal outlines than the augite, which often occurs as clumps of small rounded crystals. Intergrowths of plagioclase with pyroxene of both types are common in some of the thin sections that were studied.

A second important phase of the andesite, which at many places is gradational with the first phase, is highly vesicular to scoriaceous, is nonporphyritic to slightly porphyritic, ordinarily is highly fractured or brecciated, and is dark gray, black, or red. The vesicles, which are as much as 2 inches across, locally are elongated in the direction of flow. Smith (1898, p. 481) reported that at China Point this rock consists almost entirely of pale brownish-yellow glass containing scattered small laths of labradorite.

A third phase of andesite, which is intimately associated with the first, is distinguished by prominent platy jointing. This rock is slightly to moderately porphyritic and has a holocrystalline groundmass in which many of the crystals of plagioclase and pyroxene can be distinguished with the aid of a hand lens. The joints commonly curve in concentric shells to form onionskin structures, suggesting that much of this rock occurs as tube fillings and possibly as small intrusive bodies.

A fourth phase, possibly of dacitic composition, is a dark-gray aphanitic rock almost totally lacking in phenocrysts. This type is cut by slabby or blocky jointing, and it characteristically has small incipient fractures and flattened vesicles along the flow lines. Where weathered slightly the rock breaks into thin platy or slaty chips along the flow lines, and the weathered surfaces are characteristically light gray to light purple.

The fifth phase, a porphyritic rock that may be in part dacitic, occurs principally in two areas, one west of Wilson Cove in the northern part of the island, the other a few miles northwest of China Point in the southern part of the island. Only the exposures near Wilson Cove are differentiated; they are shown as andesite porphyry (*Tap*) on plate 1. The rock typically contains abundant phenocrysts of plagioclase and fewer phenocrysts of dark minerals in an aphanitic groundmass that ranges from bluish gray to reddish purple and grayish black. Flow banding, though not strongly developed, is a nearly universal characteristic of the rock. Thin red partings along the flow lines resemble those in some of the dacite and rhyolite. Jointing ordinarily is regular and may break the flows into plates, slabs, blocks, or polygonal columns. The rock is only locally vesicular. Under the microscope the groundmass is seen to consist of glass, magnetite dust, abundant feldspar and quartz(?) microlites, and scattered tiny laths of plagioclase. The large and abundant phenocrysts are mostly of zoned plagioclase having an average composition near the andesine-labradorite border (An_{50}). The pyroxenes are pale-green to pink hypersthene and augite of remarkably similar appearance. As in most of the other rocks examined from the island, the hypersthene shows little or no pleochroism.

DACITE (MIOCENE)

The unit designated dacite (*Td* on pl. 1) occupies a sizable area near the center of the island and is exposed also in two other small areas—one at the summit of the island, the other at Pyramid Head on the southern tip. Like the rhyolite, the dacite, where present, overlies the andesite and is characterized by prominent outcrops of dense, generally nonvesicular rock broken by widely spaced joints into large blocks or slabs. Megascopically, however, it differs from the rhyolite in having many fewer and much smaller phenocrysts and in being ordinarily somewhat darker gray or even black. The dacite occurs as two or more distinct flows and at a few places as feeder dikes or necks cutting both the dacite flows and the underlying andesite. In the central part of the island the dacite ranges in thickness from about 100 to 225 feet. The rock is extremely resistant to weathering and abrasion, and the marine terraces cut on it are not nearly as prominent or well defined as those cut on the andesite.

Megascopically the dacite is distinguished readily from the underlying andesite. The flow banding, marked by slightly wavy subparallel thin lines generally having lighter or redder color than the remainder of the rock, is unlike that in most types of the andesite. The groundmass, which with few exceptions makes up 90 to nearly 100 percent of the rock, is always aphanitic. The phenocrysts are small (2 mm or less) and are mostly clear feldspar. Fresh surfaces of the dacite are light gray to black, but much of the rock is weathered or altered slightly and has a bluish, purplish, or reddish tinge. Rims of grayish-yellow weathered rock less than half an inch thick are common at many of the dacite exposures and are unlike any weathered zones observed in the andesite. One of the most ubiquitous features of the dacite is the incipient parting developed along the thin flow lines. Only a part of the rhyolite and the porphyritic phase of the andesite (*Tap* on pl. 1) have similar parting.

Under the microscope the dacite ranges from almost completely nonporphyritic to slightly porphyritic. In the latter type the phenocrysts constitute about 10 percent of the total volume. The groundmass in most cases is pilotaxitic and moderately flow banded, consisting of a feltlike assemblage of small laths of feldspar, grains of magnetite, and scarce grains of pyroxene. A few samples contain a small amount of interstitial glass. Some phases of the rock contain micropoikilitic patches consisting of quartz and feldspar, a feature described in some detail by Smith (1898, p. 484). Most of the phenocrysts are euhedral plagioclase, commonly showing oscillatory zoning with calcic centers and sodic rims. The average composition is that of andesine (An_{40-45}). Phenocrysts of pyroxene are relatively small and scarce and are missing altogether in some of the rock. Both hypersthene and augite are present in small amounts in most specimens, although the hypersthene generally is altered to iron oxide and serpentine.

RHYOLITE (MIOCENE)

The rhyolite (*Tr* on pl. 1) is a massive to prominently flow-banded porphyritic rock deposited predominantly as flows, although a small amount of tuff occurs in the basal part of the unit. The two principal areas of exposure are a band about a mile wide across the island near the northern end and an area extending from Wilson Cove about 3 miles southward. At most places the rhyolite ranges in thickness from a few tens of feet to perhaps 100 feet; the maximum thickness may be about 150 feet near Northwest Harbor. Where present, the rhyolite overlies the andesite, and it was believed by Smith (1898) to be the youngest volcanic rock on the island, although it may be of the same age as the dacite farther south.

The rhyolite commonly forms large blocky or slabby outcrops outlined by a rectangular system of joints as much as 20 feet apart; however, much of the rock is irregularly and highly jointed. Where they have been subjected to wave action, the sides of the blocks and slabs are strongly fluted along lines of weakness parallel to flow banding in the rock. Most of the rhyolite is exceedingly dense, but in places it contains abundant small vesicles, and some of it contains small cavities formed by the solution and partial removal of the ferromagnesian minerals.

The rhyolite generally is highly porphyritic, containing white phenocrysts about 2–5 mm in diameter in a microcrystalline to vitreous groundmass. The groundmass is grayish pink, reddish purple, purplish gray, light to dark gray, yellowish gray, grayish black, and grayish blue. Streaks and lenses of light-colored material are common in some of the darker phases. In hand specimen the phenocrysts are seen to consist predominantly of white-opaque to clear plagioclase having somewhat rounded outlines. Clear quartz, magnetite(?), and small phenocrysts of pyroxene, which are generally altered to iron oxides, also can be identified in many specimens.

The rhyolite was examined microscopically by Smith (1898), who based his classification of the rock partly on mineralogy but chiefly on a chemical analysis of a specimen from Northwest Harbor; the analysis indicated silica content slightly more than 70 percent. Smith's examination of the rock revealed that it contains numerous phenocrysts of feldspar, fewer scattered phenocrysts of hypersthene and magnetite, and scattered crystals of augite and pyrite. Quartz is present in some of the rock. The groundmass is partly microcrystalline and partly glassy and most of it shows flow lines. The feldspar phenocrysts consist of andesine and commonly are much resorbed. The pyroxenes, chiefly hypersthene, are never abundant, and most of the hypersthene is altered to serpentine and epidote. Quartz and orthoclase occur with plagioclase and glass in the groundmass.

Several thin sections of rhyolite obtained from the exposure near the northern end of the island were examined by the writer, whose findings agree in general with those of Smith. The plagioclase phenocrysts are chiefly rather basic andesine (An_{40-45}), which is about the composition of the phenocrysts in the dacite and andesite. Many of the phenocrysts are zoned, having more calcic centers and more sodic rims. Quartz occurs sparsely as large fractured and corroded phenocrysts. Flow banding is virtually lacking in some of the very light-colored phases of the rock.

Both Smith's and the writer's data suggest that the rhyolite is petrologically related to the dacite and andesite present on the island and can be described as a somewhat more acidic phase of those rocks. The silica content of about 70 percent, the somewhat calcic composition of the plagioclase phenocrysts, the presence of pyroxene, and the scarcity of quartz all suggest that the rock might be classified as a rhyodacite (quartz latite) instead of a true rhyolite. The megascopic similarity of some of the rock near the base of the unit to certain types of the andesite suggests that some of the rocks referred to as "rhyolite" may be of more basic composition than true rhyolite.

A bed of compact pink to green tuff about 3 feet thick occurs at the base of the rhyolite near the northern end of the island. A somewhat thicker bed of pumice also occurs at the base of the unit in the exposures near Wilson Cove. The source or sources of the tuff, and of the rhyodacite flows themselves, were not found during the investigation.

MARINE SEDIMENTARY ROCKS (MIOCENE)

The marine sedimentary rocks consist predominantly of light-colored thin-bedded siltstone, shale, diatomite, and limestone. At many places the unit has a basal member of coarse, friable sandstone composed of andesitic detritus. Beds of water-laid tuff, tuff breccia, ash, and pumice occur locally, particularly near the southern end of the island. One exposure in a quarry at (55.8-30.3) consists entirely of massive, poorly consolidated coarse dacitic sand. The fine-grained strata generally are white to grayish yellow; the coarse sandy beds are grayish orange to moderate yellowish brown, green, pink, or reddish purple.

These rocks contain abundant diatoms, Foraminifera, and Mollusca which indicate that the unit is of Miocene age and was deposited in a marine environment of shallow to moderate depth. Smith (1898) mentioned the presence of Radiolaria, Foraminifera, diatoms, fish scales, and impressions of *Pecten peckhami* Gabb. In December 1955, J. G. Vedder of the Fuels Branch of the Geological Survey collected several fossiliferous samples and identified the megafossils. Foraminifera from the samples were identified by Mrs. G. I. Smith, also of the Fuels Branch. The following brief discussion presents the results of the determinations.

At locality F1 (55.8–30.3) about 10 feet above the base of a 25-foot-thick exposure of coarse dacitic sand is a fossiliferous layer less than half a foot thick. The fossils consist largely of *Lyropecten crassicardo* Conrad, a large pectinid that ranges in age from middle to late Miocene.

A very coarse, gritty volcanic sandstone uncovered in an excavation at locality F2 (56.6–31.8) contains abundant shell fragments, chiefly pectinids, and scattered mammalian bones. The sandstone overlies an andesitic flow rock and appears to be overlain by a terrace rubble which contains fragments of *Haliotis* sp. of probable Pleistocene age. The pectinid shells were determined to the *Aequipecten* cf. *A. andersoni* (Arnold). Vedder states that this form bears more ribs (17–19) than the typical form. *Aequipecten andersoni* s. s. is considered to be a guide to the middle Miocene.

At locality F3 (57.2–31.6) foraminiferal siltstone and fine sandstone, medium sandstone, and limestone overlie a stratum of gritty andesitic sandstone about 8 feet thick that in turn overlies a flow of platy-jointed andesite. The Foraminifera include two important guides to the Luisian stage (middle Miocene) of Kleinpell (1938), namely *Valvulineria californica* and *Siphogenerina nuciformis*.

An exposure of siltstone, fine sandstone, and diatomite along the shore 2 miles southeast of Wilson Cove (locality F4) contains a large assemblage of Foraminifera that includes *Valvulineria californica*, *Valvulineria depressa*, and *Bolivina advena striatella*. These forms presumably belong in Kleinpell's Luisian stage (middle Miocene). Similar strata at Wilson Cove (locality F5) contain phosphatized Foraminifera that are questionably of early Miocene age.

The evidence listed above seems to indicate a middle Miocene age for the marine sedimentary rocks on the island. At most places the marine sedimentary rocks overlie the volcanic rocks (andesite, dacite, and rhyolite), but locally they are intercalated with the upper part of the volcanic rocks, a relationship that was not mentioned by Smith (1898). The diatomite and tuffaceous claystone at locality (51.8–25.4) in the southern part of the island overlies andesite and is overlain by andesite breccia that in turn is overlain by an andesite flow.

The exposed thickness of marine sedimentary rocks ranges from a few feet to a maximum of between 250 and 300 feet. These rocks, which are exposed at scattered localities on the island, generally occur as remnants preserved in downthrown fault blocks. Doubtless they once were thicker and more extensive within the area of the present island.

OLDER SAND DEPOSITS (PLEISTOCENE?)

The older sand deposits (*Qso* on pl. 1) consist of sand, silt, and clay that are chiefly old dune deposits but also include old beach sand and lagoonal deposits. Most of these deposits are compact and weathered and contain yellowish-brown to medium-brown silt and clay derived primarily from alteration of the originally abundant feldspar grains. However, unweathered gray loose sand locally is abundant. Some of the sand is cemented with calcium carbonate, which is probably derived from the solution of small fragments of molluscan shells. Discontinuous irregular layers, lenses, and nodules of white caliche ($CaCO_3$) occur throughout the deposits but are most abundant in the present soil zone.

The indentifiable sand grains include feldspar, which commonly is altered in large part to clay minerals, lithic fragments, magnetite, shell fragments, and scarce pyroxene. The deposits are massive to somewhat stratified, and their predominantly eolian origin is indicated clearly by strong crossbedding in which the foreset beds dip steeply (30°–35°) eastward.

In places the older sand deposits closely resemble the sandy beds in the marine sedimentary rocks of Miocene age, and it is difficult to differentiate the two units where both are present and are essentially flat lying. Their distinction is difficult principally in the large area centered about $4\frac{1}{2}$ miles south-southeast of Wilson Cove, shown on plate 1 chiefly as exposures of older sand. Much of that area may be underlain directly by the sedimentary rocks of Miocene age.

Smith (1898) showed a sizable area of sedimentary exposures 1–3 miles southwest of Wilson Cove as Miocene deposits. The present writer, however, believes that most of the exposed deposits in that area probably are of Pleistocene age and that many of the sandy beds are of windblown origin, as previously described. The most conclusive evidence for the Pleistocene age of at least a part of these deposits is that they overlie, and at several places completely mask, the marine terraces. If the deposits were Miocene, as Smith believed, terraces should be cut into them as they are into the nearby volcanic rocks.

The maximum thickness of the older sand deposits is about 35 feet near the northern end of the island, between 75 and 100 feet in the large area southwest of Wilson Cove, between 25 and 50 feet in the area centered $4\frac{1}{2}$ miles south-southeast of Wilson Cove, and probably less than 25 feet in the vicinity of China Point. Areas where the deposits generally are less than 10 feet thick are not shown on the geologic map.

YOUNGER SAND DEPOSITS (RECENT)

The younger sand deposits (*Qs* on pl. 1), which consist of loose well-sorted gray windblown sand, form active or recently active dunes, principally near the northern end of the island. The sand grains include feldspar, fragments of volcanic rock, small fragments of molluscan shells, and grains of quartz and dark minerals in minor amounts. Land-snail shells and sand molds of tree trunks and plant roots and stems are abundant locally. The sand molds are cemented by calcium carbonate. The plants represented by the molds, as well as the land snails, are all suggestive of a moister climate on the island in the relatively recent geologic past. The maximum thickness of the deposits is about 50 feet; only those believed to be more than 10 feet thick are shown on the geologic map.

ALLUVIAL-FAN DEPOSITS (RECENT)

The alluvial-fan deposits (*Qf* on pl. 1) are ill-sorted masses of gravel, sand, and silt that were deposited as small alluvial fans and cones on the lowest terraces near the mouths of the larger canyons along the southwestern and southern margins of the island. The larger fragments, mostly of andesite, are subrounded to subangular and range in size from cobbles to boulders several feet in diameter. The maximum thickness of the deposits may locally exceed 30 feet;

only the deposits exceeding 10 feet in thickness are shown on the geologic map (pl. 1).

GEOLOGIC STRUCTURE

San Clemente Island is the emerged portion of a crustal block bounded on the northeast by a large northwestward-trending fault, designated the San Clemente fault by Shepard and Emery (1941, p. 24). (See pl. 1.) Shepard and Emery suggested that the movement on the San Clemente fault may have been principally horizontal or strike-slip, in which the southwestern side, the San Clemente block, moved northwestward relative to the northeastern side (right-lateral movement). Whatever the actual direction of movement may have been in the vicinity of the island, the San Clemente block is elevated with respect to the block northeast of the fault; the top of the island is more than a mile above the sea floor northeast of the fault. This great escarpment, comparable to many on the mainland, has an average slope of 15°; however, the fault plane or fault zone itself probably has a considerably steeper dip and may be vertical. The San Clemente fault appears to extend several tens of miles, at least, both northwest and southeast of the island. Southeastward the trace is marked by a narrow submarine rift valley which gives way to a large southwestward-sloping escarpment comparable in height and slope to that on the northeast side of San Clemente Island, although facing in the opposite direction. The San Clemente fault parallels most of the major faults on the California mainland to the northeast, notably the Newport-Inglewood, Elsinore, San Jacinto, and San Andreas faults. These faults on the mainland probably have a major component of right-lateral movement that may be measured in miles, if not tens of miles.

Movements of the San Clemente fault block, perhaps together with upwarping of a more extensive area, have deformed the volcanic rocks of the island into an elongate and possibly asymmetrical dome modified by a rather complex system of faults. The dome, or anticline, plunges gently (2°–3°) northwestward and southeastward from its high point in the central part of the island. The northeastern and southwestern flanks of the dome dip considerably more steeply—probably about 5°–10°. (See pl. 1.) The northeastern flank may dip more steeply than the southwestern, as is suggested by the trend of the base of the extensive body of dacite in the central part of the island and by the attitude of flow layering in the rhyolite on the northern part of the island. However, as suggested by Smith, instead of being domal, the southern third of the island may be essentially homoclinal, (sec C–C′, pl. 1) having gentle southwestward dips, and being modified by faults.

Superimposed on the overall domelike structure are a number of small, gentle flexures, many of which are associated with faults. These small folds are difficult to trace in the crudely bedded volcanic rocks but are mapped readily in the marine sedimentary rocks (pl. 1).

Not all the numerous faults on San Clemente Island were mapped; only those are shown that were determined in the field from such evidence as displacement of beds or flows, zones of gouge and fault breccia, drag folds, fresh scarps that clearly are not wave-cut features, and straight, narrow ravines that aline with other fault features. Doubtless, more detailed mapping would reveal additional faults, particularly in the southern part of the island where many of the canyons and larger ravines, which are parallel to the known faults, may have been cut along faults. However, the principal trends and systems are believed to be delineated on plate 1.

The dominant trend of the major faults on the island is north to north-northeast, at angles of 30°–60° to the trend of the San Clemente fault. In the northern part of the island, a less prominent set of faults trends about N. 20°–30° W.—more nearly parallel to the San Clemente fault and to the long axis of the island. The movement on some of the faults appears to have been chiefly vertical, but on many the movement has been dominantly horizontal (strike-slip) for example, on the important northward-trending fault half a mile west of Wilson Cove. Vertical displacement on most of the faults is a few tens to several hundreds of feet. Horizontal displacement is more difficult to estimate but may be about a quarter of a mile on the fault half a mile west of Wilson Cove. The right-lateral movement on this fault has produced a series of tension faults trending about N. 25° W. in the block to the east, between the main fault and another northward-trending fault about a third of a mile east.

Alinement of certain submarine topographic features with faults on the island suggests that these faults continue beneath the sea floor. Two such faults are the large fault on the west side of Pyramid Cove and the fault on the west side of Horse Cove, both near the southern end of the island.

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