PAUL M. MERIFIELD
D. L. LAMAR } *Lamar-Merifield, Geologists-Geophysicists, 1318 Second Street, Suite 27, Santa Monica, California 90401*
M. L. STOUT *Geology Department, California State College at Los Angeles, Los Angeles, California 90032*

Geology of Central San Clemente Island, California

ABSTRACT

Central San Clemente Island is underlain primarily by nonmarine volcanic rocks. A 1,200-ft core hole, drilled near sea level on the west coast of the island, penetrated a homogeneous sequence of basaltic andesite flows varying in thickness from 11 to 169 ft. Whole-rock potassium-argon dates of samples taken near the top and bottom of the core hole indicate that the cored sequence was extruded in less than 1 m. y. during Miocene time. Unconformably overlying the andesitic flows are dacitic flows reaching a total thickness of about 300 ft. A distinctive volcanic breccia, which is in part of sedimentary origin, is commonly present at the base of the dacites. Miocene sediments and Quaternary beach sands overlie the volcanic rocks.

The Tertiary rocks are folded into a northwest-trending anticline. The axis of the anticline corresponds approximately to the topographic crest of the island located about .5 mi inland from the eastern shoreline. North-northeast to northeast-trending faults cut the Miocene rocks but do not displace the prominent surf-cut terraces. Striations within well-exposed fault zones indicate that most movement has been oblique, with a principally horizontal component. The faults may be left-lateral, secondarily related to major right-slip movement along the northwest-trending San Clemente fault.

INTRODUCTION

San Clemente Island is situated about 60 mi (96 km) off the coast of Southern California (Fig. 1). The long axis of the island trends N. 40° W., roughly parallel to the major physiographic and structural features of the Peninsular Range province of Southern California. The southwestern slope of the island is characterized by a remarkable development of surf-cut terraces. Terraces are poorly developed on the northeastern slope of the island. Previous geologic descriptions of San Clemente Island have been presented by Lawson (1893), Smith (1898), and Olmsted (1958).

As the initial phase of this study, two 4 sq mi areas surrounding Eel Point and Lost Point (Fig. 2) were mapped in detail (scale: 1 in. to 400 ft) to determine the suitability of these locations for a Rock-Site installation (Merifield and Lamar, 1967). The Rock-Site concept and its applications to offshore petroleum production have been described by Austin (1966, 1967), and the related offshore geology is described by Ridlon (1968). The remainder of the area shown on Figure 2 was mapped at 1 in. to 2,000 ft on the San Clemente Island central quadrangle, published by the U.S. Geological Survey in 1950.

During the mapping, detailed observations were made of the orientation of joints in bedrock, the attitudes of remarkably well-exposed fault zones, and the rake of striations within the fault zones. The San Clemente fault (Shepard and Emery, 1941, p. 24) is situated directly northeast of San Clemente Island; this fault is believed to have a major component of right-slip and may continue to the southeast in Baja California as the Agua Blanca fault (Allen and others, 1960; Krause, 1965). Because of the excellent exposures and the detailed observations required to determine the engineering properties of the bedrock, a unique opportunity was provided to consider the structural relationship between the San Clemente fault and the fault and joint pattern in an immediately adjacent area.

Subsequent to the mapping, continuous cores from a 1,200-ft hole drilled at Eel Point were logged and studied in thin section (Lamar and others, 1968). Whole-rock potassium-argon dates were obtained for two samples near the top and bottom of the hole. These are the

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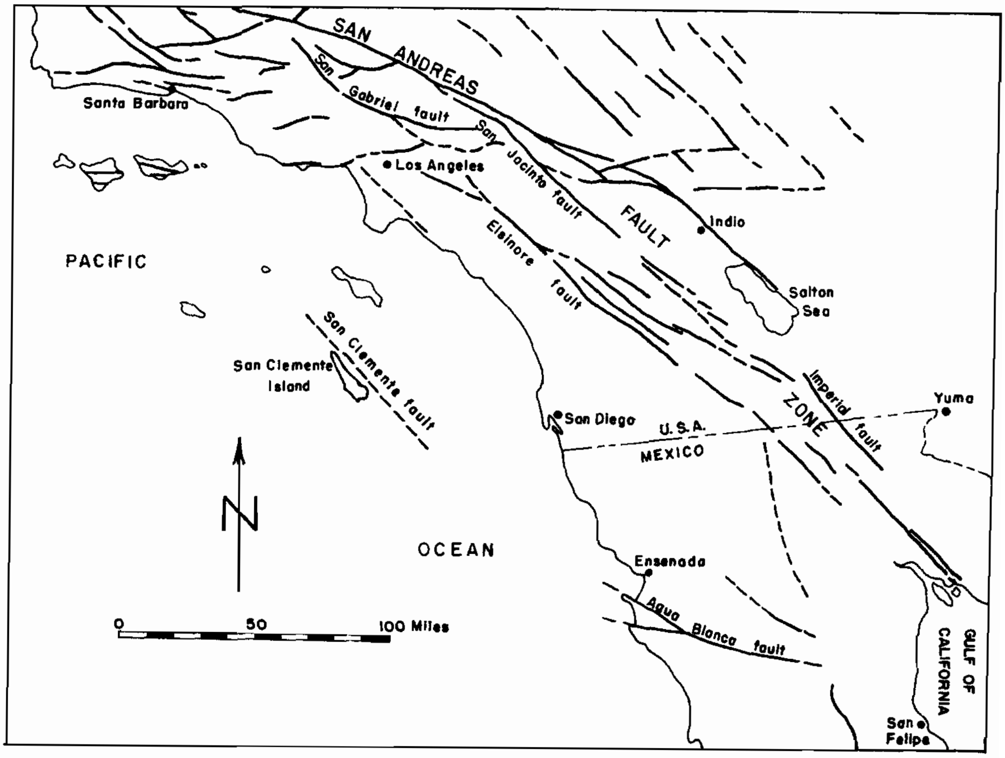

Figure 1. Index map showing location of San Clemente Island and San Clemente fault. Redrawn *from* Allen and others (1960).

first dates reported for the volcanic rocks of San Clemente Island and bear on the tectonic history of Southern California.

DESCRIPTIVE PETROLOGY

Bedrock of the island consists of andesite flows overlain unconformably by dacite; a breccia up to 30 ft thick occurs locally at the base of the dacite. Patches of Miocene marine sediments and Pleistocene beach sand rest unconformably on the volcanic rocks. Landslide debris is present on the steep northeastern side of the island.

Potassium-Argon Age Determinations

Geochron Laboratories, Inc., performed whole-rock potassium-argon age determinations on samples from near the top and bottom of the core hole. The results are as follows:

Depth	Age
40′	15.7 ± 0.8 m.y.
1,158′	15.5 ± 0.7 m.y.

These results indicate that the rocks were extruded in about 1 m.y. during the Miocene.

This range of 14.8 to 16.5 m.y., plotted on Figure 1 *of* Yeats (1968), fits his observation that the age of Cenozoic rocks decreases, from west to east, southwest of the San Andreas fault in California. Yeats has suggested that this is the result of migration of the East Pacific Rise to the present site of the Gulf of California. In contrast, Hawkins (1970) reviewed data on the ages of Cenozoic volcanic rocks in Southern California and northwestern Mexico and noted that over this larger area the locus of volcanic activity appears to have shifted westward. He suggests a relationship between volcanism, faulting, and crustal dilation. Under his hypothesis, the San Clemente Island volcanic rocks and San Clemente Island fault may be related.

Nature of Andesite Flows

Previous descriptions of the volcanic rocks and marine sediments exposed on San Clemente Island are presented by Smith (1898) and Olmsted (1958). However, the core hole penetrated rocks which, for the most part, are not exposed on the island. In the drill core, 29

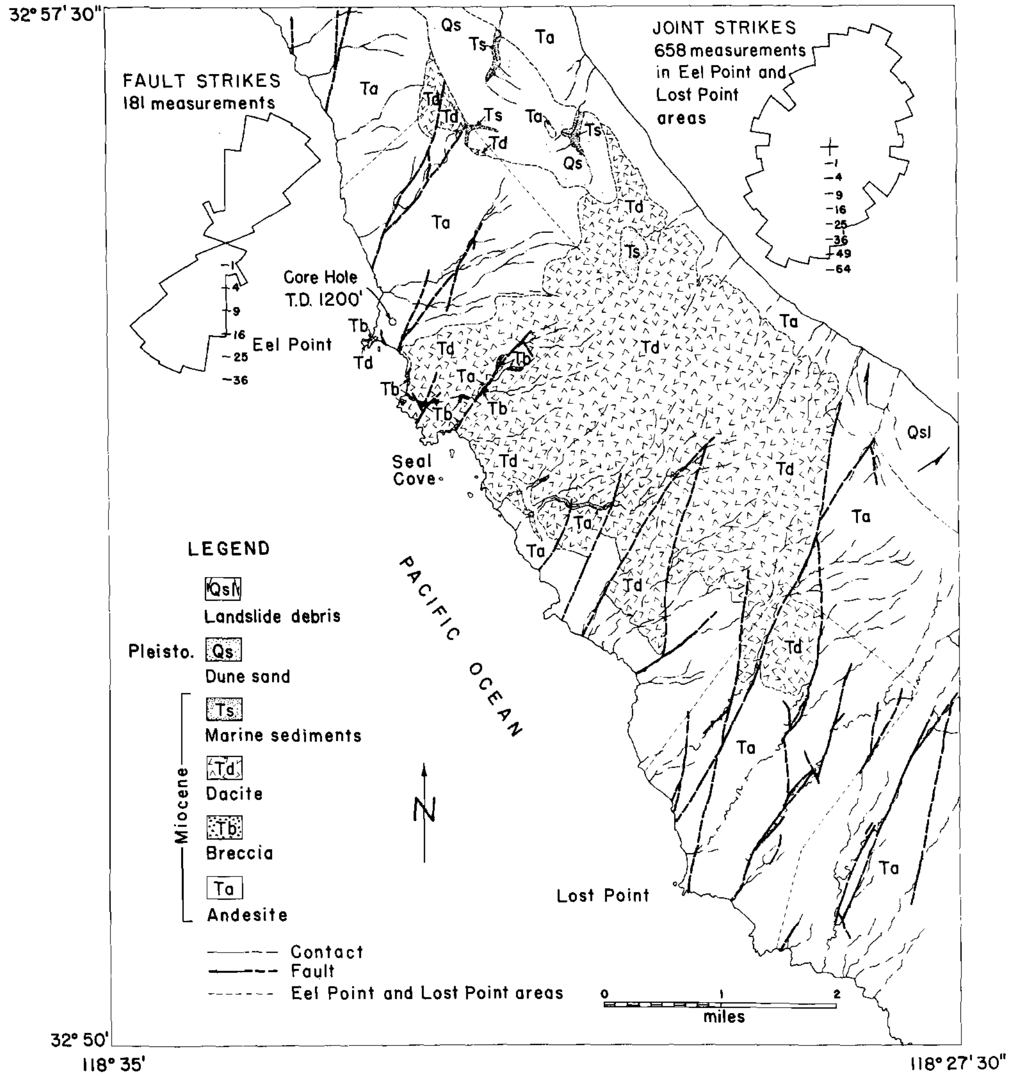

Figure 2. Geologic map of the central San Clemente Island quadrangle, California.

andesite flows were separated, varying in thickness from 169 ft (depth 762-931) to 11 ft (depth 931-942). As expected for a series of flows that were extruded in a brief geologic interval, the individual flows are remarkably similar in composition and texture. Variations are largely related to position within individual flows rather than to compositional differences between flows. The flows are unusually fresh; minor alteration is restricted to a few flows and within about 70 ft of the surface.

The andesite near the flow boundaries is usually darker in color and more vesicular than the rock in the interior. Flow breccias consisting of blocks of andesite up to 150 cm in diameter are characteristic of the tops and bottoms of some flows. In thin section, the rocks near the flow margins commonly have a hyalopilitic texture of feldspar and pyroxene phenocrysts set in a matrix of feldspar microlites and opaque to dark gray tachylitic glass. The central portions of the flows are lighter in color due to a matrix which is predominantly feldspar and pyroxene. The microlitic plagioclase is usually andesine (An_{40} - An_{48}).

The percentage of phenocrysts in the solid rock (omitting voids) ranges from 25 to 70 percent and averages 40 percent. The phenocrysts display no significant variations in mineralogy or texture throughout the core hole. The largest phenocrysts are generally plagioclase feldspar ranging from 3 to 5 mm in longest dimensions. Pyroxene phenocrysts are somewhat smaller. The plagioclase phenocrysts are commonly oscillatory zoned with core values as high as An_{78} and rim values as low as An_{47}; thus, the rocks may be termed basaltic andesites. The percent of pyroxene in the phenocrysts ranges from 5 to 25 percent and averages 15 percent. Both clinopyroxene and orthopyroxene are present. The clinopyroxene is augite and diopsidic augite; the orthopyroxene is hypersthene. The orthopyroxene is usually not greater than 5 percent of the total pyroxene and was absent in several thin sections.

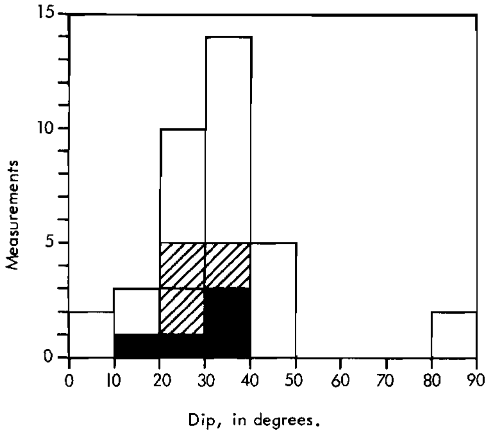

Figure 3. Magnitude of dips measured in cores. Contacts: solid. Flat-floored vesicles: cross-hatched. Streaked-out vesicles and other flow-banding: blank.

GEOLOGIC STRUCTURE

Attitude of Flows

The flows are folded into an anticline; the axis corresponds approximately with the northwesterly trending topographic crest of the island and is located about .5 mi inland from the east coast. Limited observations along the steep east slope of the island suggest that the east flank of the anticline dips 10 to 30 degrees northeastward. The west flank dips gently (0 to 15 degrees) in a westerly to southwesterly direction; the highest dips occur near the west coast.

Structure within the andesite is less obvious because of the rarity of well-defined contacts between individual flows. Flow structures are generally not well developed and in many places are not parallel to recognizable contacts. On the western slope of the island, excellent exposures in the main canyons permitted mapping of several flows for a few hundred yards. The outcrop patterns indicate that the andesite flows are essentially horizontal within the central portion of the island and dip seaward near the west coast. Figure 3 shows a plot of a number of dips determined in the 1200-ft core hole drilled at Eel Point. There is no consistent increase or decrease in dip as a function of depth. Streaked-out vesicles dip from 0 to 90 degrees and average about 35 degrees. The dip of contacts between flows and flat-floored vesicles ranges from 10 to 40 degrees and averages about 30 degrees. In outcrop, the average dip of the andesite in the vicinity of Eel Point is about 15 degrees to the southwest. It is probable that the dips in the cores are similarly oriented with individual flows dipping an average of 30 degrees to the southwest. The reason for the discrepancy between the surface and subsurface dips is unknown but it may indicate initiation of folding of the island before the youngest flows were extruded.

Faults

The principal direction of the faults is north-northeast to northeast as indicated by the rose diagram shown in Figure 2. (The rose diagram represents an equal-area plot so as not to unduly emphasize the principal directions.) However, a few faults trend north-northwest, parallel to the shorelines. All faults dip steeply; the dips of individual faults are plotted in Figure 4. None of the faults offset the surf-cut terraces.

Faults are generally exposed in zones from 1 to 15 ft wide (Fig. 5), but some up to 100 ft wide were encountered. Within the fault zones, zones of hard slickensided gouge a few inches thick are surrounded by fault breccias. These breccias are well cemented in some places, but in others they are friable and loosely consolidated. The size of the brecciated fragments is generally that of very coarse sand, although cobble- to boulder-sized fragments are also present. The breccias are white to light tan, and the volcanic rocks on either side of the fault zones are usually bleached white, particularly along fractures.

The rakes of striations on slickensided gouge zones are plotted in Figure 6. The dominant movements have been oblique, with a pro-

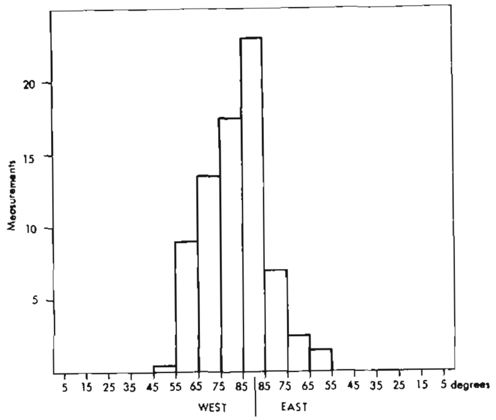

Figure 4. Dip of faults, central San Clemente Island.

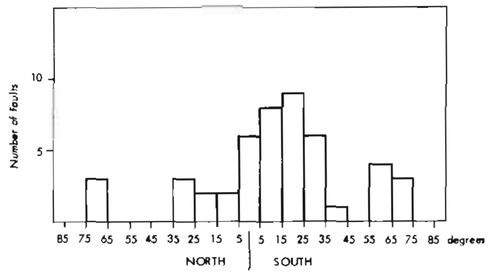

Figure 6. Average rake of striations on fault planes, central San Clemente Island.

nounced horizontal component. The geologic map (Fig. 2) reveals no consistent sense of horizontal fault separation of the contact between dacite and andesite. This may be because the horizontal separation is largely a reflection of the vertical component of displacement on a gently dipping contact and, in this case, the actual horizontal displacement would be obscured. In a few cases, left-lateral displacement was demonstrable on northeast-trending faults and right-lateral displacement on northwest-trending faults. Maximum separation is on the order of a few hundred feet.

Figure 5. Fault breccia exposed 1 mi northeast of Eel Point.

Joints

Jointing in the rocks is present throughout but is more prevalent and continuous in the dacite and massive or platy flows in the andesite. Continuous vertical fractures over 200 ft long can be seen in the dacite at Seal Cove. Spacing of the joints varies from a few inches to about 6 ft, but most commonly is 0.5 to 2 ft. The directions of 658 measurements on joint sets are plotted in the rose diagram in Figure 2. A strong north-northeast to northeast trend is indicated, although all directions are represented. The dominant trend may be of tectonic origin related to the faulting, superimposed on a random pattern produced during cooling.

Tectonic Relations

Because of the close proximity of the area studied to the San Clemente fault, it is appropriate to speculate on the possible tectonic relationships. Directly to the northeast, the San Clemente fault—believed to be a major right-lateral fault—strikes N. 41° W.; thus, the angle between the San Clemente fault and the dominant fault strike direction indicated on the rose diagram (Fig. 2) is roughly 70 degrees. Hence, the faults on San Clemente Island may represent complementary first-order wrench (left-lateral) faults, as defined by Moody and Hill (1956). Chinnery (1966) has questioned Moody and Hill's analysis and presents a different theory of secondary faulting. The faults on San Clemente Island could equally well represent secondary left-lateral faults of type F (Chinnery, 1966, p. 182).

It should be noted that the San Clemente fault is based primarily on physiography. The faults which cut the Miocene volcanic rocks on San Clemente Island do not cut the marine terraces; thus, they must have moved prior to the elevation of the island relative to sea level, and are probably unrelated to the movement which formed the San Clemente fault scarp. These faults may, however, be related to an earlier period of movement on the San Clemente fault.

ACKNOWLEDGMENTS

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REFERENCES CITED

Allen, C. R., Silver, L. T., and Stehli, F. G., 1960, Agua Blanca fault—a major transverse structure of northern Baja California, Mexico: Geol. Soc. America Bull., v. 71, p. 457-482.

Austin, C. F., 1966, Manned undersea structures—the rock-site concept: NOTS TP 4162, China Lake, California, U. S. Naval Ordnance Test Station.

Austin, C. F., 1967, Undersea drilling and production sites for petroleum: Jour. Petroleum Technology, v. 19, p. 1309-1316.

Chinnery, M. A., 1966, Secondary faulting, II. Geological aspects: Canadian Jour. Earth Sci., v. 3, p. 175-190.

Hawkins, J. W., 1970, Petrology and possible tectonic significance of late Cenozoic volcanic rocks, Southern California and Baja California: Geol. Soc. America Bull., v. 81, p. 3323-3338.

Krause, D. C., 1965, Tectonics, bathymetry, and geomagnetism of the southern continental borderland west of Baja California, Mexico: Geol. Soc. America Bull., v. 76, p. 617-650.

Lamar, D. L., Merifield, P. M., and Stout, M. L., 1968, Engineering geology of rocks in core hole, Eel Point, San Clemente Island, California: NWC TP 4487, China Lake, California, Naval Weapons Center.

Lawson, A. C., 1893, The post-Pliocene diastrophism of the coast of southern California: California Univ. Dept. Geol. Bull., v. 1, p. 115-160.

Merifield, P. M., and Lamar, D. L., 1967, Engineering geology of central San Clemente Island, California: NWC TP 4469, China Lake, California, Naval Weapons Center.

Moody, J. D., and Hill, M. L., 1956, Wrench-fault tectonics: Geol. Soc. America Bull., v. 67, p. 1207-1246.

Olmsted, F. H., 1958, Geologic reconnaissance of San Clemente Island, California: U. S. Geol. Survey Bull. 1071-B.

Ridlon, J. B., 1968, San Clemente rock-site project: Offshore geology. Part 1, Detailed survey off Eel and Lost Points area. NWC TP 4442, China Lake, California, U. S. Naval Weapons Center.

Shepard, F. P., and Emery, K. O., 1941, Submarine topography off the California coast: Geol. Soc. America Spec. Paper 31.

Smith, W. S. T., 1898, A geological sketch of San Clemente Island, *in* Part II. 18th Annual Rept., U. S. Geol. Survey, p. 459-496.

Yeats, R. S., 1968, Southern California structure, sea-floor spreading, and history of the Pacific Basin: Geol. Soc. America Bull., v. 79, p. 1693-1702.

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