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LATE CENOZOIC HISTORY OF THE SOUTHERN CALIFORNIA ISLANDS[1]

James W. Valentine and Jere H. Lipps

University of California, Davis and Los Angeles

INTRODUCTION

The floor of the ocean off southern California consists of a series of low depressions and basins separated by high ridges, some of which protrude above sea level to form the Southern California Islands. The basins and many of their intervening sills are at depths that are much greater than usual for the continental shelf. This peculiar region of complicated topography has been called the "continental borderland" by Shepard and Emery (1941). It lies offshore from the continental shelf of the mainland but inshore of the continental slope which extends down to regions of oceanic depths and structures.

The basins and ridges are somewhat elongated, and most are aligned in a northwest-southeast direction, parallel to the major structural features of the mainland; a few of these ridges bear islands which are also elongated along a northwest-southeast trend (fig. 1). However, in the north there is a transverse ridge, locally rising above sea level to form an east-west chain of islands. This ridge is separated by the transverse Santa Barbara Basin from the east-west mainland coast formed along the flanks of the Santa Ynez Mountains. For convenience, the islands will be grouped here as Northern Channel Islands (Anacapa, Santa Cruz, Santa Rosa, and San Miguel, from east to west) and Southern Channel Islands (Santa Catalina, San Clemente, Santa Barbara, and San Nicolas).

The bedrock geology of the Northern Channel Islands indicates that they represent a westward extension of the general geologic and structural style of the Santa Monica Mountains, with a granitic core (exposed on Santa Cruz Island) intruded into what are

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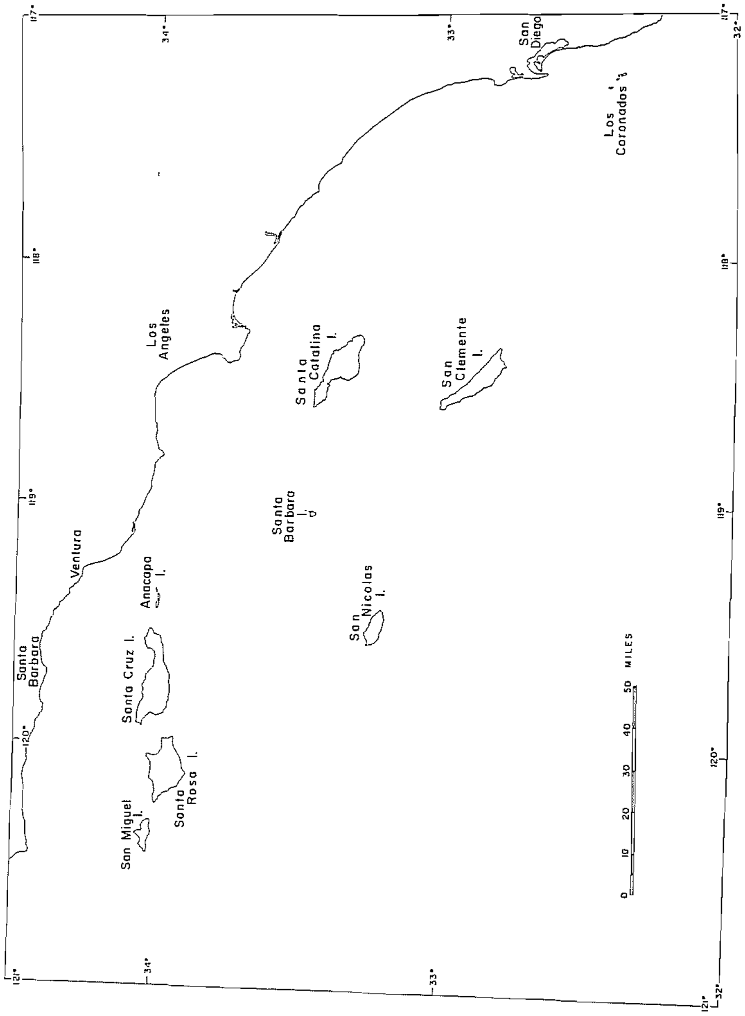

Fig. 1. Index map of the Southern California Islands.

now slates, phyllites, and schists, overlain by Cretaceous and Cenozoic sedimentary and volcanic rocks. In fact the Northern Channel Islands and the Santa Monica Mountains have been united as the structural province of "Anacapia" by Reed and Hollister (1936). The Southern Channel Islands, together with the Palos Verdes Hills area, which is stratigraphically similar to these southern islands and was an island itself until joined to the mainland during the Quaternary (Pleistocene or Recent), are assumed to have a basement of metamorphic rocks of the "Franciscan" type, which crop out on Catalina Island and at Palos Verdes Hills. These islands and Palos Verdes Hills were included in a "south Franciscan area" or a "southern Geosynclinal Basin" by Reed and Hollister (1936). The Franciscan rocks are overlain by Cenozoic sedimentary and volcanic rocks. Pliocene rocks are not known to crop out on any of the islands but have been dredged from submarine slopes and ridges chiefly south of the Northern Channel Islands (Emery, 1960, p. 68); marine Pliocene rocks are exposed at Palos Verdes Hills and in the Santa Monica Mountains.

The chief cause of the elevation of the ranges and subsidence of the basins is faulting, although some displacements may involve steep folds; the inferred fault pattern of the area is well displayed in a figure by Emery (1960, p. 79). The underlying causes are not known but must involve processes at depth in the crust and upper mantle of the earth. At any rate, our knowledge of the origin and significance of this topography does not preclude the assumption of vertical movements on the order of the elevation of the islands, whenever such movements seem required as a parsimonious explanation of the geologic record. Basin-range style of topography probably began developing in the Miocene (Corey, 1954; Emery, 1960), and by at least the later Pliocene the major topographic features present today seem to have become established. The major ridges and islands are usually pictured as standing above sea level during the Pliocene since they are not known to bear marine Pliocene sediments (Corey, 1954), but it is possible that they were submerged at that time.

THE LATE CENOZOIC RECORD

General

Late Cenozoic sediments, probably all of post-Pliocene age, are known as relatively thin veneers on parts of most of the islands. Marine sediments with diverse and locally abundant fossils occur on surf-cut terrace platforms which sculpture the islands from sea-level to elevations as great as nearly 2,000 feet, although those above 1,000 feet are not well-documented. Probably all of the islands bear terraces; fossiliferous marine sediments are recorded from all islands except Santa Catalina where the terraces are highly eroded (Emery, 1960, p. 8). Non-marine deposits, some containing fossils, have been found overlying the marine terrace sediments and on the sides of canyons. The fossils from the islands, especially when taken together with their mainland record, form a pattern in space and time which may serve as a basis for tentative interpretation of the late Cenozoic island history.

Mainland Record

The late Cenozoic (late Pliocene through Recent) marine record on the southern California mainland is usually found in one of three distinctive settings. Most upper Pliocene and lower Pleistocene sediments are contained in basins (Ventura and Los Angeles) which formerly indented the coast as deep embayments but which became essentially filled at some time during the Pleistocene. These basins seem quite analogous structurally to the basins of the continental borderland, but have been filled by virtue of their proximity to mainland sources of abundant sediment. Another sequence of marine Pliocene and lower Pleistocene sediments, which evidently accumulated as shelf deposits, is now exposed in the San Diego region. Most of these early deposits have been more or less deformed.

Marine terraces are extensively developed on the seaward slopes of most coastal hills and ranges in southern California. Where sediments on the terrace platforms overlie upper Pliocene or lower Pleistocene rocks, the relationship is usually one of angular unconformity. In the Los Angeles and Ventura Basin regions, the time represented by locally extensive deformation of lower Pleistocene or older sediments and preceding the development of marine terraces is sometimes called the middle Pleistocene, and the deformation associated with this interval has been referred to as the "mid-Pleistocene orogeny" (or the "Pasadenan orogeny" of Stille, 1936).

The position of the Pliocene-Pleistocene boundary in California is in question. Undoubted Pliocene marine sediments, dated by association with vertebrate remains or by radiometric age estimates, contain a large number of extinct mollusks (Woodring, 1952; Woodring, Stewart, and Richards, 1941). Many of these extinct forms are abundant and widespread. Later marine sediments that lie near or above the Pliocene-Pleistocene boundary contain far fewer extinct forms. Unfortunately, vertebrate faunas indicative of the Pliocene-Pleistocene boundary are not documented in association with these marine sediments. Furthermore, a suitable standard Pliocene-Pleistocene boundary is not well-defined and dated, even in the type area in southern Italy. A potassium-argon analysis based on glauconite from the Lomita Marl in Los Angeles Basin (fig. 2), which has been assigned to the lower Pleistocene by Woodring and others (Woodring, Bramlette, and Kew, 1946; Woodring, 1952), has yielded an age estimate of 3.04 million years B.P. (Obradovich, 1965). It is not yet certain whether this will prove to be a late Pliocene or an early Pleistocene age, but it probably lies near the boundary, perhaps within a half million years or so. Upper Pleistocene terrace faunas, however, are nearly modern in composition with a few extinct forms that are very rare. Most of the specimens of extinct forms collected from upper Pleistocene deposits have come from areas where the terrace platforms bevel lower Pleistocene sediments, and there is a suspicion that some of these are reworked fossils. Radiometric age estimates by the helium-uranium (Fanale and Schaeffer, 1965) and ionium (Broecker and Kaufman, in preparation *fide* Fanale and Schaeffer, 1965) methods suggest that other terraces at Palos Verdes Hills range in age from about 120,000 or more years for the lowest terrace (Palos Verdes Sand, fig. 2) to between roughly 360,000 and 380,000 years B.P. for the highest terrace (terrace 12 of Woodring, Bramlette, and Kew, 1946). The chronology of Pleistocene stages is disputed; this age range may represent essentially the whole Sangamonian interglacial stage (Riss-Würm), or it may embrace earlier stages as well (see Broecker, 1965 for a review).

Late Pleistocene terrace faunas suggest that a provincial boundary formerly lay at about the latitude of the Northern Channel Islands, separating a region to the south containing species now restricted to Panamanian and southern Baja Californian waters from a region to the north which lacked such species but contained southern Californian forms (Grant and Gale, 1931; Valentine, 1961). On this basis, the Verdean (type locality, Palos Verdes Hills) and Cayucan (type locality, Cayucos) late Pleistocene faunal provinces have been distinguished (Valentine, 1961). Paleotemperature estimates based on oxygen isotopic and biogeographic data have tended to confirm the temperature significance of the provincial break (Valentine and Meade, 1961), but data are incomplete and the conclusions tentative.

Island Record: Marine

With the general nature of the fossil record of the late Cenozoic on the mainland in mind, the fragmentary record known from

NORTHERN ISLANDS				SOUTHERN ISLANDS			MAINLAND	"STANDARD" CALIFORNIA COLUMN
SAN MIGUEL	SANTA ROSA	SANTA CRUZ	ANACAPA	SAN NICOLAS	SANTA BARBARA	SAN CLEMENTE	PALOS VERDES HILLS	
Undescribed.	Terraces near 25' and 75' with *Tegula brunnea* and *Amicula stelleri* (Orr, 1960).	Terraces between 20' and 100'; fossils not described (Bremner, 1932).	Terrace near 25' to 30' with small banal fauna (Lipps, 1964).	Terrace near 25' to 30' with small banal fauna; terrace near 100' with *Tegula brunnea* (Vedder and Norris, 1963).	Terrace near 25' with *Acanthina lugubris* and *Tegula montereyi* (Lipps, Valentine and Mitchell, in preparation).	Terrace near 100' with small banal fauna (Lipps, in preparation).	Terraces from near 75' (Palos Verdes Sand) to over 1215', some with *Acanthina lugubris* and *Tegula brunnea* (Woodring *et al.*, 1946). *Calicantharus fortis* on lower terrace (Arnold, 1903).	UPPER PLEISTOCENE
Deposit (terrace?) near 600' with *Calicantharus fortis* (Cockerell, 1938).	Terrace near 250' with small banal fauna (Orr, 1960).	Terraces near 700' or higher, fossils not described (Bremner, 1932).	Terrace near 250' with *Arca sisquocensis*, *Calicantharus fortis*, *Tegula montereyi*, and *Amicula stelleri* (Valentine and Lipps, 1963)	Terraces between about 380' and 900' with *Arca sisquocensis*, *Humilaria perlaminosa*, *Calicantharus fortis* and *Acanthina* cf. *A. lugubris* (Vedder and Norris, 1963).	Terrace near 150' with *Calicantharus fortis* (Lipps, Valentine and Mitchell, in preparation).	Deposit (terrace?) near 800' to 860' with small banal fauna (Cockerell, 1939).		MID-PLEISTOCENE OROGENY
		Possible lower Pleistocene unit (Bremner, 1932).					San Pedro Sand Timms Point Silt	LOWER PLEISTOCENE
							Lomita Marl	UPPER PLIOCENE

Fig. 2. Summary of the faunal aspect of the marine molluscan assemblages from the late Cenozoic of the Southern California Islands and Palos Verdes Hills. The suggested correlations are tentative.

the islands can be assessed. The general aspects of the Pleistocene marine faunas from the islands are summarized in fig. 2. Fossiliferous sediments on Santa Cruz Island were assigned to the lower Pleistocene by Bremner (1932), but this occurrence is presently being restudied. The presumed lower Pleistocene deposits are described as horizontal, overlying tilted Miocene rocks and overlain by marine terrace deposits; they are evidently terrace deposits themselves. At any rate, the other recorded late Cenozoic marine strata from the islands are probably all terrace deposits. Most of the invertebrate fossil assemblages represent associations of mollusks, foraminifera and ostracodes together with a few barnacles, echinoids, and corals that commonly live today along rocky shores. These assemblages may contain representatives of offshore shallow-water habitats. Assemblages from the lower terraces, below about 100 feet, closely resemble terrace faunas from mainland upper Pleistocene localities, and like them have a distinctly modern aspect. However, terrace levels from near 150 feet and above regularly yield representatives of a small but persistent element which includes such well-defined extinct molluscan species as *Arca sisquocensis*, *Humilaria perlaminosa*, and *Calicantharus fortis* and the extinct echinoid *Dendraster venturaensis*. Some of these forms, especially *C. fortis*, are widespread and locally abundant in the higher island terrace deposits. These species are most common in upper Pliocene and lower Pleistocene beds on the mainland, although some occur as rare (and possibly reworked) fossils in the mainland upper Pleistocene. However, the presence of this extinct element imparts to the high terraces an ancient cast, and if they occurred on the mainland such faunas would no doubt be considered older than the usual upper Pleistocene assemblages. Lipps, Valentine, and Mitchell (in preparation) point out that the extinct element occurs at 15 of the 17 well-defined localities recorded from higher terraces and at none of 10 well-defined localities on lower terraces. The probability that these high and low localities are random samples of the same fauna is only 7.82×10^{-6} (see also Valentine and Lipps, 1965). Sampling error can be discounted as a source of the difference between high and low terraces insofar as the extinct element is concerned. Furthermore, the flightless marine duck *Chendytes milleri*, which occurs on higher terraces, seems ancestral to the late Pleistocene *C. lawi*, known from lower island terraces and mainland deposits (Howard, 1955). The higher terrace faunas thus form a biostratigraphic unit—an assemblage zone—which can be distinguished from the faunas of the lower island and mainland terraces by the extinct element.

There are small but significant geographic differences among the faunal assemblages from different islands. Statistical assessment of matching coefficients calculated between all pairs of assemblages with between 75 and 90 recorded species (an interval chosen to reduce bias among the coefficients that arises because of differences in the number of species in the assemblages) demonstrates that, on the basis of total faunal similarity, islands differ from each other significantly while lower and higher terrace faunas on the same island do not differ significantly at the five percent level (Lipps, Valentine, and Mitchell, in preparation). In addition to these gross faunal differences, the provincial break on the mainland seems reflected in the islands. Species that belong to the southern element of the Verdean province, for example *Acanthina lugubris*, appear on the Southern Channel Islands but are not known on the Northern Channel Islands. The Verdean-Cayucan boundary seems to have lain south and inshore of the Northern Channel Islands but north of the others.

When the island terrace faunas are compared to those terrace faunas called "Upper Pleistocene" on the mainland, then, the lower island terrace faunas appear to be "Upper Pleistocene", but higher island terrace faunas seem older. Comparison with the upper Pliocene-lower Pleistocene faunas from the mainland is quite difficult because that sequence does not contain documented exposed rocky-shore assemblages. The extinct element from the islands is present, locally in abundance, together with other extinct forms. The mid-Pleistocene orogeny which provides a utilitarian criterion for separating upper and lower Pleistocene faunas on the mainland evidently did not deform the older sediments on the islands (Valentine and Lipps, 1963), and therefore lack of deformation of beds does not preclude an early Pleistocene age for the higher island sediments. We conclude that marine faunal evidence suggests that the upper island terraces are older than the "Upper Pleistocene" of the mainland but that a definite lower age limit younger than upper Pliocene cannot be strongly supported from molluscan and foraminiferal evidence alone.

Although detailed inter-island correlation of the higher island terraces is equivocal, that of the lower terraces which have been studied is somewhat clearer. Along the northern side of the Northern Channel Islands, a series of terraces at elevations of 5, 25, 75, and 100 feet have been described (Orr, 1960; Valentine and Lipps, 1963; Lipps, 1964). These terraces and their associated deposits may record sea level fluctuations during the later Pleistocene and Recent. On Santa Rosa Island (see Orr, 1960), deposits formed during and immediately succeeding terrace erosion at 25 feet overlie the 100-foot terrace, and these are truncated by the 75-foot terrace. All of these terraces and deposits are, in turn, overlain by non-marine sediments extending to below present sea level, where submarine terraces are known to depths of over 400 feet. Of particular interest is the consistent presence on the islands and parts of the mainland coast of a terrace level at about 25 feet which is overlain by marine sediments grading upward into nonmarine deposits. The similarity in elevation and sediments may indicate that these terraces were formed by the same stand of sea level.

Island Record: Non-Marine

The late Cenozoic non-marine record of the islands is poorly known as only a few detailed local studies have been made, although non-marine sediments occur widely on all islands as stream deposits in canyons and as alluvial debris covering the flattened areas underlain by marine terraces. The remains of many terrestrial species of plants and animals are found in these deposits, although not all in association, including "dwarf" mammoths (Stock and Furlong, 1928) and "giant" mice (White, 1966)—a combination that invokes amusing speculations—together with plants now living no closer than 440 miles to the north (Chaney and Mason, 1930) and the remains of early man (Orr, 1960). These fossils occur in several kinds of deposits associated with the lower terraces on the Northern Channel Islands. The mammoth and the mice are related to forms known from the mainland, and at least in the case of the mammoth, seem to indicate a migration along the Northern Channel Islands at a time when they were connected as a peninsula to the mainland. Although mammoth remains have been found on San Nicolas Island, they are believed to have been transported by man (Stock, 1935); otherwise these larger mammals are unknown on the Southern Channel Islands.

Mammuthus, of Eurasian ancestry, first appeared in North America in Irvingtonian faunas (C.A. Repenning, personal communication) and thus must have crossed the Bering land bridge during the low sea stand accompanying Kansan glaciation. It is possible that *Mammuthus* reached southern California also during the Kansan, or perhaps not until the Illinoisan. The size reduction characteristic of the island species, *Mammuthus exilis* (Stock and Furlong, 1928), indicates some period of isolation preceding its appearance in Rancholabrean sediments, including the marine terrace deposits (Sangamonian?) and the non-marine terrace cover (Wisconsin?).

Fossil land snails, some of them endemic to the islands and many others restricted to the southwestern United States and adjoining parts of Mexico, are known from all the islands. Their distributions suggested to Pilsbry (1939) that even the Southern Channel Islands were connected by land areas. Probably such land areas did not exist in the late Cenozoic, and the distribution of the fossil snails as well as much of the modern biota has resulted from transportation over water barriers by rafting or some other means, at least among the Southern Channel Islands. Since land snails could evidently reach these southern islands across water, their distributions on the Northern Channel Islands cannot be invoked as support for the former presence of land connections there.

SUMMARY AND INTERPRETATION OF LATE CENOZOIC HISTORY

In summary, the series of events outlined below are regarded as most probable on the basis of present evidence. This proposed history is considered to be only a working hypothesis and cannot now be confirmed generally, as will be evident from the foregoing discussions. However, it may serve as a model to be tested and altered as new data come to light. Absolute dates are based chiefly on an expanded Pleistocene chronology (see Cox, Doell, and Dalrymple, 1965).

1. Appearance of early basin-and-range structures in the continental borderland, between perhaps 20 and 11 million years ago (Miocene).

2. Topographic highs and lows become increasingly well-differentiated, and sedimentation becomes significant in near-shore basins (Ventura and Los Angeles). The submarine ridges are shallow and perhaps islands appear. One ridge extends from the Santa Monica Mountains westward along the site of the Northern Channel Islands. These events occurred between about 11 to about three million years ago (Pliocene).

3. Islands probably appear near sites of most modern Southern California Islands, and it is possible that the uppermost, unstudied terraces on the highest islands were formed at this time. There is, however, no evidence to support the contention of Clements (1955) that sea level stood 3,000 feet lower than today over the borderland during the early Pleistocene. In fact, reconstructions based upon such assumptions (Clements, 1955, fig. 1) fail to account for fairly continuous deposition of marine sediments in Los Angeles and Ventura basins and some deposition in the San Diego region during this interval of time. A paleogeographic model for this interval is depicted in fig. 3. This interval ranged from three or more to two million years ago (late Pliocene?-early Pleistocene).

4. Tectonic emergence continues, forming terraces with "older terrace" faunas. Sea level is presumably fluctuating eustatically

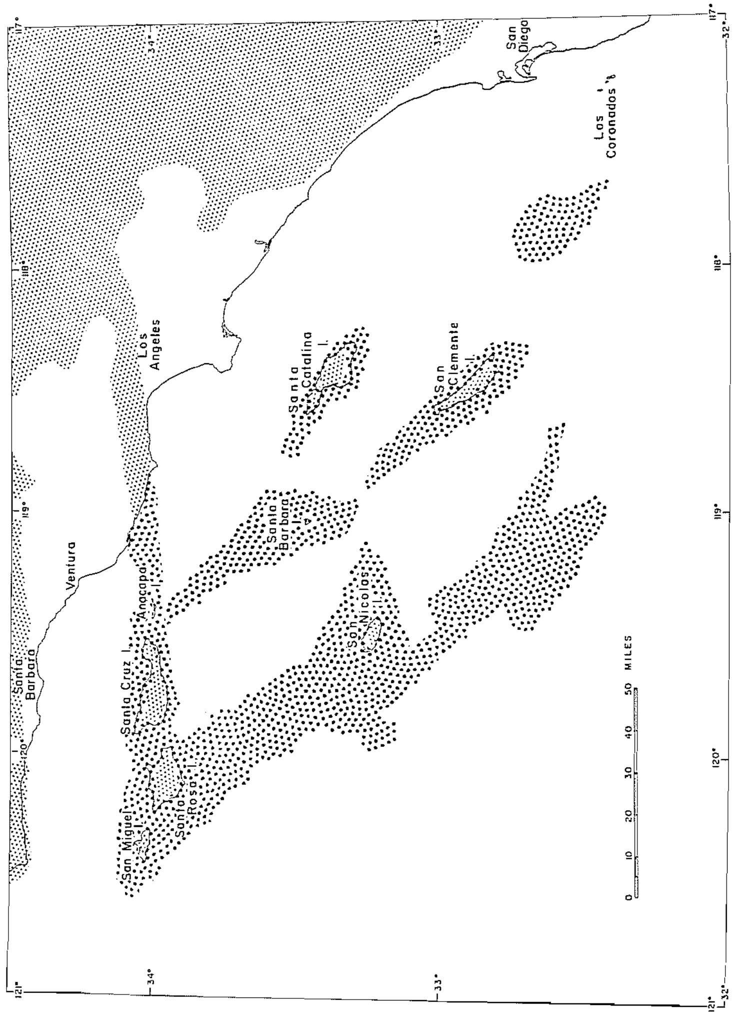

Fig. 3. Suggested generalized paleogeography of the California borderland and adjoining mainland during the late Pliocene and early Pleistocene. Small dots indicate land areas, large dots submarine ridges. Modified from Corey (1954).

in response to continental glaciations in higher latitudes; in addition there are local relative sea level changes owing to tectonic movement. Perhaps these events occurred between one and two million years ago (medial Pleistocene).

5. Tectonic emergence continues, and at times of eustatically low sea level, the Northern Channel Islands are connected as a peninsula to the mainland (fig. 4). Mammoths and other land organisms migrate westward. Mid-Pleistocene orogeny underway on mainland at some time during this interval, which may have extended from near 1.5 million to a few hundred thousand years ago (medial Pleistocene, perhaps Irvingtonian—Kansan—or early Rancholabrean—Illinoisan).

6. Eustatically rising sea level (certainly coupled with at least local tectonic effects, as tilting and warping in the Santa Barbara Channel) separates the peninsula from the rest of the mainland and isolates mammoths and other terrestrial organisms, which henceforth undergo endemic evolution, resulting most markedly in body size changes. The lower terraces form. This probably occurred between a few hundred thousand to about 100,000 years ago (late Pleistocene, Rancholabrean, probably Sangamonian to early Wisconsin).

7. Sea level falls below the present stand. Northern Channel Islands interconnected but probably not joined to the mainland. Man migrates to the California Islands at least by the end of the last glaciation. This interval ranged from about 100,000 to 18,000 years ago (late Pleistocene, Wisconsin).

8. The post-glacial sea level rise to near present stand, perhaps including a slight rise to form terraces near five feet, occurred from 18,000 years ago to present (late Pleistocene and Recent).

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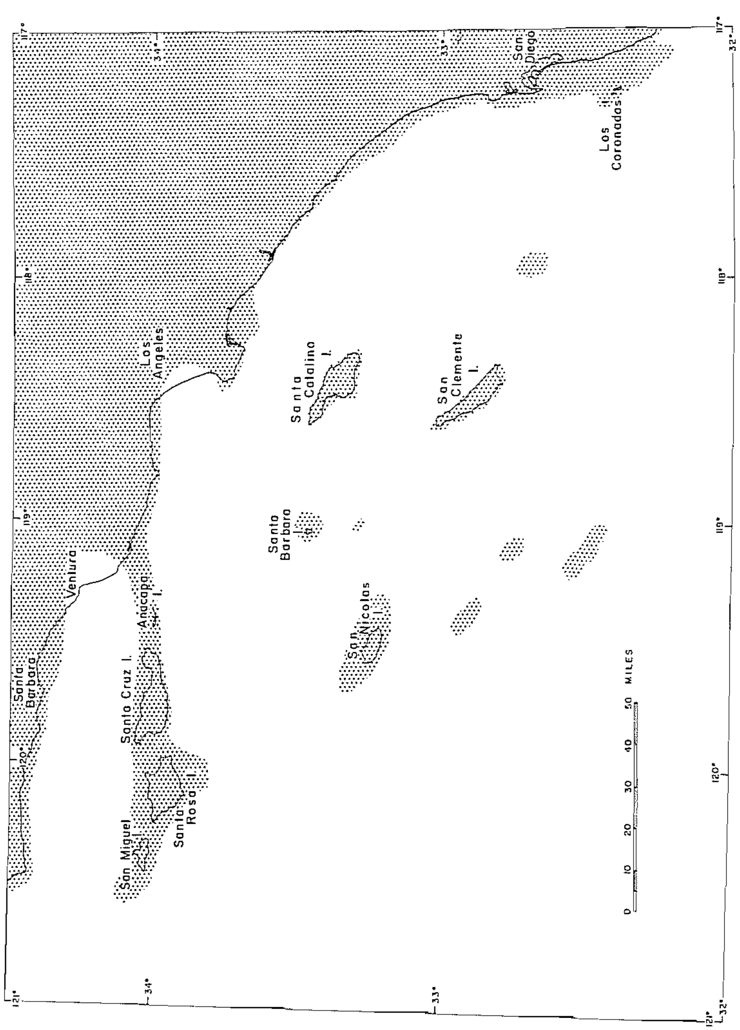

Fig. 4. Suggested land areas (dots) of the California borderland and adjoining mainland during lowered sea levels of the medial Pleistocene.

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