PALEOGEOGRAPHIC IMPLICATIONS AND GEOLOGIC HISTORY

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Geologic History

Isle of Structure.—The Southern California Borderland of which the Northern Channel Islands are a part, was a great deal of geographic and geologic diversity. This may perhaps be attributed to the major faults that have been active in the area at various times in the Mesozoic time.

It has been suggested that the orientation of the east-west trending Transverse Ranges (see Reed and Hollister, 1951), which are made up of clastic and volcanic rocks ranging in age from Late Cretaceous to Recent and which occur in fault contact with Late Jurassic crystalline or older metamorphic basement rocks, is a reflection of the Cretaceous extension of the Murray fracture zone. The latter is one of a series of great east-west trending faults of the eastern Pacific which does not appear to cut the Rocky Mountain. Major east-west trending left lateral faults that cut the Borderland and appear to have played a major role in its development are the Santo Tomas Fault and the central Baja California and continue westward along the Borderland with an estimated 15 kilometer offset (Moore, 1966), the Santa Monica-Santa Rosa Island (fig. 14) with possibly as much as a ten mile offset, the Santa Ynez Fault (Dibbilee, 1966) with an unknown and perhaps comparable displacement. These three faults may have produced eastward extending blocks that collectively have shifted the southwestern coast of the North American continent westward as much as 30-35 miles since Miocene time.

The present study has centered its attention on the islands and the Malibu-Santa Rosa Fault system associated with the northern end of the Southern California Borderland. The 21,000 feet of Late Cretaceous to mid-Tertiary sediments and volcanics are exposed on these islands (Santa Cruz, Santa Rosa, San Miguel). They rest depositional cover or in fault contact with a Late Jurassic and Cretaceous basement complex of metamorphic and plutonic rocks.

It has been shown in the foregoing chapters that this Cretaceous and Cenozoic sequence of rocks was deposited over an area large enough to which still largely submerged beneath the sea, both south and north of the Santa Ynez Fault, with only a few outcrops on the north and northwestern edge of the Interior Basin. The Cenozoic sediments exposed on these Northern Channel Islands have been received from both a south-western and a northeastern source area (fig. 16). The sediments to the south as exposed on San Nicolas Island, and the north as known only from numerous submarine cores, have definite affinities to those exposed on one or more of the Northern Channel Islands. Thus it is clear that these islands are part of a geologic province that extends outward from them for a considerable distance to the north as well as to the south and east. To the east lie the Santa Monica Mountains with which the islands have often been compared and shown to be geologically related; to the west and southwest lie the Peninsoa Escarpment which forms the western limit of the Southern California Borderland and which is the deep oceanic basin. And, although the islands form the southern limit of a transverse structural province, in terms of petro-provenance they are closely related to the Peninsular Range Province, at least its western portion which is largely submerged on the continental borderland, as well as to the Transverse Range Province.

The sphere of environmental influence that has played a role in the evolution of the Northern Channel Islands thus cuts across the major structural trend that forms the southern limit of the Transverse Ranges. To the north, the limit of this influence was the Santa Barbara Embayment-Ventura Basin, a basin or series of basins of deposition that originated in the Cenozoic. The eastern end of the east-west trending axis of the embayment has shifted slightly but progressively southward through time with marked fluctuations. Its central and western portion has maintained remarkable stability in orientation throughout its existence. The eastern portion, which has the thickest stratal sequence, was centered in the Topa-Topa Mountain and Ventura areas, extending westward and offshore, generally in the vicinity of what is now a folded belt of Cenozoic strata centered on the Rincon Trend and that includes the Ventura Avenue Anticline and the so-called Three Mile Trend and Five Mile Trend, and continues westward toward and beyond Point Conception (fig. 16). The Rincon Trend was the site of thickest deposition since late Miocene time, but today structurally it represents the highest trend in the entire Santa Barbara Embayment. The axis of this fold-belt is generally parallel and close to the present day shoreline along the Santa Barbara coast; as a basin of deposition it had not shifted very far from that location until post-Pliocene time. Today the deepest part of that basin, the Santa Barbara Basin, is centered half way between the mainland, west of Santa Barbara, and Santa Rosa Island; here its bathymetric depth is over 2,000 feet.

Structurally the Santa Barbara Embayment-Ventura Basin is characterized by east-west trending fold-axes involving 40,000-50,000 feet of Cenozoic sediments cut by nearly parallel reverse faults. The latter include converging low angle thrusts to the east, toward the San Gabriel fault zone and the San Cayentano and Santa Susanna thrusts, but westward they appear to diminish in significance and even diverge toward the present day Santa Barbara Basin and beyond.

The largest and most significant fault in this northern area is the oblique-left lateral-Santa Ynez Fault, the plane of which can be shown to have rotated through the vertical and thus involves both reverse and normal components of movement (Dibbilee, 1950; Bailey and Jahns, 1954). Compressional forces, apparently operating in a north-northeastern south-southwestern line, produced oblique fault movements with largely reverse and left lateral components (Dibbilee, 1950, 1966; Hill, 1932). By late Miocene time these tectonic forces began to play a direct role toward producing the present day landscape, and they became intense during the mid-Pliocene. Earlier Cenozoic effects had been largely obliterated by the extensive mid-Tertiary marine transgressions. The late Cenozoic left lateral displacement along the Santa Ynez Fault produced relatively large scale northwest-trending "drag" folds oblique to these east-west-trending faults (fig. 14; Dibbilee, 1966). Nearly east-west-trending echelon folds were produced directly by these same compressional forces. The compression was most intense to the east, in the eastern Ventura Basin, where low-angle thrusts and overturned folds were formed. To the west, folding and faulting were less intense and their displacement less severe, particularly in the central part of the embayment, although they were still of consider-
tion occurs north of Ford Point and east of Soledad, although it is lacking here immediately north of the fault; but north of the fault it does occur a few miles farther west as a finer-grained facies and again in the coarse-grained facies at Sandy Point on the western end of the island.

Large scale en echelon folds trending northwest-southeast, oblique to the major island fault system, have probably been produced by the same compressional forces that produced the late Cenozoic movement along the faults on the north side of the Santa Barbara Embayment. These folds included among others such prominent fold-axes as the Christi Anticline and its complimentary syncline on the southwest corner of Santa Cruz Island; the Tecolote Anticline, Beechers Bay and Sandy Point synclines on the north side of Santa Rosa Island; and the Soledad Anticline and its complimentary Pedregosa Syncline on the south side of Santa Rosa Island, although these latter two fold-axes are repeatedly cut by secondary faults. The Black Mountain Anticline on Santa Rosa Island is a fold-axis that parallels the east-west-trending fault system and is to be compared to those along the Santa Barbara coast which parallel the east-west-trending Santa Ynez Fault.

Between the major fault systems that limit the northern and southern flanks of the Embayment are east-west-trending extensions of structures that have long been recognized east of Ventura and Oxnard in the Ventura River Valley, the Santa Clara River Valley, in the Oak Ridge-South Mountain

Figure 16

Santa Cruz Island. The Santa Cruz Island Fault occupies the valley in the center of the picture with schist and diorite basement rocks exposed immediately to the left of the fault, and volcanic rocks and Monterey Shale to the right (courtesy of Brooks Institute of Photography).
area, the Simi Hills, and the Santa Monica Mountains (Kew, 1924). These are mostly east-west-trending slightly arcuate faults and fold-axes which largely parallel the other structural features of the Santa Barbara coast and channel islands (figs. 9, 14). These structures, like those mentioned on the islands, are inferred to have played major roles in the distribution of middle and late Cenozoic sediments.

Thus it appears that the Santa Ynez Fault on the north and the Malibu Coast-Channel Island Fault system on the south are similar east-west-trending oblique-slip faults which, like their mid-channel relatives, show steep reverse or normal dip-slip components of movement. They extend westward from the San Gabriel Fault zone where some of these faults have become low angle thrusts across the northern portion of the California Borderland to the oceanic basin. The Santa Ynez Mountains in the north, and the Santa Monica Mountains and their seaward extension, the Channel Islands, on the south, were produced along their respective axes of deformation, probably by the same forces acting at the same time, compressing the adjacent blocks against one another at an oblique angle to these principal axes of deformation, producing both vertical and horizontal fault displacements of considerable significance, as well as oblique trending en echelon and parallel folding.

Although the late Cenozoic compression referred to above folded the mid-Miocene transgressive deposits and drastically affected the distribution as well as folding and faulting of the Pliocene and lower Pleistocene stratal sequences, sedimentological and paleontological evidence suggests that these same structural trends played a major role in the earlier Cenozoic evolution of the province, although the structural trends often have been in position of reverse relief, i.e., some areas that are now structural or topographic highs were relatively low in early Cenozoic and late Mesozoic time and vice versa. Examples include: the Santa Rosa-Cortes Ridge including San Miguel and Santa Rosa islands which were high in Pliocene and Pleistocene time and are

Santa Cruz Island, southwest side of El Montanon. Offset of fence line by Recent movement of a fault (see white mineralized zone) cutting the Santa Cruz Island Volcanics.

Western Santa Cruz Island. Axis of Christi Anticline within the Canada Shale in Canada de los Sauces de Ojuer. (W. W. Rand, 1933)

Western Santa Cruz Island. Faulted Christi Anticline in the Canada Formation as it appears on the beach south of Christi Ranch. (W. W. Rand, 1933)

Southeastern Santa Cruz Island viewed from above with north to the right. An example of "keel geology" at Middle Anchorage. See also geologic map (Courtesy of Mark Hurd Aerial Surveys, Inc.)

high now by deposition; deep (-645 ft) Paleogene and San Nicolas Islands deeply buried by sediment that is 200 feet thick, probably of Cenozoic age, within these Santa Cruz Island area appears to have been date of formation.

The Santa Cruz Island is a Miocene to Pleistocene succession of volcanic rocks, which are dominated by andesite and dacite lavas and pyroclastic deposits. The island is part of the Santa Cruz Island Group and lies off the coast of California. The geology of the island is characterized by a series of overlapping volcanic cones, with the youngest cones being the highest. The island is also known for its unique fauna, including the Santa Cruz Island brown pelican, the Santa Cruz Island finch, and the Santa Cruz Island tree snail. The island is protected as a national wildlife refuge and is a popular destination for birdwatchers and nature enthusiasts.

Nonetheless, the original deposit is over the Jurassic in age, and it is thought that the schist associated with these deposits was formed by a combination of metamorphism and deformation. The schist is thought to have been formed as part of a larger tectonic event that affected the region in the late Mesozoic and early Cenozoic. The schist is characterized by a variety of minerals, including feldspar, quartz, and mica, and it is thought to have been formed by the metamorphism of pre-existing sedimentary rocks.

Although the exact age of the local batholith is not known, it is thought to be of late Mesozoic age, and it is thought to have been formed as part of a larger tectonic event that affected the region in the late Mesozoic and early Cenozoic. The batholith is characterized by a variety of minerals, including feldspar, quartz, and mica, and it is thought to have been formed by the intrusion of magma into pre-existing sedimentary rocks.
Late Jurassic-Early Cretaceous Deformation.—During and following the plutonic emplacements in the Late Jurassic, extensive orogenic activity took place which metamorphosed not only the Alamos Tonalite but also affected the Santa Cruz Island Schist. The metamorphism was of a regional type, and it is not known whether any Early Cretaceous deposits were affected, since these are not known in the area. On the north side of the Santa Barbara Embayment, however, north of the Santa Ynez Fault, Dibblee (1966) reports Early Cretaceous sandstones and shales of the lower Espeada Formation to be unaffected by that metamorphism and serpentine intrusion which affected area prior to Espeada time, but which did affect post- Franciscan deposition of Jurassic and possibly earliest Cretaceous time. Thus it would seem that the diastrophism which affected the greater part of the northern Transverse Ranges as well as all of the present-day Coast Ranges of California, often referred to as being synchronous with the great Nevanian orogeny, also affected the California Borderland as evidenced by the exposures of the basement complex on Santa Cruz Island.

Late Cretaceous Deposition.—Whether the borderland region emerged from the sea as a result of the Jura-Cretaceous diastrophism is not known. It is also not known whether chronologic equivalents of the Early Cretaceous Espeada Formation of the San Rafael Mountains were ever deposited on the borderland. It is certain that in the vicinity of San Miguel Island in Late Cretaceous/Turonian time normal marine conditions had already begun the deposition of the sands and muds that were to make up the Jalama Formation and totalled over 6,300 feet in thickness before Cretaceous time was over. These deposits were laid down under tropical oceanic conditions at outer shelf or upper slope depths. It is thought that these bathymetric conditions extended to the east beyond southwestern Santa Cruz Island, as distinguished from the situation in the area to the north, in the vicinity of the western Santa Ynez Mountains, where these warm seas were depositing similar clastic material but in a near-shore shallow environment suitable to rich molluscan life as evidenced by the abundant fossil mollusks found there today. It seems likely that these two areas on opposite sides of the future Santa Barbara Embayment represented part of a continuous basin of deposition, and that the Late Cretaceous shore line lay north of the present day Santa Ynez Mountains (Dibblee 1950, p. 61). This same shore line extended east beyond the Simi Hills where clastic Cretaceous deposits, now rich in fossil mollusks (Kew, 1924), are inferred to have been deposited in an inner neritic environment similar to that in which the Jalama Formation was deposited in the western Santa Ynez Mountains.

Deformation at the Close of the Cretaceous.—The only exposed Tertiary-Cretaceous stratigraphic relationship known from any of the Channel Islands to date is displayed in the Simonton Cove area of San Miguel Island. It is inferred to represent a continuous depositional sequence from Upper Cretaceous to Paleocene. Dibblee (1950), however, reports a regional unconformity in the Santa Ynez Mountains between various Tertiary units and the Cretaceous Jalama Formation, indicating a period of widespread emergence in that region. The stratal hiatus involved in this northern area is most severe to the north and east although it is almost nonexistent in the west-center where, at the type locality of the Anita Formation in the vicinity of upper Cañada de Santa Anita, most if not all of the Paleocene Series is represented and some 100 feet of highly glau-
conitic andesitic andesite, a concordant intrusive body in the southern part of the island.

The northwestern part of the island, extending from near the southern tip of Cape Suckling to Cape Colville, is composed of a series of andesitic and basaltic flows, with minor amounts of andesitic and dacitic lavas. The flows are generally thin and strike in a northwest-southeast direction. The lavas are characterized by their dark, glassy appearance and are often interbedded with volcaniclastic sediments. The flows are overlain by a thin layer of andesitic tephra, which suggests a volcanic eruption from a nearby source.

The northeastern part of the island, extending from Cape Colville to Cape Scammon, is composed of a series of andesitic and dacitic flows, with minor amounts of andesitic and basaltic lavas. The flows are generally thicker and strike in a northeast-southwest direction. The lavas are characterized by their dark, glassy appearance and are often interbedded with volcaniclastic sediments. The flows are overlain by a thin layer of andesitic tephra, which suggests a volcanic eruption from a nearby source.

The southern part of the island, extending from Cape Scammon to Cape Lamb, is composed of a series of andesitic and dacitic flows, with minor amounts of andesitic and basaltic lavas. The flows are generally thin and strike in a northeast-southwest direction. The lavas are characterized by their dark, glassy appearance and are often interbedded with volcaniclastic sediments. The flows are overlain by a thin layer of andesitic tephra, which suggests a volcanic eruption from a nearby source.

The western part of the island, extending from Cape Lamb to Cape Drygalski, is composed of a series of andesitic and dacitic flows, with minor amounts of andesitic and basaltic lavas. The flows are generally thick and strike in a northwest-southeast direction. The lavas are characterized by their dark, glassy appearance and are often interbedded with volcaniclastic sediments. The flows are overlain by a thin layer of andesitic tephra, which suggests a volcanic eruption from a nearby source.

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The southeastern part of the island, extending from Cape Drygalski to Cape Colville, is composed of a series of andesitic and dacitic flows, with minor amounts of andesitic and basaltic lavas. The flows are generally thin and strike in a northeast-southwest direction. The lavas are characterized by their dark, glassy appearance and are often interbedded with volcaniclastic sediments. The flows are overlain by a thin layer of andesitic tephra, which suggests a volcanic eruption from a nearby source.

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ness of 3,400 feet.
During and following the Ynezan orogeny, red beds
agglomerates, sandstones, and silstones were
posed to a thickness in excess of 500 feet in the
portions of the Santa Rosa-Cortes Basin on
the site of Santa Rosa Island. The sediments were
reworked from recently exposed outcrops
Eocene and/or older conglomerate beds. The west-
edge of this terrestrial remnant of the previous basin
in the vicinity of the southwestern corner of Santa
land as shown by the few feet of red beds that occur at
the top of the Cozy Dell Formation there. To the north
es of the Santa Rosa-Cortes Basin the site of Santa
Island, terrestrial trias deposition gives way to
moderately high relief marine conditions. Into this
was the marine remnant of the basin were deposited
iments of the Alegria and Gaviota formations (Klein-
pell and Weaver, 1963; Dibblee, 1950). This is not to
suggest that marine fingers did not intrude beyond the
limits noted above, but it is thought that there were areas
where marine conditions tended to persist although
considerable topographic relief was displayed, and there
areas of predominantly terrestrial nature, although there
were erosional highs and depositional lows here also.
Examples of topographically high areas during Eocene time
the region of the islands would be the sites of the central
portion of Santa Cruz Island and San Miguel Island.
An example of a terrestrial basin would be the Santa
Island area and perhaps along the site of the Santa
Cortes Ridge, and in the Ventura Basin on the north side
of the embayment.
Following the climax of the Ynezan orogeny in late
Refugian or early Zemorrian time much of the Oligocene
peninsula that was formed as a northwestern extension of
Catalina was inundated by a transgressive Zemorrian sea,
as were the northern and eastern portions of the Santa
Barbara Embayment. In the vicinity of southwestern
Santa Cruz Island, marine conditions returned with the
deposition of the coarse-grained basal conglomerates of
the Vaqueros Formation, rich in plutonic clasts resembling
the Alamos and Willows intrusives, as well as fragments of
green schist and volcanic pumices. This evidence reveals
the contemporaneous but relatively unroofed on Santa Cruz
Island had been widely unroofed by Zemorrian time as a result of
the Ynezan orogeny and were supplying detritus to the sur-
rounding basins. The deposition of the coarse-grained ma-
terial in the vicinity of Santa Cruz Island was followed by
Vaqueros sand deposition and this by the mud of the
Rincon Formation as the source area came progressively
subdued and as the sea deepened slightly by late Zemorrian and early Saucian time. These Zemor-
ian and early Saucian shelf sea conditions extended west-
ward at least as far as Santa Cruz Island (see figs. 3, 16,
the Santa Rosa Shelf) and constituted an environment that
permitted a neritic molluscan fauna, as well as a sparse
water foraminiferal community, to thrive. In the
vicinity of Santa Rosa and San Miguel islands, the texture
of the sediment deposited is generally finer-grained but
composed of material of similar composition to that
deposited in the site of southwestern Santa Cruz Island.
Where conglomerates were deposited on this shelf as on
San Miguel Island they are thinner, in general, and the
plutonic clasts are not conspicuous. Moreover, the late
phases of Rincon mud deposition, at least in the
vicinity of Santa Rosa Island, contained small sand- and silt-sized
clasts of glauconite schist in addition to the green schist
and meta-volcanic debris.
It is indicated that Catalina was not entirely sub-
merged by the late Oligocene (Zemorrian-early Saucian)
transgression and that this land mass, although subdued
since the climax of the Ynezan orogeny, perhaps even
existed in the form of a series of islands, and that as such
it supplied detritus from newly exposed green and blue
schist and plutonic basement rocks as well as the ever
present source of volcanic porphyries and quartzites.
Early Miocene (late Saucian) Deformation and the Loma-
copan Orogeny. — The Miocene along the site of the
Northern Channel Islands began with a renewed uplift of
Catalina. Affected was the old basement complex exposed
along the Santa Cruz Island structural trend which was
uplifted and which now skewed its debris southward across
the northeastern portion of the Santa Rosa Shelf
(fig. 16) and also northward across the Oxnard Shelf. This
debris was rich in large boulders of glauconite schist and
chlorite schist and included a variety of plutonic rocks and some garnet amphibolites. The shedding of the debris toward the north extended along a Miocene shore line that reached from north of Carrington Point, on Santa Rosa Island, eastward toward Point Dume along the Santa Monica coast line, and then southeast toward Oceanside, California.

The newly exposed basement rocks which were part of the Catalina Island land mass were, in the vicinity of Santa Cruz Island, apparently brought up along the nearly east-west trending Santa Cruz Island and associated fault systems. Movements along these faults during the Lompocan and Ynezan orogenies had clearly played a role in establishing the east-west transverse structural trend that formed the Santa Barbara Embayment: and such faulting was widespread in the Coast Ranges in association with the appearance of the San Onofre Breccia at the time of the Lompocan orogeny (see Reed and Hollister, 1936, pp. 120-124; Kleinpell, 1936, p. 119).

The area affected by this orogeny appears to be much the same as that for the preceding Ynezan orogeny, although epiregional and faulting were more pronounced in the Lompocan. This is like conditions along the San Rafael Uplift on the north side of the Santa Barbara Embayment where the early Miocene disturbance was first named the “Lompocan orogeny” by Dibblee (1950, p. 63). And, as emphasized by Dibblee for that area, these two orogenies, the Ynezan and Lompocan, were very important in the geologic history of the Transverse Ranges for they brought about great changes in the paleogeography of the area in general. They developed into a mature form the Santa Barbara Embayment, an east-west trending structural province that had its beginnings in early Paleogene time. Related to the Lompocan orogeny and perhaps its underlying cause, is the early Miocene plutonic intrusion that invaded Catalina Island and is presently exposed on Catalina Island where its hornblends have been dated as 19 m.y. (oral communication, John Forman).

Early Miocene Deposition and Volcanism.—During and immediately following the Lompocan orogeny, debris from the newly exposed sources of diorites, green and blue schist, and other material was dumped down steep slopes on to the Santa Rosa and Oxnard shelves and into the Santa Rosa Basin where they blended with the later Rinconite muds deposited there on the outer shelf areas. The conglomerates and breccias, designated the San Onofre Breccia, reached a thickness of 1,500 feet on the southwestern corner of Santa Cruz Island, but thinned rapidly southwestward.

Although the earliest result of the Lompocan orogeny on the early Miocene deposition in the island area was the shedding of the large boulders making up the San Onofre Breccia, intensive and extensive volcanic activity appeared almost simultaneously.

The volcanic activity occurred along a front that extended from west of San Miguel Island where one center of volcanism occurred, to Santa Cruz Island (north of the Santa Cruz Island Fault) where there was another center, and then on eastward to the site of the western Santa Monica Mountains where a third center of volcanic activity was present. Early basalt flows and other basic magmas were followed by andesitic and dacitic flows, dikes, and breccias, similar to a fourth center of volcanism at the site of Tranquillon Mountain in the western Santa Ynez Mountains (Dibblee, 1950). At the site of the Santa Cruz Island volcanism, the volcanic flows, intrusives, and breccias that make up the Santa Cruz Island and San Miguel Island volcanics were emplaced along with the Conejo volcanics of the Santa Monica Mountains as the basins subsided following the Lompocan orogeny.

As these volcanic rocks piled up faster than subsidence took place, and were accompanied by pyroclastic activity, erosion was carrying the resultant debris out on to shelf areas where it mixed with the debris of the San Onofre Breccia and the Rinconite muds. The flows did not extend out far from their center on Santa Cruz Island where they were thickest, but their eroded debris mingled with the San Onofre deposits extended out as far north as the site of the Montalvo Trend (see fig. 14), as evidenced by subsurface data. To the south, adjacent to the volcanic center in Santa Cruz Island and along a story of the recently emerged coastline, shallow water and tenacious conglomerates were deposited. At first they consisted of diorite and green and blue schist boulders and the San Onofre Breccia. Later, 1,400 feet of tuffaceous mud flows which supported coarse clastic volcanic and basaltic debris were deposited; they make up the Blanca Formation.

The volcanic center near the site of San Miguel Bay sent its flows and eroded debris out on to the Santa Rosa Shelf and into the deeper basin which lay to the south, but these deposits contained little if any San Onofre debris. It appears that the coarse clastic San Onofre debris did not spread southwestward much beyond Carrington Point on northeastern Santa Rosa Island, where it mixed with the volcanic debris coming from the San Miguel volcanic center as well as the Santa Cruz Island volcanic center.

The volcanic and basement highland (fig. 16) which produced the clastic debris for deposition on the San Rosa and Oxnard shelves must also have contributed cobbles, pebbles, and sands to the northwest toward the axis of the Santa Barbara Embayment, although no concrete evidence is available to support this suggestion. This is the case, the finer-grained sands may have reached as far as the center of the trough i.e. almost to the site of the present day Santa Barbara coast line.

Although volcanic ash falls continued on into the Relizian and Luisian times of the mid-Miocene, especially on Santa Barbara Island and in the Santa Monica Mountains (Kleinpell 1930, p. 164), volcanic flows and eruptions ceased by early Relizian time in the vicinity of Northern Channel Islands.

Mid-Miocene Deposition. — The close of the San Miguel land and/or the beginning of the Relizian was marked by the marine deposition of particularly thick and widely distributed volcanic tuffs (see fig. 3), followed generally by a chalky and siliceous deposits of Monterey mud which lay up on the newly formed volcanic highlands. Although the mid-Miocene chalky and siliceous seas eventually drove most of the San Rafael Uplift in the northern portion of the Santa Barbara Embayment, as is widely the case elsewhere in California, such was not the case at the site of the Northern Channel Islands. The volcanic center on San Cruz Island and the basement rocks there, which are associated structurally, probably remained as a discrete island chain at the northwestern end of Catalina Island chain continued to supplied cobbles, pebbles, and sands to the slopes which drained southwest toward the site of Santa Rosa Island where they were deposited intermixed with the muds of the Monterey shale at outer shelf depths. These somewhat coarser deposits, with their intermittently deposited sand beds, have been named the Breechers Bay Member of the Monterey; they reach maximum thickness westward, as suggested by the mid-Miocene deposition.

Toward the southeast of the volcanic area, where the channel was dominated by intermittent flow, many of the deposits (Breechers Bay) continued in stream eroded channels. Although the deposits of these channels are relatively thin, the interbedded sand and silt layers were preserved because of the thinning of the sedimentary layers are characteristic of the large channels which drained into the sea from the highland through the Breechers Bay Member of the Monterey; they reach maximum thickness westward, as suggested by the mid-Miocene deposition. Toward Breechers Bay, the channel was dominated by intermittent flow, many of the deposits (Breechers Bay) continued in stream eroded channels. Although the deposits of these channels are relatively thin, the interbedded sand and silt layers were preserved because of the thinning of the sedimentary layers are characteristic of the large channels which drained into the sea from the highland through the Breechers Bay Member of the Monterey; they reach
Thus the southern part of the Santa Barbara Embayment, along the site of the northern islands, there appears to have been a general emergence during these times of increasing surface relief. In addition, it is evident that the present day Santa Rosa-Cortes Ridge, the Santa Cruz and probably the Santa Monica basins, and the ridges associated therewith, matured and possibly originated with the Pliocene orogeny, although these areas had also been affected by the Lompocan orogeny (figs. 14, 16). To the north across the Oxnard Shelf, the Montalvo-Oak Ridge Uplift was formed, which acted as a southern barrier for subsequent Pliocene turbidite sands (Repetto and Pieo formations) that were to erode from the Topa-Topa high to the northeast (figs. 9, 16; Natland and Kuenen, 1951; Jennings and Troxel, 1954). These sands were deposited in the trough that existed at the close of the Miocene and had received the Miocene cherty diatomite and muds; its east-west axis was located approximately along the present day Santa Barbara shore line. This trough extended eastward to the site of the Ventura and Santa Clara rivers, in the vicinity of which 15,000 feet of sediments were deposited into a basin that by latest Miocene or earliest Pliocene (Rafaelian) times had reached abyssal depths. Although on the whole these Pliocene turbidite sands were not able to pass southward over the mid-channel buttress represented by the Montalvo-Oak Ridge Uplift, the finer-grained silts and muds did to some degree do so and lapped up on to the top of this east-west structural high, although they never reached the site of the Channel Islands, at least during lower and middle Pliocene times. By late Pliocene or early Pleistocene time, the deep portions of the basins had partially filled, and relief was more subdued than still evident. This was followed in Pleistocene time by the deposition of the shallow water Santa Barbara-Saugus sands in the Ventura Basin, which may have extended across the channel where their partial equivalent, the Potato Harbor Formation, was deposited on the tip of northeastern Santa Cruz Island.

In the Santa Barbara Channel area the details of the early structural history of these Pliocene basins has been largely masked by the mid-Pleistocene Pasadena (“early Coast Range”) orogeny. It would appear that beginning with the Rafaelan orogeny there was periodic structural deformation, such as that which peaked as the Zaca orogeny, throughout Pliocene and Quaternary times, with a maximum at a mid-Pleistocene orogenic peak (Reed and Hollister, 1936).

The extent of the Pliocene land mass at the site of the Channel Islands (Western AnaCapiai of Reed and Hollister) is not clear from the data at hand. Northern AnaCapia had a mainland connection eastward to the site of the Santa Monica Mountains and extended westward beyond San Miguel in early Pliocene time at least. It may have extended northward from there toward Point Concepcion as suggested from the geophysical data. It appears that the lower and middle Pliocene sea of the Santa Barbara Embayment was almost an inland sea with just a small marine strait leading to open ocean at its western end.

Pleistocene and Recent times saw further orogenic disturbances such as the “late Coast Range orogeny” (Dibblee 1946, pp. 65), and great fluctuations in the relative sea levels as evidenced by present day submarine and subaerial terrace deposits; and these, coupled with movements along the well established structural Trends, at times all but
drowned western Anacapia in shallow cool water seas. Only in late Pleistocene and sub-Recent times did the mainland connections briefly re-establish themselves to permit a Pleistocene mammoth fauna, which had only arrived in North America in the mid-Pleistocene, to reach as far west as San Miguel Island.

Paleogeography and Structure.—In summary, it can be said that land connections during the Cenozoic Era between Anacapia and the mainland were general for the first time in Oligocene time and reached a maximum during the Pliocene and late Pleistocene or Holocene (“sub-Recent”), but that the general emergences were in each case separated by an interval of submergence sufficient to all but destroy the connections. Indeed, the middle Miocene transgression is thought by most workers to have completely drowned western Anacapia. The studies on Santa Cruz Island, however, suggest that localized remnants of this early Miocene center of volcanic activity may have remained as a vestige of the earlier peninsula. A comparable scene must have existed during Pleistocene time, for marine terraces cover all but the top of Green Mountain on San Miguel Island and occurred possibly as high as 1,300 feet on the north side of Santa Cruz Island.

The east-west structural framework of the Santa Barbara Embayment had its embryonic development, as indicated by various lithofacies on both sides of the embayment, perhaps as early as Paleocene and Eocene time. As a result of the Ynezan and Lompocan orogenies, however, a mature east-west structural trend had developed during the Oligocene and earliest Miocene which affected the distribution of sediments by dividing the embayment into northern and southern portion. The northern was that of the Ventura Basin and the Rincon Trough, the core of which was close to and paralleled the present Santa Barbara coast line. The southern portion was the Santa Barbara Sill, the Santa Monica Basin(s) and was the center for much volcanic activity.

Orogenic activity was renewed during middle and late Miocene times and of these the Rafaelan orogeny initiated the reversal of several topographic and structural trends such as the Santa Cruz Basin and the Santa Rosa-Casa Ridge, as well as the Santa Cruz-Santa Monica Basin. Earlier Miocene times, but strengthened the Montalvo Trend which subsequently acted as a barrier to the distribution of Pliocene turbidites. The periodic recurrence of orogeny, such as the Zaca during the Pliocene, and climaxing in the mid-Pleistocene Pasadenaan orogeny with a falling off of the late Pleistocene and Holocene, produced the present structural and topographic expressions of the Santa Barbara Uplift, the Rincon Trend, the Montalvo-Oak Ridge Uplift, the Northern Channel Islands, the Tecolote Uplift and the entire Southern California Borderland.
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