NATURAL HISTORY OF THE CORONADO ISLANDS, BAJA CALIFORNIA, MEXICO

San Diego Association of Geologists

FRONT COVER. Aerial photograph of the Coronado Islands. View towards the southeast with North Island in foreground (1936). Photograph courtesy of Historical Collection, Title Insurance and Trust.

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OF THE
CORONADO ISLANDS,
BAJA CALIFORNIA, MEXICO

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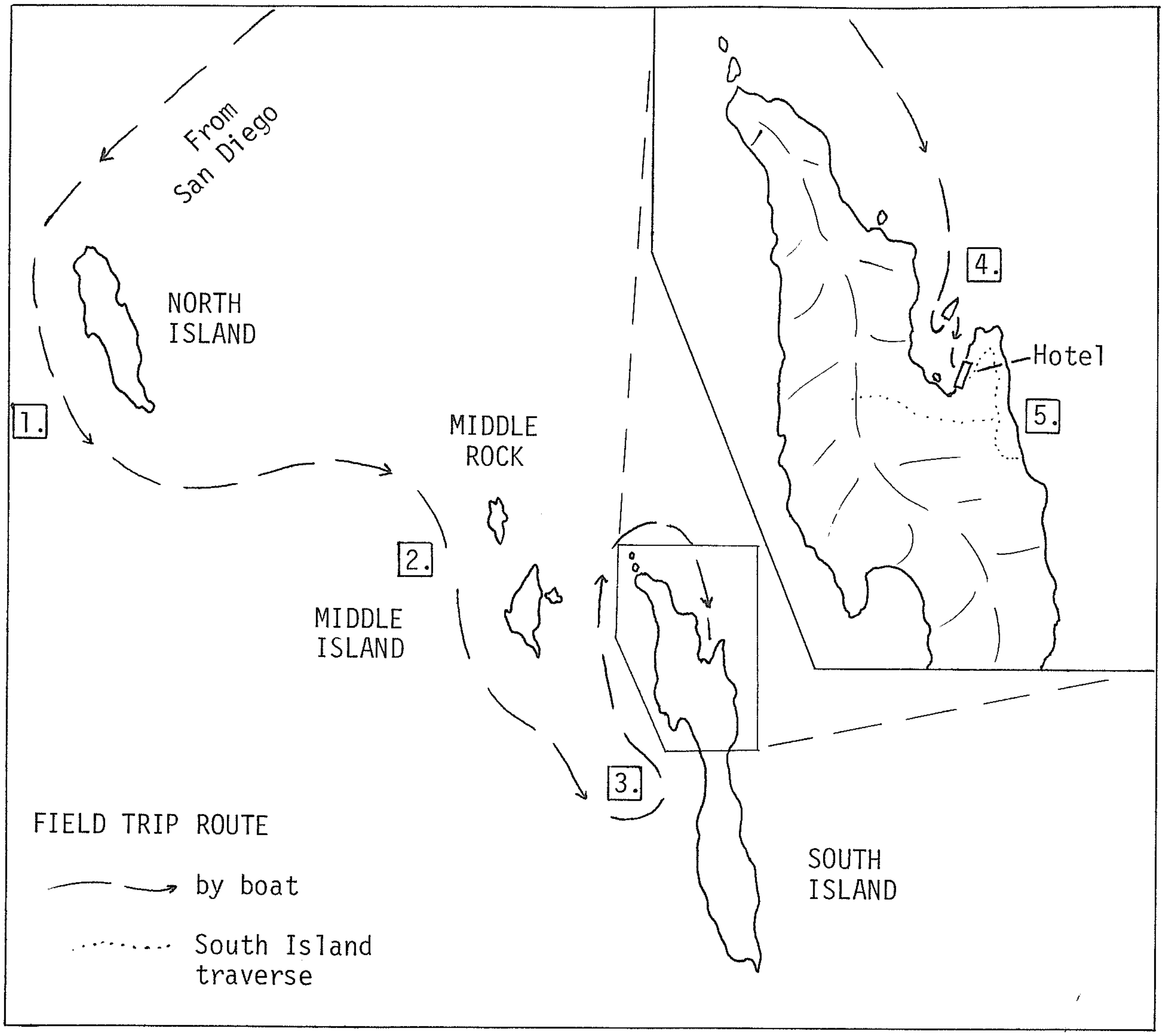


ITINERARY

1. North Island*. 2. Middle Rock and Middle Island*. 3. South Island's Seal Cove*. 4. Puerto Cueva Cove (anchor and shuttle to shore). 5. South Island, hike up peninsula ridge, down to east side of island, possibly to ridge west of Middle Peak.

* observe from the boat

NATURAL HISTORY

from Los Coronados Island
by Helen Ellsberg, 1970
La Siesta Press

There they lie, Islas Los Coronados, fifteen miles offshore from Point Loma Light, seven miles from the mainland of Baja California; a singular group of four rocky peaks and a peaklet rising precipitously from the sea. They are bleak and barren, wind-raddled and wave-tortured, waterless, and therefore tenantless, save for lighthouse keepers and a small garrison of Mexican military personnel who must be supplied with fresh water from the mainland. They might seem to be of little interest to anyone besides the Sea Lions basking on the rocks, or the circling birds above them. Yet these islets have always been somehow intriguing to the imagination. They have even inspired such fanciful phrases as "mystic-violet dreaming isles, floating in the westering seas", doubtless by an author who never had been close to them.

A rocky cliff on the northern island bears a striking resemblance to a human profile and is known, of course, as Old Stone Face. This face has looked down upon an endless parade of visitors-the sailing ships of the early explorers and privateers; the dories of the seal hunters; excursion boats with picnic parties; glass-bottom boats; the silent sails of the smugglers, and the wasp-like speedboats of Prohibition days who rendezvoused with the rum-runners; sightseers' yachts; boatloads of naturalists; and fishing boats by the thousand.

The islands may well have sunk beneath the weight of all the names that have been wished upon them at one time or another. In September, 1542, Cabrillo passed by. He noted in his log their lack of soil; that one of the islands was larger than the others and afforded shelter from the west winds; that they were three leagues from the mainland and were in 34 degrees. He named them "Las Islas Desiertas."

Came Vezcaino in 1602, leading an expedition of four small ships on an exploration of the west coast. Aboard was a Carmelite friar, Father Antionio de la Ascencion, who kept a personal diary in which he noted as they approached San Diego that they " reached some four small islands, two shaped like sugar loafs and the other two somewhat larger." The friars named these Los Cuatro Coronados, in November, 1602, because November 8 was the day of the Cautro Coronados, four brothers allegedly put to death for their death for their Christian faith in the time of Diocletian.

There is an account that Vizcaino named them the Coronados in honor of Francisco Coronado, Governor of the province of Jalisco under Hernan Cortez. However, this is discounted, and Vizcaino himself complicates matters by presenting us with a chart on which the island group bears the name of San Martin.

Other written accounts have stated that they were named for the explorer Coronado who reached Arizona and New Mexico in search of the "Seven Cities of Cibola"; another that they were so named because they resembled a crown when viewed from a distance. An eastern writer said that they reminded him of Bishop's mitres and said that he would have called them Los Obispos.

For some reason, for a number of years in the 1800's, they underwent a change of gender, and all San Diego newspapers referred to them as Las Coronadas. Also, about this time, some imaginative soul decided that one of the islands resembled a coffin, and they became known as The Sarcophagi, or Dead Men's Islands. North Island for a time was called Cortez. Then someone saw it as resembling a body draped in a shroud, and it became Corpus Christi, and was sometimes known as the mummy island. Later, it was declared to resemble a feeding elephant, but fortunately no one ever got around to naming it Jumbo.

Now, after the mists of nomenclature have cleared away, they stand officially Islas Los Coronados in their native Spanish; The Coronados Islands (with the plural spelling) in English.

Let us look at them more closely.

South Coronado, largest of the islands, is nearly two miles long, 672 feet high at its loftiest point, and a half mile across. It appears wedge-shaped when viewed from northward or southward, and when one stands at the summit and looks along its crest, it somewhat resembles the sharp back of a huge dinosaur. It has the one harbor on the islands, a quiet cove called Puerto Cueva, sometimes referred to as Smuggler's Cove. The lighthouses at each end of the island are manned by a Mexican civilian. When the first Mutiny on the Bounty was filmed, this was the site used to duplicate Pitcairn Island.

North Island, the second in size, is 467 feet high and over a half mile long. It has no harbor, but boats can anchor safely in a bight on the eastern side and put passengers ashore in a skiff. A rickety structure known as the Lobster Shack stands in a depression on this side of the island-useful as a landmark or a place to spend the night for a stranded fisherman. This is the island famous for its nesting sea birds on the leeward side, and its Sea Lion breeding colony on the windward.

Middle Island is 251 feet high, a rocky peak with a mass of cactus and brush near its summit. It is the nesting place of numerous birds, principally the Murrelet and Auklet, and is the home of a colony of Harbor, or Leopard Seals.

Middle Rock is 101 feet high, difficult to land upon, and offers little enticement to do so, as it has little vegetation, and is white with the guano of roosting birds.

A large rock off the north end of South Island is called North Rock. It is sometimes shown on maps, and is included whenever the islands are listed as being five in number.

There is a hiatus of information about the Coronados between the records of the explorers and the indexed San Diego newspapers of the 19th Century, but it is known that their fantastically rich fishing grounds had been discovered early in southern California's settlement. Difficulty in landing and the absence of fresh water discouraged an early interest in the islands themselves.

A decaying section of rude stone wall on South Island, said to have been laid by Russian or American seal hunters serves as a reminder of the days when these hunters slaughtered the Fur Seals, Elephant Seals, and Sea Otters until they all disappeared from the Coronados. Although hunting them has long been forbidden, the Elephant Seals are the only ones so far to begin making a comeback here.

The cliffs of the islands were stripped of thousands of abalone by the Chinese and Japanese, who sold the beautiful shells by the ton. These were sent to Germany where they were made into jewelry and sent back to the United States.

The first available newspaper account of the Coronados is in 1869, describing a phenomenon which still intrigues watchers from the California shore during times of great heat when the wind is down, creating mirage conditions. "On Monday, the 21st ult. during mirage; their sides gradually grew vertical till they resembled castles, and then their tops expansed so that they took the shape of fans and letter V's."

The next account is of an 1870 excursion to "Las Coronadas," and the tone of the account indicates that such trips were common. The steamer Vaquero made the excursion with "a party intent on fishing and egg gathering." Captain Dunnells advertised another excursion on the coming Saturday when the party would camp overnight on the islands and return the next afternoon. A band of music was to be among the attractions. "Round trip fare, $1.00."

In this same year, two California commercial fishing companies began operating on the islands shipping fish-mostly Rock Cod- "Superior to any cod...seen in the markets" to coastal outlets.

In 1872, building stone of excellent quality was discovered on North Island and temporarily exploited by Colonel Manuel Ferrer and Tore Fidel Pujal. Sr. Fidel was editor of La Baja California, a newspaper published at La Paz. They secured a patent for the island in 1873, and for a time the newspapers printed numerous accounts of the quarries and what was being done with the building stone, including interest by the railroads in procuring the stone to use for riprap. There is a final 1882 entry, "Ex. Col. M.A. Ferrer and partners Gatewood and Winder, owners of the Coronado Island have sent Doc Martin on the sloop New Hope out to the quarry for the purpose of working the mine." After this-silence.

H.C. Hensley states in his undated, unpublished manuscript, Early San Diego, Volume I, "While large ledges of fine brownstone exist on this island (North) the extreme difficulty which would be met in bringing it away no doubt has stood in the way of any development of an industry.

There was a flurry of excitement for a time when specimens of copper-bearing ore were discovered on the islands-one almost pure copper. In 1880, an enthusiastic account reads,"There is little doubt that a rich mine exists here." But like so many of the Coronados incidents, it comes to a dead end, and is not mentioned again, adding one more to the islands' history mysteries.

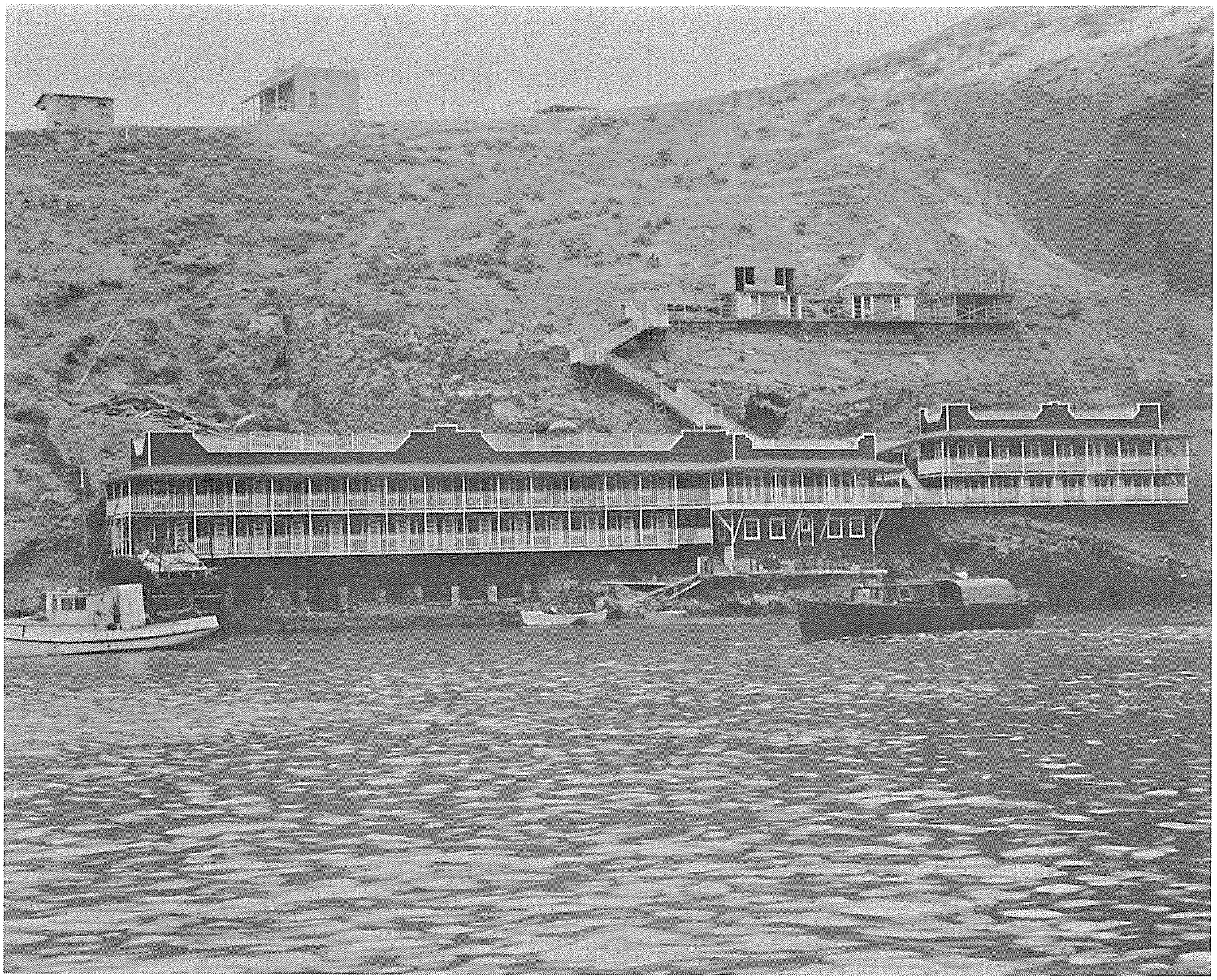
All during this period there are accounts of excursions to the islands, of fishing, picnics, and overnight parties. That many of these parties behaved with typical North American lack of consideration is evidenced by the fact that in 1872 a Mexican Man-of-War was sent to the islands to prevent trespassing. Its visit seems to have had no lasting effect.

During one period, the Coronados were used as a way station in the profitable business of smuggling Chinese into California. This was halted abruptly after a group of Chinese were found there, abandoned and starving.

During Prohibition days there was considerable traffic in rum-running with the Coronados as a rendezvous. The big rum runners anchored off the islands in Mexican waters. Then, at night the swiftest of speedboats ran the cargo to San Diego under cover of darkness. As the Coast Guard was never able to capture one of these speedboats, there seem to be no newspaper accounts of their illicit activities.

The 1930's saw an unsuccessful attempt to run a resort and casino on the islands. A California businessman, Fred Hamilton, former manager of Benson Lumber Company, and Mariano Escobedo, a Tijuana businesman, obtained a twenty-year lease and permission to construct a building on one side of the cove on South Island, "with the main building to house a cabaret, cafe, and other features." It was named The Coronado Islands Yacht Club, but at the time of its opening, the main attraction was gambling. There were also numerous "Mr. and Mrs. Smiths" on the register.

Hamilton and Escobedo sank $200,000 into this enterprise, but their timing was unfortunate. Although the casino enjoyed a moderate success for a time, these were the years of the Great Depression when money was tight. Then, 1933 brought the end of Prohibition. A newspaper item in June of 1934 reports "the Coronado Yacht Club nearly deserted since repeal," and on December 1, 1934 President Lazaro Cardenas dealt the hotel its coup de grace by signing the official order abolishing gambling in Mexico.



Photograph of Coronado Yacht Club (1930). Photograph courtesy of Historical Collection, Title Insurance and Trust.

A final attempt was made in 1935 to rescue the hotel from bankruptcy. A Grand Opening was advertised for May 25, 1935, and a coupon published in the paper good for a free trip opening week. The management was to specialize in seafood-everything at mainland prices; "Good music, dancing, swimming, hiking, and fishing, with a glass-bottom boat to view the submarine gardens; speedboats to leave the foot of Broadway at 4:30 Saturday, Tuesday, and Thursday p.m. and returning leave Coronado Islands Sunday 5:30 p.m.; Wednesday and Friday 7:00 a.m."

But the cards were stacked against the venture, and the hotel reverted to the Mexican government. It now houses the Mexican military personnel stationed on the island along with their families. It is a lonely station, with a supply boat from the mainland only once a month. But lobster fishing is a lucrative sideline and there are frequent requests for extensions in the normal six month's tour of duty.

At about the same time the Yacht Club was begun, plans were announced by S.G. Vasquez, Mexican Colonization Agent and Fish Game Commissioner for a rival attraction-a "floating palace" to be anchored off the Coronados for fishing, dancing, and dinner parties. It was to be known as Los Coronados International Sport Fishing Club with Arturo Cubillas, Jr. of San Diego as President; S.G. Vasquez, Secretary and Director. There is no further mention of this venture.

At the time misguided seafarers decided to stock the offshore islands with goats, the Coronados did not escape. However, the animals did not prosper here as they did on Guadalupe and some of the other islands, and died off after a number of years; the last hardy specimen evidently expiring of old age in the early 1950's. Evidently, they obtained enough moisture from their food to sustain life at least for a time. Although there was plenty of food available, they seem to have been unable to live without fresh water, and died out quickly.

During the thirties, the Star and Crescent Company made regular boat excursions to the islands, but these were discontinued. Then, in 1958, their steamer, Silver Gate, resumed excursions for the summer, sailing daily for the islands towing a glass-bottom boat which was to operate in the cove on South Coronado. How successful the venture was at this time is not reported, or whether or not it was repeated in subsequent years. At any rate, the custom was again discontinued, and regular excursions of any kind have not been conducted for some time.

GEOLOGY

Thomas N. Lamb
Catlin and Company
La Mesa

INTRODUCTION

General Setting and Scope

The Coronado Island group consisting of North Island, Middle Rock, Middle Island, and South Island, is located on a shallow submarine shelf approximately 12 km west of Rosarito Beach, Baja California, and 25 km southwest of San Diego, California. All of the Coronados are tilted fault blocks that lie en echelon to one another on a shallow submarine shelf. This shelf is incised by Coronado Canyon 7 km north of the islands and is terminated on the west by the 1100m Coronado Escarpment (Fig.1). Maximum interisland water depths, as well as depths between the islands and the Mainland, do not exceed 50m.

The Coronado Islands are geologically importnat in that they are located in a transition zone between disrupted ridge-and-trough geology of the Continental Borderland and more stable rocks of the Mainland. The present paper, condensed from a Master's Thesis completed in 1974 at San Diego State University, summarizes the stratigraphy and structure of the Coronados and relates the islands' geology to that of southern California, Baja California and the offshore Continental Borderland. The author studied the Coronados with the assistance of students from the School of Marine Sciences, Ensenada, Baja California. Since the Coronados have not been topographically mapped, mapping was done on air photos from which formline maps were drawn. Although some rocks of the Coronados have been recognized as seaward equivalents of formal mainland formations, in the present report each island is divided into numbered mappable units. For example, Middle Island rocks, proceeding upward stratigraphically, are assigned as units m-1 through m-5.

Previous Work

The geology of adjacent Baja California and Alta California is relatively well known compared to the submarine and island geology of the local offshore area. Mainland geology of the Tijuana, Rosarito Beach area directly east of the Coronados has been studied by Minch (1967) and Flynn (1970). The most complete accounts of immediate offshore geology are in papers by Butcher (1951), Emery and others (1952), Krause (1965), and Shepard and others (1969). Regional studies of the San Onofre Breccia by Stuart (1974, 1975) include descriptions of Miocene rocks of the Islands and local mainland, whereas reports of Woodford (1925), Hanna (1927), and Beal (1948) briefly mention the Coronados.

NORTH ISLAND

General Statement

North Island lies 3km east of the major slope break of the Coronado Escarpment and 7km south of Coronado Submarine Canyon (Fig. 1). The island is 1.5 km long, 0.3km wide, and 130m high at Middle Peak. Typical of the Coronados, North Island has a narrow ridge along its entire length, steeply sloping sides, and cliffs 20-40m high along the western (windward) shoreline (Fig.2). Rock is exposed over most of the island except near the crest where a thin sandy soil covers sandstone bedrock.

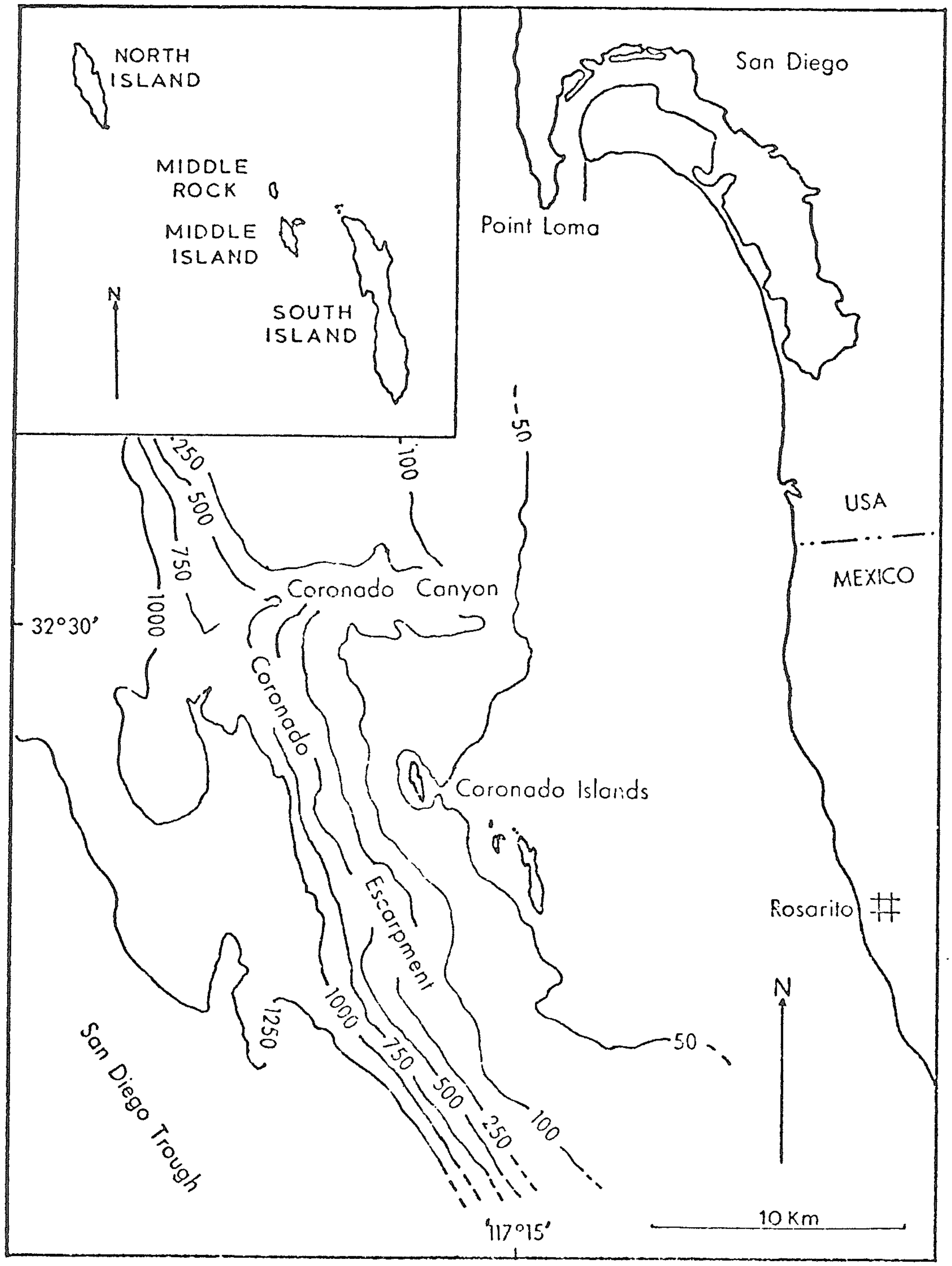


Figure 1. Coronado Islands and Adjacent Area. Adapted from U.S. Coast and Geodetic Survey Map 1206N-16, 1967. Submarine contours in meters.

Unit N-1

North Island is composed almost entirely of red sandstone and interbedded shale of unit n-1 (Plate I, Fig.3). Over 200m of these redbeds are exposed both north and south of two main faults west of Lobster Cove. The sandstone is well-indurated, fine-to coarse-grained, feldspathic litharenite to lithic arkose. The red color of the rock is derived from a silty iron oxide cement and volcanic rock fragments in various stages of oxidation. Rock fragment distributions in thin sections average 50% plutonic, 30% volcanic, 15-20% sedimentary, and less than 1% metamorphic. Plutonic fragments are predominately aggregations of feldspar and quartz. Volcanic rock grains are severely weathered, but appear to be of quartz latite to dacite compostion. Most sedimentary rock fragments are intraclasts of shale chips and red, fine-grained sandstone.

Average thicknesses of individual sandstone beds range widely from 2cm to 3m, but beds 2 to 10cm thick prevail (Fig. 4). Sedimentary structures such as scours, load casts, cross-beds, current crescents, and graded bedding are present, but attitudes are variable, revealing no dominant current or paleoslope direction. Shale rip-up clasts are common, some having been detached and rolled sufficiently to form armored mudballs.

Interbedded with the sandstone, but comprising less than 5% of the total stratigraphic section, are beds of red siltstone and shale a few millimeters to 15cm thick. Bedding contacts with sandstone layers are sharp, reflecting distinct periods of silt depostion followed by turbulent depostion of sand.

Pebbles and cobbles are dispersed throughout unit n-1 redbeds, but actual conglomerate outcrops are rare. A few lenticular conglomerate beds crop out near the south end of the island. Clasts appear to be derived from basement rocks of the Peninsular Ranges of northern Baja and San Diego County, including, in order of decreasing abundance, green-brown to black volcanic and metavolcanic rocks with plagioclase phenocrysts, quartz monzonite, granodiorite, vein quartz and quartzite.

Unit N-2

Unit n-2 consists of two andesitic dikes that crop out near the central faulted area of the island. The dikes are 0.5m to 1.5m wide, trend northeast, and dip 40 to 65°east. Weathering makes rock identification difficult, but their composition appears to be andesitic. Though massive in most outcrops, near Lobster Cove the dikes are largely volcanic breccia containing angular chunks of andesite and locally derived sandstone.

Unit N-3

Small erosional remnants of a well-indurated Pleistocene(?) conglomerate comprise unit n-3. Patchy outcrops near Lobster Cove are the only exposures located by the author, but other outcrops may be present near sea level in inaccessable portions of the island. Sixty percent of the clasts are angular fragments of red sandstone typical of unit n-1, and the remainder are rounded, reworked metavolcanic, quartzite, and plutonic clasts also derived from unit n-1. The Lobster Cove outcrops were deposited on a wave-eroded terrace cut into unit n-1 sandstone. Outcrops are no more than 2-3m above sea level and range in thickness from thin coatings to isolated masses 1.5m thick.

Geologic Structure

The redbeds of North Island form a homoclinal structure that strikes N10° W to N25°W and dips 20 to 33° west. Bedding attitudes, even near faults are consistently uniform. Major faults of the island strike northeast, whereas jointing is dominated by a conjugate system of fractures trending northwest and northeast. Unlike the west-dipping strata, all faults and joints observed dip east 45 to 75°. Relative displacement along faults has not been determined due

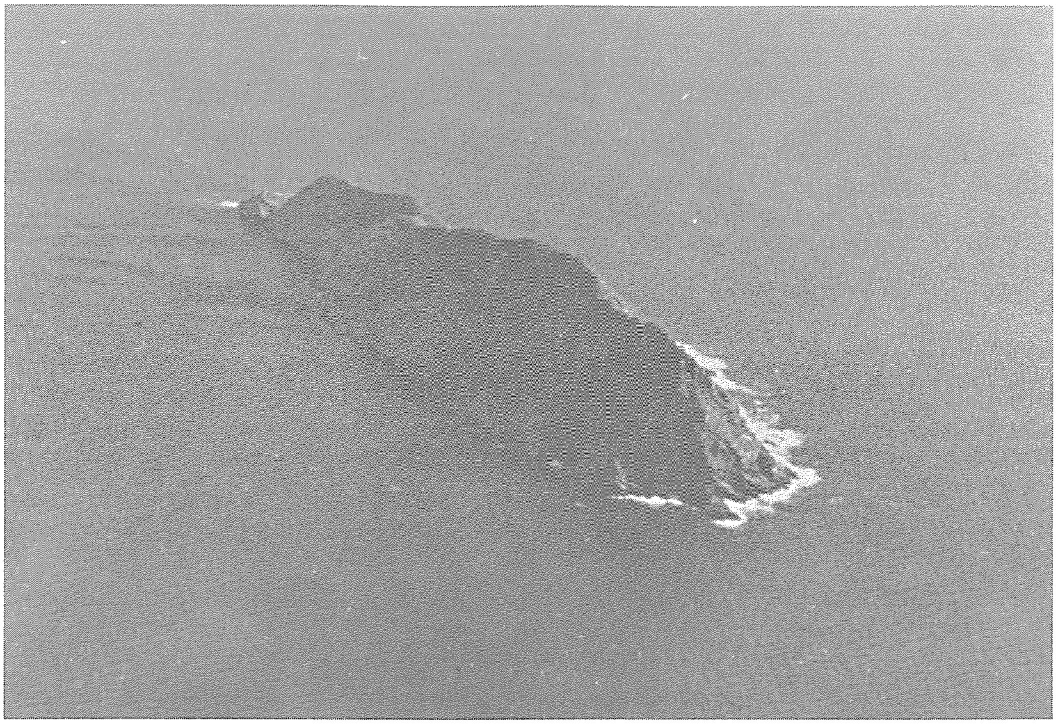
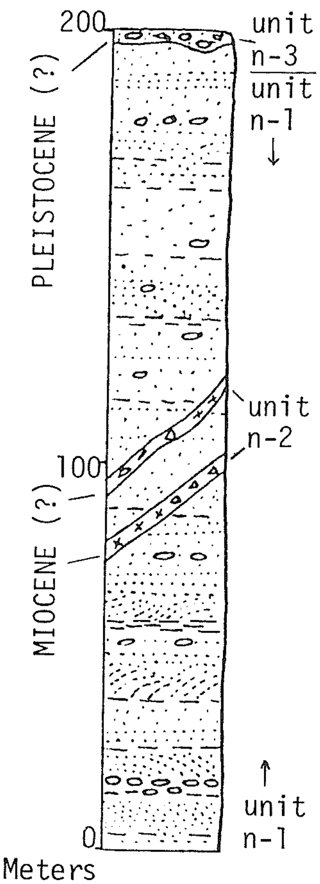


Figure 2. North Coronado Island. View is to the southwest.

to lack of marker beds, but slickensides on all major fault planes plunge a few degrees east of down dip, indicating nearly dip slip movement, at least in the later stages of faulting.

Age and Origin of North Island Rocks

A definitive age determination for the unit n-1 redbeds is not presently possible since the rocks appear to be unfossiliferous, however, lithologic similarities between North Island rocks and the late Cretaceous Lusardi Formation of the San Diego region warrant a tentative correlation. The Lusardi Formation (Nordstrom, 1970) is a nonmarine, poorly sorted conglomerate and sandstone unit deposited on basement topography of high relief. Subaerial outcrops are located in San Diego County near Rancho Santa Fe (Nordstrom, 1970) and Poway (Peterson, 1971). Lusardi sediments were deposited over much of the San Diego Coastal region in Late Cretaceous time following uplift and erosion of the Southern California batholith)Peterson, 1971). Although surface outcrops of the Lusardi appear to be limited to the Rancho Santa Fe-Poway area, a correlation with subsurface redbeds 20 km northeast of the Coronados in the southwest San Diego area is suggested by Peterson and Nordstrom (1970). These Lusardi equivalents were encountered at depth in three exploratory wells. The Borderland Exploration Company's Point Loma #1 well located near the northeast end of the Point Loma Peninsula met a hard reddish brown sandstone at 842m and a hard red conglomerate at 1,116m, yielding a total redbed sequence over 270m thick (Hertlien and Grant, 1939). Similarly, the Egger #1 well near the southern end of San Diego Bay in the Otay River floodplain encountered conglomerate redbeds from 1,496m to 1,596m, and the Holderness #1 well in the Tia Juana River floodplain struck redbeds at 1,568m to 1,686m (Elliott, 1964). A similar lithologic sequence occurs in all three wells, that is, red sandstone and/or conglomerate below known Upper Cretaceous sedimentary layers with basement rock 15 to 150m below the contact.



UNIT N-3: CONGLOMERATE. (Crops out near sea level at Lobster Cove only) light brown, calcite-bearing, medium-to coarse-grained matrix, poorly sorted, well indurated, clasts are local reworked metavolcanic, plutonic, quartzite, and red sandstone rocks.

UNIT N-2: ANDESITIC DIKES. Massive to volcanic breccia, green-brown, moderately-to severely-weathered local concentrations of angular andesite and red sandstone clasts 3cm to 1m diameter, average dike thickness 1m+.

UNIT N-1: SANDSTONE WITH INTERBEDDED SHALE AND SILTSTONE. Sandstone; reddish brown, mica-bearing, fine-to coarse-grained, well indurated, beds 2cm to 3m thick, localized cross-beds, load casts, scours, graded bedding, and armored mudballs, locally conglomeratic containing Peninsular Ranges clasts of green-brown to black volcanic and metavolcanics, quartz monzonite, granodiorite, vein quartz, quartzite, orthoclase-rich pegmatite.

Figure 3. Generalized columnar section of North Island.

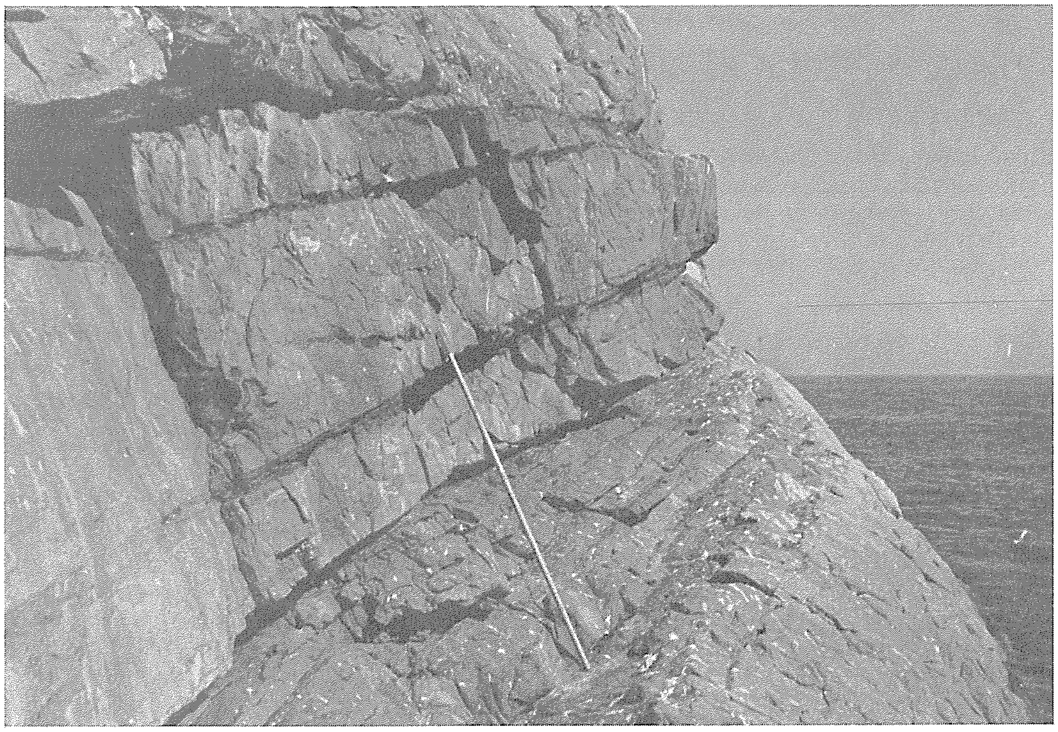


Figure 4. Sandstone and interbedded shale of unit n-1 north of Lobster cove. View is to the north.

A correlation of North Island redbeds to the Lusardi Formation entirely on the basis of nonmarine appearance would be tenuous at best. However, a comparison of mainland and north Island conglomerate clasts strengthens the suggested correlation. A unique property of the Lusardi Formation and other conglomerates in the Rosario Group is the absence of Poway Suite clasts (Peterson and Nordstrom, 1970) Poway clasts were transported by rivers to southwestern San Diego County during Eocene time from source areas east of the Peninsular Ranges (Minch, 1972). The most indicative clasts of the Poway Suite (Peterson and others, 1968) are resistant purple to red, weakly metamorphosed, dacite to rhyolitic, volcanic and pyroclastic rocks. Comprehensive studies of these clasts are found in the works of Bellemin and Merriam (1958), Delisle and others (1965), and Woodford and others (1968). Poway Suite rocks, abundant in the Poway Group deposits, are also present as reworked clasts in virtually all post-Eocene formations in the San Diego area (Peterson and Nordstrom, 1970). Miocene sediments of South and Middle Coronado Islands also contain reworked Poway clasts, however, in accord with Cretaceous sediments of the San Diego area, the redbeds of North Island are devoid of Poway-type rocks, but do contain abundant rocks and minerals of the Peninsular Range batholithic and metamorphic terrain. This correlation with Cretaceous rocks of the Mainland must remain tentative at present. It is possible that North Island rocks were deposited in Paleocene or early Eocene time before Poway-type clasts were introduced, though Paleocene to early Eocene rocks have not been found in the San Diego-northwestern Baja Region. Also, the Paleocene-early Eocene climate was apparently humid (Peterson and Abbott, 1977), presenting poor conditions for development of redbeds. It is more likely that the unit n-1 redbeds are seaward equivalents of the late Cretaceous Lusardi Formation, based on clast associations, non-marine character, and the presence of similar rocks at depth on the Mainland.

The andesitic dikes of North Island (unit n-2) are too weathered to be radiometrically dated. Intrusion may have occurred in Miocene time when volcanism was widespread in the region.

Conglomerate outcrops of unit n-3 are probably Pleistocene in age. These deposits have had sufficient time to become well-indurated since their depostion on wave-cut terraces. Depostion most likely occurred during a relatively higher stand of sea level.

MIDDLE ISLAND

General Statement

Middle Island and Middle Rock are located about 1km west of South Island. Middle rock is 150m long and about 25m maximum height. Middle Island is 300m long and 90m above sea level at the high point of a narrow ridge extending the length of the island. A small islet to the east is separated from Middle Island by a narrow water passage except during low tide. Middle Island is the smallest of the main Coronados yet is structurally the most complex. Twelve major fault blocks have been assigned to five mappable units on the basis of relative stratigraphic position and lithologic similarities (Plate II).

Unit M-1

Reddish brown sandstone and conglomerate of unit m-1 comprises all of Middle Rock and the western margin of Middle Island. Unit m-1 redbeds are, by volume, roughly half conglomerate lenses and half sandstone and conglomeratic sandstone with a total exposed thickness of 50-60m (Fig. 5).

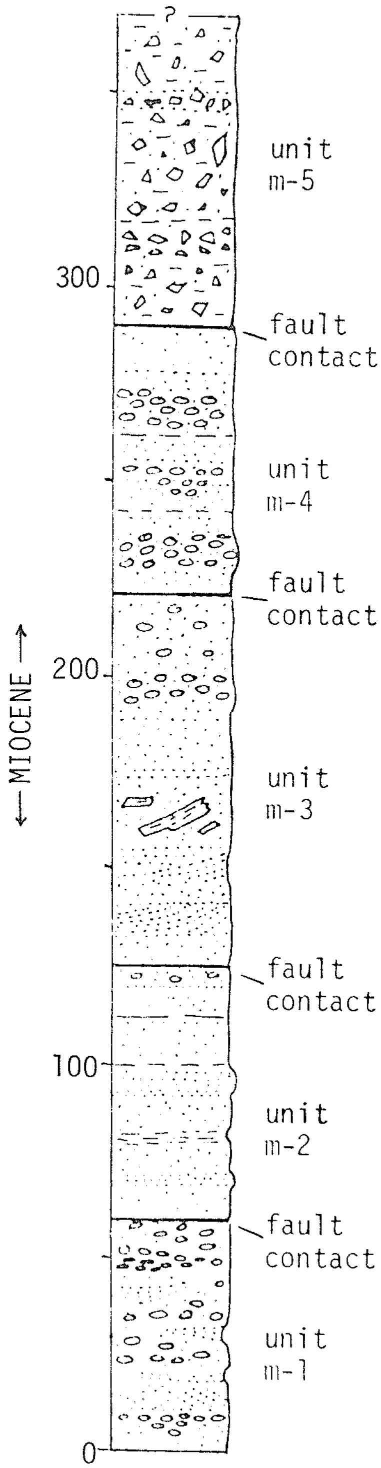
Sandstone beds are lenticular and vary from a few centimeters to massive layers over 1m thick. Sand grains are medium to coarse, and typically consist of 35-45% quartz, 20-25% feldspar, 35-40% rock fragments and 1-3% minor constituents. The rock fragment population is about 80% volcanic, 15% metamorphic, and 5% plutonic and sedimentary. Unit m-1 rocks are well-indurated due to a clayey, red iron oxide cement and interstitial calcite spar.

Conglomerate interbeds crop out in lenses 2 to 5m in length or as channel fills 1 to 5m across and 0.5 to 1m thick. Clasts range from small pebbles to boulders 0.5m in diameter, though rocks in the 3 to 10cm range are most common. Visual field estimates of rock type percentages are 50 to 80% rhyolite, dacite, andesite, basalt, and slightly metamorphosed equivalents of these volcanics, 10 to 30% quartzite, vein quartz or quartz-rich schists, 2 to 10% sandstone and shale, and less than 2% plutonic clasts of quartz monzonite to granodiorite composition. About half of these plutonic clasts are slightly epidotized. In addition, there are scattered clasts of quartz-rich amphibole and chlorite schist, chlorite-plagioclase schist and blueschist typical of Catalina Schist rocks described by Woodford (1924). The majority of clasts in unit m-1 are reworked rocks of the Poway and Peninsular Ranges Suites.

A subaerial fluvial origin for unit m-1 is probable because of its red color, coarseness, lenticular channel-type deposition and the well-washed nature of all detritus. It is clear that current action played a major part in sediment transport, though a moderately steep slope may have been present to facilitate movement of larger conglomerate clasts. Channel orientations are difficult to determine because of the two dimensional perspective of most exposures, but a north-south component is evident in several conglomerate-filled channels at the southern end of the island.

Unit M-2

Unit m-2, croping out in the east and northern portions of Middle Island, consists of over 60m of fractured and folded marine sandstone, siltstone, and shale. The unit is 90% gray, fine-to medium-grained sandstone with thin gray-brown shale and siltstone interbeds. Other features include a high degree of induration and localized concentrations of fossil burrow casts and wood chips. Units m-1 and m-2 are separated by normal east-dipping faults (Fig. 6). Although the exact stratigraphic relationship between these units is unclear, unit m-2 at all locations comprises the downdropped block, hence is stratigraphically higher than m-1.



UNIT M-5: VOLCANICLASTIC BRECCIA. Green-brown clayey groundmass with angular andesitic basalt clasts up to 50% of unit by volume, 5-20cm average clast size with a few large clasts up to 6 m across.

UNIT M-4: SANDSTONE, SHALE AND CONGLOMERATE. Sandstone and conglomerate matrix; green-brown to gray, fine-to coarse-grained, well indurated, lenticular beds 30cm average thickness. Conglomerate clasts include quartzite, metavolcanics, rhyolite, basalt, vein quartz, sandstone and plutonic rocks, and over 10% Catalina Schist clasts such as plagioclase-rich amphibole and chlorite schist, mica schist.

UNIT M-3: SANDSTONE, CONGLOMERATE, AND CONGLOMERATIC SANDSTONE. Sandstone; gray-brown, fine to medium-grained, well indurated, calcite cement, lenticular beds 10-30cm thick. Conglomerate matrix, same as sandstone but fine-to coarse-grained, mixed Peninsular Range and Poway Suite clasts with a few Catalina Schist rocks similar to unit m-1 below. Scattered fossil burrow casts and exotic red shale clasts, at least one of which is 10m long.

UNIT M-2: SANDSTONE, SILTSTONE, AND SHALE. Sandstone; gray, mica and calcite bearing, fine-to medium-grained, moderately well indurated, beds 10cm to .5m thick (locally thin bedded). Siltstone and shale; gray-brown, thinly bedded, moderately well indurated.

UNIT M-1: SANDSTONE AND CONGLOMERATE. Sandstone and conglomerate matrix; red-brown, medium-to coarse-grained, well indurated, lenticular beds 3cm to 1.5m thick, sand grains approximately 35-45% quartz, 20-25% feldspar, 35-40% rock fragments (most are volcanic) 1-3% minor constituents. Conglomerate lenticular beds 2-5m long, clasts 3cm-.5m diameter (3-10cm most common), average visual clast count, 50-80% rhyolite, dacite, andesite, basalt, and metavolcanic rocks, 10-30% quartzite, vein quartz, and quartz-rich schists, 2-10% sandstone and shale, 2% plutonic rocks, and less than 1% Catalina Schist rocks (quartz-rich amphibole and chlorite schist, chlorite-plagioclase schist, and blueschist.

Figure 5. Generalized columnar section of Middle Island.

Figure 6. Fault on west side of Middle Island separating rocks of unit m-1 (to left of fault) and unit m-2. View is to the northwest.

Unit M-3

Unit m-3 is a faulted west-dipping homocline located in the east-central part of the island. Ninety-five meters of sandstone with interbeds of conglomerate and conglomeratic sandstone crops out from sea level to the highest crest of the island. The sandstone is well-indurated, grayish brown, fine-to medium-grained with calcite cement. Bedding is mostly massive with some lenticular interbeds 10-30cm thick. Conglomerate and conglomeratic sandstone interbeds are concentrated in the upper 40m of the section, and make up less than 15% of the unit by volume. The conglomerate matrix is fine-to coarse-grained and calcite cemented. Most beds are lenticular, having been depostied in channels eroded into underlying sandy deposits. Clasts include a mixed suite of Peninsular Ranges and Poway type rocks with scattered chlorite schist and blueschist cobbles of the Catalina Schist.

The upper 30m of unit m-3 contains a few sand-filled fossil burrow casts suggesting a marine or lagoonal origin (Fig. 7). Deposition was probably near-shore as indicated by scattered fossil wood chips and angular, deformed red shale rip-up clasts presumably derived from a nearby subaerial source. A red shale slump block 1m thick and 10m long crops out 31m stratigraphically above the eastern shoreline. A moderately steep slope must have been present to facilitate transport of this block. Graded beds in the coarse conglomeratic sandstone and conglomerate also suggest movement by gravity, but most of unit m-3 was deposited by current action.

Unit M-4

Fault blocks in the northeast and southeast parts of the island containing beds of marine sandstone, shale, and conglomerate, are designated unit m-4. These blocks probably represent different stratigraphic horizons, but both have conglomerate lenses containing abundant Catalina Schist clasts, hence are grouped as one unit.

Figure 7. Fossil burrow in sandstone of unit m-3.

The southern exposure of unit m-4 is a topographically high fault block comprising 50m of marine sedimentary rock. Sandstone beds are fine-to medium grained except in conglomerate matrix where coarse grains prevail. Conglomerate clasts include rhyolite, basalt, various metavolcanic rocks, quartzite, vein quartz, sandstone and plutonic rocks, as well as Catalina Schist clasts of plagioclase-amphibole schist, chlorite schist, mica schist, and blueschist. Clast sizes range from small pebbles to boulders 0.5m diameter, but clasts 3 to 6cm diameter predominate. Plutonic, volcanic, and quartz-rich rocks, most of which have been reworked, are rounded-to-well rounded, whereas sandstone and Catalina Schist-type clasts are subangular-to-subrounded.

The northern exposure of rocks assigned to unit m-4 is a fault block adjacent to the islet on the east side of the island. Here, an estimated 60 to 70m of sandstone and conglomerate similar to outcrops in the southern m-4 exposures crop out on a steep east-facing slope.

Unit M-5

Unit m-5 is entirely volcaniclastic and forms the islet east of Middle Island (Fig. 8). A northwest-trending fault, exposed at low tide, separates the islet from the main island. Even though Middle Island shelters the islet from western swells, its less-resistant rock has been more susceptible to wave erosion than Middle Island proper.

Except for a few tuff beds 7m in total thickness in the western portion of the islet, massive volcanic breccia, having no apparent bedding, accounts for all of the islet's rocks. This breccia is comprised of angular clasts of finely crystalline andesitic basalt and basalt scoria in a greenish-brown clayey groundmass. The andesitic basalt clasts make up nearly 50% of the unit by volume. An average clast size of 5 to 20cm prevails, but some boulders over 1m diameter are present. On the northern peninsula of the islet a block of basaltic flow rock over 6m across crops out of the breccia. This

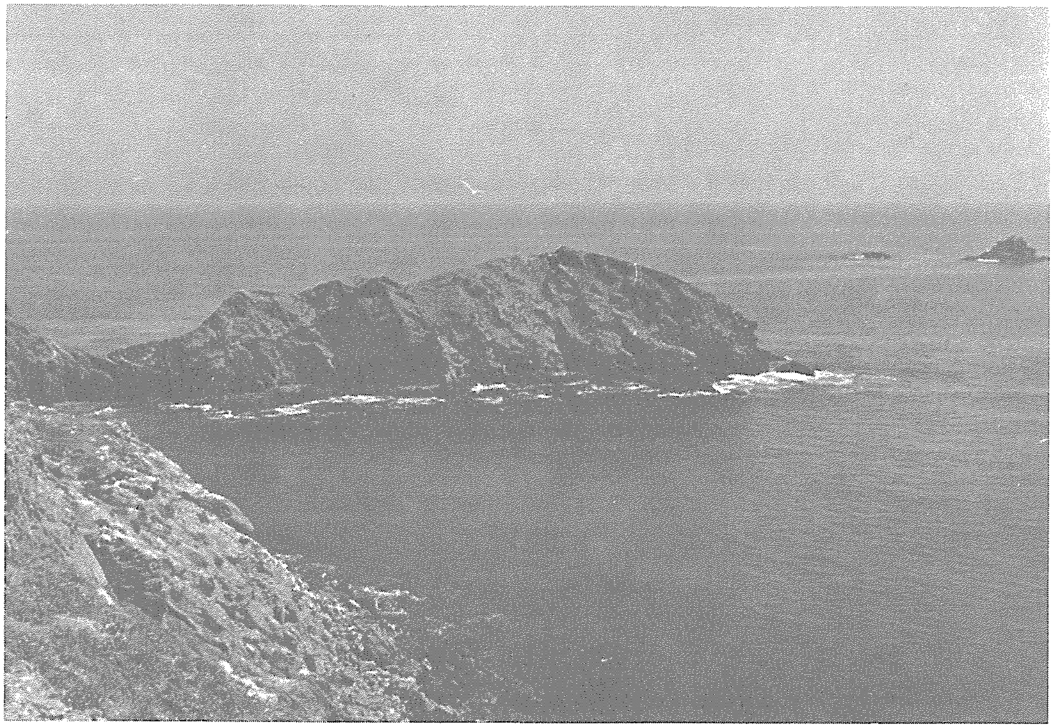


Figure 8. Islet east of Middle Island composed of volcaniclastic breccia (unit m-5).

rock is massive with a few deformed vesicles suggesting molten flow. Since there are no pillow structures or other water indicators in the block, it probably cooled subaerially and later slid into the sea.

The islet is highly fractured, though actual faults are difficult to determine and trace. Fault gouge high in silica with greenish alteration is locally abundant, but usually traceable for only a few meters.

Unit m-5 is believed to be marine on the basis of proximity to marine rocks of Middle Island, and the similarity to unit s-5, a marine volcaniclastic breccia of South Island.

Geologic Structure

Tilted fault blocks with varying attitudes dominate the structural geology of Middle Island. The strata of Middle Rock and the west side of Middle Island strike northwest and dip to the west in accord with Coronado Island bedding attitudes in general. The remainder of the Island exhibits northwest to northeast strikes and a wide range of east and west dips as a result of fault block tilting and drag near faults.

Major faults of the island strike northwest or northeast and dip to the east. Two subparallel northwest-trending faults on either side of the island have the greatest lithologic contrast between fault blocks and probably represent the greatest stratigraphic displacement (100m and possibly much more) of any Middle Island faults. Fault-related folding, slickensides, and secondary faults indicate a normal sense of movement along both faults.

Faults trending northeast are less conspicuous than the northwest-striking counterparts. All observed northeast-trending faults dip southeast, but no drag features or secondary faults were located that would indicate a sense of movement.

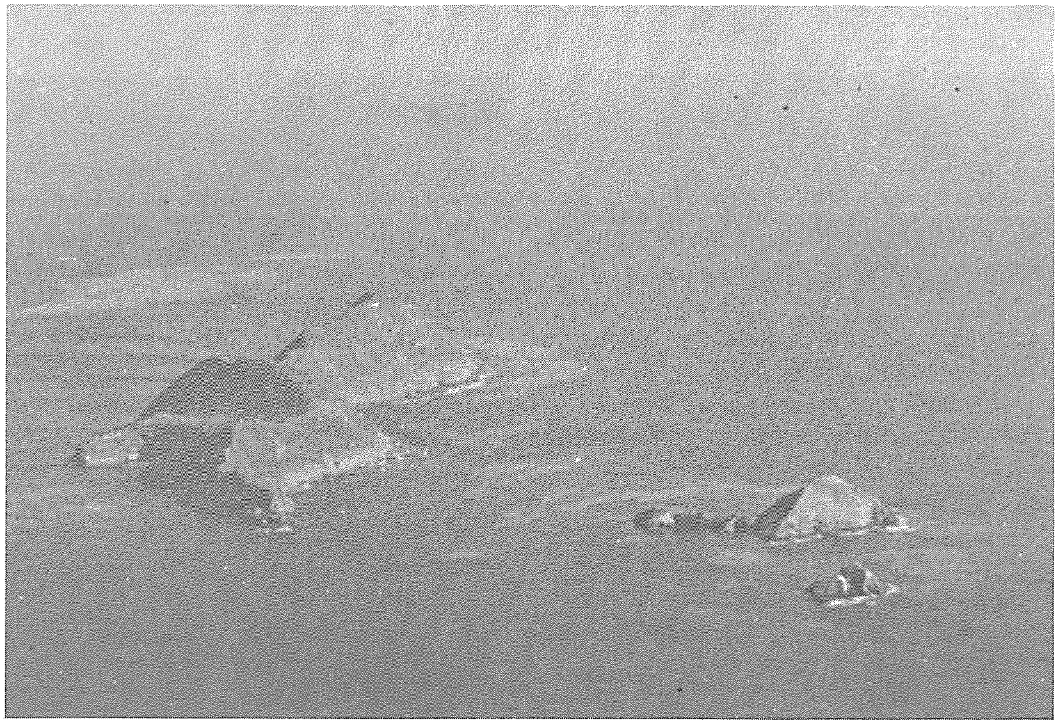


Figure 9. South Island (on left), Middle Island and Middle Rock (right foreground). View is to south.

Age of Middle Island Rocks

No diagnostic fossils have been found on Middle Island, but conglomerate beds contain an abundant population of reworked Eocene Poway Suite clasts and some scattered Catalina schist rocks. A middle Miocene age for Middle Island rocks is inferred due to the presence of Catalina Schist clasts, as well as the close proximity and physical similarity to known Middle Miocene rocks of South Island, in particular the likeness of units m-3 and m-4 to units s-2, s-3, and s-4 of South Island.

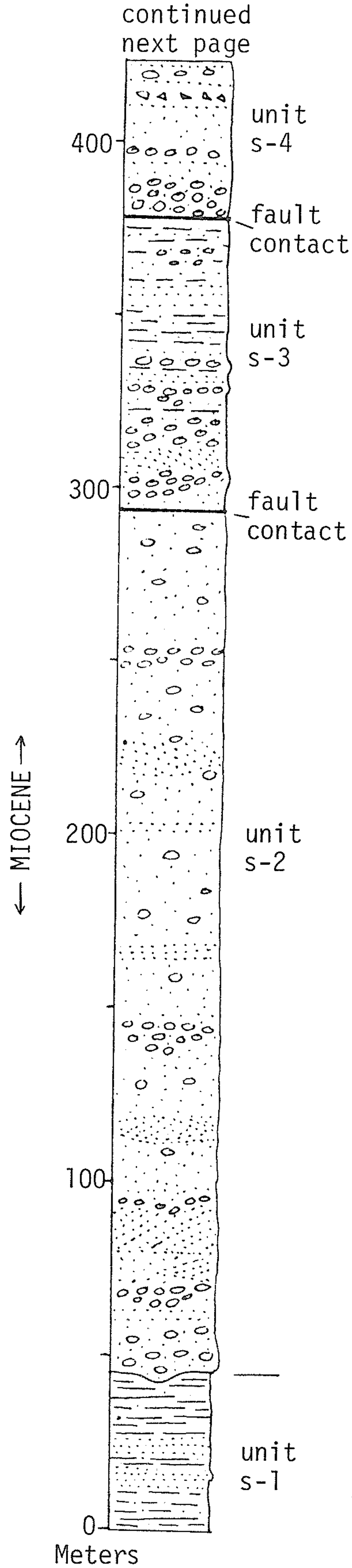
SOUTH ISLAND

General Statement

South Island, the largest of the Coronados, is 3.5km long and 190m high at Middle Peak, A narrow central ridge extends its full length and steep flanks culminate at the shoreline in 15 to 30m sea cliffs (Fig.9). The island contains three main structural blocks. The north and south blocks are largely San Onofre conglomerate and sandstone, whereas, the middle downdropped block contains San Onofre-type rocks, plus volcaniclastic breccia, siltstone, and tuffaceous sandstone (Plate III).

Unit S-1

Interbedded shale, siltstone, and sandstone make up unit s-1, the lowest stratigraphic unit of South Island (Fig. 10). The largest outcrop is along the eastern shoreline at the north end of the island where the unit forms a steep slope from the shoreline 45m stratigraphically upward to an abrupt contact with cliff-forming rocks of unit s-2. About 70% of the exposure is dark gray, well-indurated, fissle shale in beds 0.5 to 5m thick. Interbeds are brown, fine-to coarse-grained sandstone and brown, well-indurated siltstone with numerous calcite-rich concretions. Near the contact with overlying unit s-2 sandstone, unit s-1 shale has shiny, sub-horizontal parting surfaces resulting from compaction and shearing.



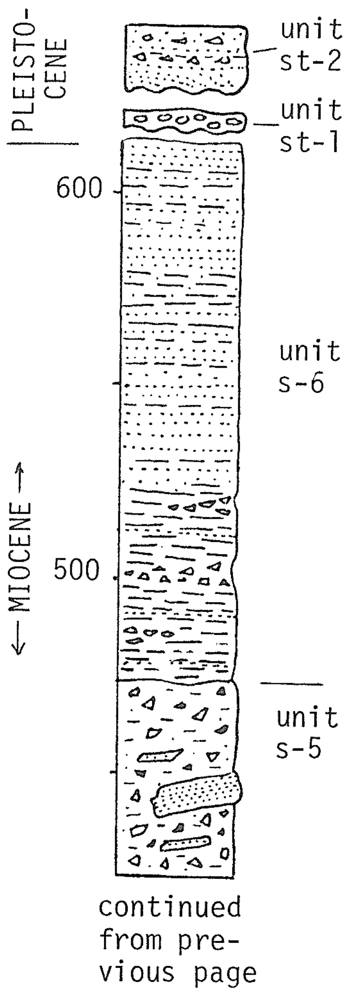
UNIT S-4: CONGLOMERATIC SANDSTONE, CONGLOMERATE, AND VOLCANICLASTIC BRECCIA. Sandstone and conglomerate matrix; green-gray to light brown, fine-to grit-grained, lenticular beds 15cm average thickness, clasts include quartzite, quartz-rich amphibole and greenschists, vein quartz, amphibole schist, mica schist, rhyolite, metavolcanic rocks, chlorite schist, blueschist, scattered granitic clasts. Volcaniclastic breccia; angular andesitic basalt clasts in a brown mudstone matrix, one bed only, at 32m stratigraphic level, 2.5m thick.

UNIT S-3: SANDSTONE, CONGLOMERATE, AND SILTSTONE. Sandstone; brown, locally pink to gray, calcite bearing, fine-to coarse-grained. Conglomerate; similar to unit s-2 below, but gray-brown in color, fine-to grit-grained, 15-30cm-thick beds most common. Siltstone; yellow-brown, massive, mica bearing, locally shaley.

UNIT S-2: CONGLOMERATIC SANDSTONE AND CONGLOMERATE. Sandstone and conglomerate matrix; light green to light gray, medium-to coarse-grained, poorly sorted, well indurated, lenticular beds 15cm to 4m thick. Conglomerate, lenticular beds .5 to 6m thick, clasts average 3-40cm diameter with some to 1.5m diameter, clasts include quartz chlorite schist, quartz amphibole schist, quartzite, vein quartz, chlorite garnet schist, blueschist, rhyolite, metavolcanics, sandstone, siltstone, a few plutonic clasts. Numerous sedimentary structures at base of unit include groove casts, shatter marks, rollmarks, flute casts, and pebble-related scours, dominant current direction NNE.

UNIT S-1: SHALE, SILTSTONE, SANDSTONE. Shale; dark gray, calcite bearing, well indurated, evidence of lateral shearing in upper 5m of unit. Siltstone; dark brown, well indurated, numerous calcite-rich concretions. Sanstone; brown, fine-to coarse-grained, beds 1 to 10cm thick.

Figure 10. Generalized columnar section of South Island.



UNIT ST-2: MUDSTONE, BRECCIA, UNCONSOLIDATED CONGLOMERATIC SAND. Mudstone; red-brown, moderately well indurated, contains mudstone breccia interbeds. unconsolidated sand; white, fine-to medium-grained massive, abundant Gastropod and Pelecypod fossils.

UNIT ST-1: CONGLOMERATE. Matrix material is red-brown, medium-to coarse-grained, poorly indurated, clasts are well rounded locally-derived pebbles and cobbles.

UNIT S-6: SILTSTONE, SANDSTONE, TUFFACEOUS SANDSTONE, VOLCANICLASTIC BRECCIA. Siltstone; light brown to gray, mica bearing. Sandstone and tuffaceous sandstone; light brown to green brown, fine-to medium-grained, beds 3mm to 20cm thick. Volcaniclastic breccia, angular basalt and andesitic basalt clasts 3cm to 30cm diameter in a brown, muddy, fine-to grit-grained matrix.

UNIT S-5: VOLCANICLASTIC BRECCIA. Matrix; green-brown mudstone. 95% of clasts are angular andesitic basalt 5cm to 0.5m diameter, some clasts epidote or pyrite bearing, 5% of clasts are sandstone, basalt, chlorite schist, chlorite-actinolite schist and other Catalina Schist rocks. Unit contains exotic sandstone slump blocks up to 15m long.

Figure 10 continued.

A second unit S-1 outcrop is located at the base of a vertical cliff near the shoreline 30m south of the landslide debri (unit ls) in the east-central portion of the island. Though separated from the northern unit s-1 outcrops by down-faulted rocks including the major graben in the center of the island, this shale, as in the northern exposures, has shiny irregular fracture surfaces subparallel to the bedding, and an abrupt contact with overlying conglomeratic rocks of unit s-2. Sedimentary structures on the exposed base of the overlying unit s-2 are similar and show the same general current directions at both localities, hence, the author is reasonably sure these rocks directly correlate.

Unit S-2

The fine-grained rocks of unit s-1 are contrasted by overlying unit s-2, a coarse sandstone, conglomeratic sandstone, and conglomerate section over 250m thick. Sixty meters of these rocks crop out in the northern portion of the island an a section 250m thick comprises the southern two-thirds of South Island (Plate III). South Peak marks the highest stratigraphic exposure of unit s-2, but rocks higher in section may crop out beneath the sea several tens of meters west of the present shoreline. Unit s-2 and the down-faulted but stratigraphically higher units s-3 and s-4 of this report are the rocks considered by Woodford (1925) and subsequent workers to be southern equivalents of the San Onofre Breccia.

Unit s-2 is a resistant cliff-forming sequence containing interbedded, subequal amounts of sandstone, conglomeratic sandstone and conglomerate. Sandstone and conglomerate matrix material is generally light green to light gray, medium-to coarse-grained, poorly sorted, and well-indurated feldspathic volcanic arenite containing 15 to 35% volcanic rock fragment grains. Beds are 15cm to 4m thick and lenticular, though some beds over 1m thick are traceable 50m or more laterally. Conglomeratic beds are 0.5 to 6m thick, lenticular, and contain clasts 3 to 40cm average diameter. Most clasts over 0.5m diameter are either blueschist, greenshcist or amphibole schist, some measuring 1.5m across. Reworked cobbles of the Poway and Peninsular Ranges Suites are found in all conglomerate outcrops, although Catalina Schist clasts and non-diagnostic quartz-rich rocks are more common.

Sedimentary structures related to currents are numerous in the lower portion of the unit, particularly at the contact with unit s-1, where chatter marks, roll marks, groove casts, flute casts, and scours behind pebbles are exposed on the bottom of unit s-2. Flute casts and scours associated with pebbles indicate prevailing currents were flowing north to northeast. Most groove casts and chatter marks are oriented north-northeast, and cross-beds show north to east apparent dips of 15 to 25° (Fig. 11). Recognizable sedimentary structures in the middle and upper portions of unit s-2 are rare, but the few conglomerate-filled channels and scours observed have north-south trends.

The influx of coarsely clastic unit s-2 over unit s-1 shale was aided by north-northeast currents, swift enough at times to move boulders and create cross-beds with foresets over two meters long. Transport of larger conglomerate clasts must have been assisted by a moderately steep slope.

Unit S-3

Unit s-3 crops out in the northern part of South Island west of Puerto Cueva Cove and northeast of Middle Peak (Plate III). These rocks have dropped down relative to unit s-2 along normal faults with at least 250m of stratigraphic separation. Unit s-2 does not conformably contact s-3 above sea level, but may do so at depth. The outcrops east of Middle Peak are not positively correlated with unit s-3 west of Puerto Cueva Cove, but both exposures lie stratigraphically between units s-2 and s-4.

Unit s-3 outcrops west of Puerto Cueva Cove contain 85m of interbedded sandstone, conglomerate, and siltstone. The lower 40m of section is 80% conglomerate and 20% sandstone similar to unit s-2 rocks except for a brown (rather than green-gray)

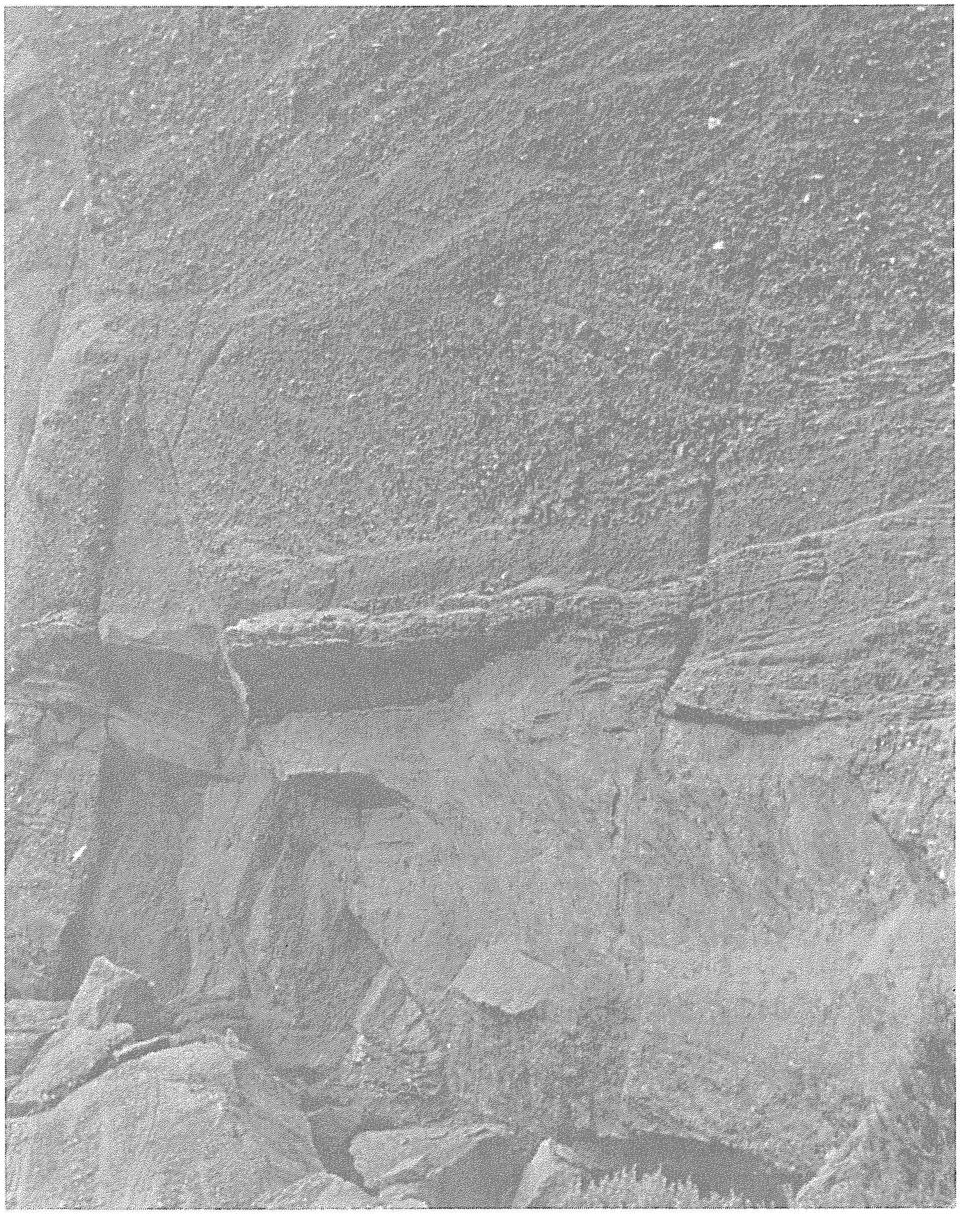


Figure 11. North-dipping cross-beds of unit s-2 at shoreline east of Middle Peak. Vertical field of view is approximately 4m.

color imparted by hematitic matrix material Between the 25 to 50m stratigraphic levels yellow-brown, massive, shaley siltstone is interbedded with the coarse-grained rocks and makes up nearly all of the beds in the upper 30m of this exposure.

Rocks assigned to unit s-3 northeast of Middle Peak are interbedded sandstone, conglomerate, and siltstone similar to the lower 40m of unit s-3 west of Puerto Cueva Cove. These beds are 25m thick and consist of 90% conglomerate and sandstone, and 10% evenly dispersed siltstone interbeds. Several pink sandstone beds that crop out near the shoreline are distinctly tuffaceous, and all sandstone beds of the unit contain 20-35% volcanic rock fragments.

Unlike unit s-2, where paleocurrent indicators are numerous and paleoslope structures are uncommon, unit s-3 contains abundant structures reflecting paleoslope directions. Along the shoreline of Puerto Cueva Cove, sandstone and conglomerate beds contain flame structures, channels, convolute bedding, deformed load casts, and rip up structures, nearly all of which indicate a major northward paleoslope component (Figs. 12 and 13). In most cases a disturbed fine-grained sandstone or siltstone bed is overlain by coarse-grained sandstone or conglomerate. Current indicators are rare, but a few sandstone layers have well-developed cross-beds dipping east to northeast. Fossil burrow casts in sandstone are present west of Puerto Cueva Cove and fossil wood chips up to 3cm long are found in unit s-3 rocks.

Unit S-4

Unit s-4, with the exception of a volcaniclastic bed 2.5m thick, is composed of 40m of conglomeratic sandstone and conglomerate similar to unit s-2 and the lower portion of unit s-3. These rocks are the lowest stratigraphic beds exposed in the main down-dropped, but topographically high, fault block forming the central portion of the island. The stratigraphic distance between unit s-3 and s-4 is unkonwn, but all contacts are faults, along which at least 150m of stratigraphic displacement has occurred. Unit s-4 is more indurated than conformable overlying rocks of the main central fault block, hence it forms the resistant peninsula on the east side of Puerta Cueva Cove (Plate III).

The lower 30m of unit s-4 is dominated by massive green-gray conglomerate with clasts ranging from small pebbles to boulders 1.5m diameter. Clasts include, in decreasing abundance, quartzite, quartz-rich amphibole and greenschists, vein quartz, sandstone, amphibole and mica schists, rhyolite and metavolcanic rocks, chlorite schist, blueschist and a few granitic clasts. Sandstone interbeds are lenticular, light brown, poorly sorted, fine to very coarse-grained lithic volcanic arenite.

At the 32m stratigraphic level near the north end of the peninsula, a volcaniclastic breccia bed 2.5m thick crops out in sharp contact with adjacent conglomerate. A precursor to the volcanic breccia of unit s-5 10m stratigraphically above, this bed is entirely of volcanic origin, consisting of 50% angular andesitic clasts up to 0.5m diameter with a brown mudstone matrix. All rocks of South Island have abundant volcanic rock fragments, but this outcrop is the lowest stratigraphic volcaniclastic bed.

The upper 10m of unit s-4 is conglomerate and conglomeratic sandstone similar to that of units s-2, s-3, and the lower portion of unit s-4.

Unit S-5

Unit s-5 is a massive volcaniclastic breccia 45 to 50m thick conformably overlying unit s-4. Outcrops are located at the south end of Puerto Cueva Cove as a vertical cliff and small sea stack, and on the west side of the island at Seal Cove (Plate III). Puerto Cueva and Seal Coves exist because of differential erosion into this relatively less-resistant breccia by wave action.

At Puerto Cueva Cove the breccia is green-brown with a clayey feldspar-bearing mudstone matrix and 10 to 50% volcanic clasts (Fig. 14). Thin section study

Figure 12. Slump block in unit s-3 sandstone at shoreline south of north lighthouse. View is to southwest.

Figure 13. Sandstone rip-up in unit s-3 conglomerate at shoreline south of north lighthouse. View is to west.

Figure 14. Volcaniclastic breccia of unit s-5 at north end of Seal Cove. View is to northwest.

of the clasts revealed an andesitic basalt composition. About 90% of the clasts are dark gray and massive, the remainder are gray and vesicular. Seal cove outcrops contain up to 40% clasts, which are 95% green-brown andesitic basalt, and 5% sandstone, basalt, epidote-rich volcanic rock, chlorite schist, chlorite-actinolite schist and other Catalina Schist rocks. The few shcist clasts in unit s-5 are the highest stratigraphic occurrance of Catalina Schist in Miocene rocks of the Coronados.

At least ten sandstone slump blocks 1 to 15m long are exposed in unit s-5 near Seal Cove. The largest block is a fine grained thinly bedded sandstone 15m long and 6m thick (Fig. 15). These blocks differ lithologically from underlying sandstone beds of South Island, hence must have originated some distance up slope.

No diagnostic sedimentary structures were observed in unit s-5. The unsorted chaotic nature of the breccia and the presence of megaclasts suggest submarine mudflow transport from a high relief source area down a moderately steep slope of undetermined attitude.

Unit S-6

Strata of unit s-6 are the highest stratigraphic Miocene deposits of the Coronado Islands. Accounting for much of the topographically high, but structurally down-dropped central fault block, the unit consists of 140m of siltstone, sandstone, breccia and tuffaceous sandstone. Contact with underlying unit s-5 is abrupt and irregular, caused by either an initial wavy surface on the last unit s-5 mudflow, or by scouring action prior to unit s-6 deposition (Fig. 16).

The lower 40m of unit s-6 is light brown well-indurated siltstone in beds ranging from 1mm to 0.5m thick. Interbedded sandstone, shale, and siltstone in sharply defined beds a few millimeters to 30cm thick make up most of the section from 40m to the 90m stratigraphic level. These low energy deposits contrast with the underlying coarse breccia of unit

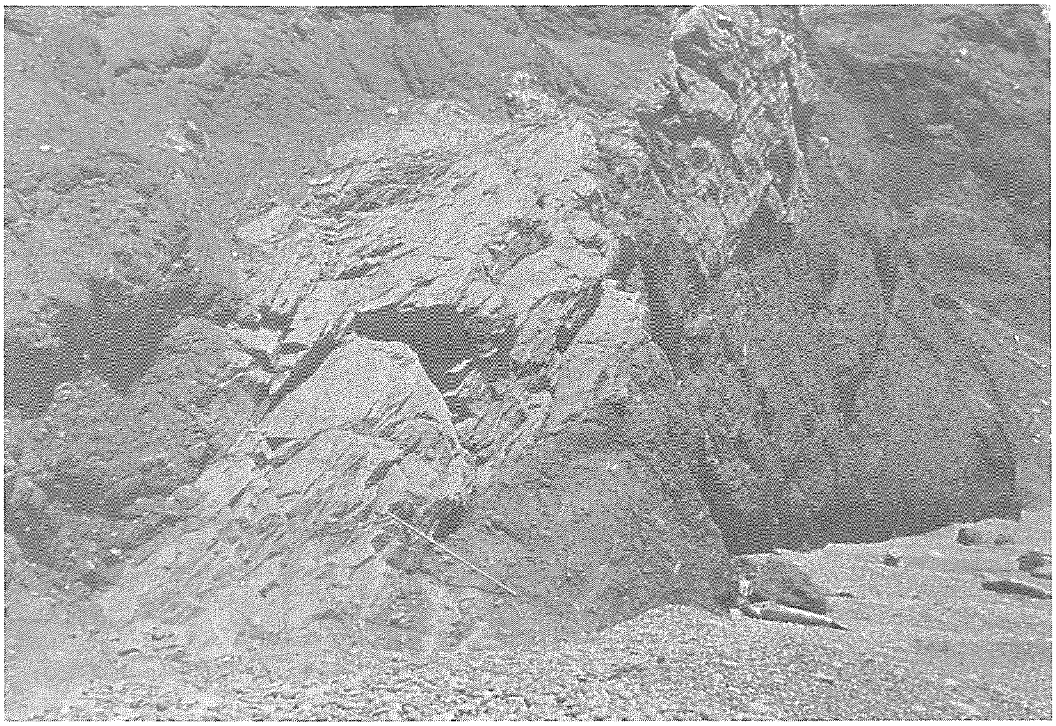


Figure 15. Sandstone slump block (15m long) in unit m-5 volcaniclastic breccia at north end of Seal Cove. View is to northeast.

s-5, possibly reflecting an increase in basaltic volcanism in the source area at the time of deposition.

The upper 50m of unit s-6 is interbedded sandstone, tuffaceous sandstone, and shale (Fig. 17). Bedding is especially thin (1mm to 6cm) and well defined in these rocks, reflecting quiet, low energy depositional conditions. Many silty tuffaceous beds are 1-3mm thick and may have accumulated through direct settling rather than bottom transport.

Siltstone beds in the lower 40m of unit s-6 contain a few groove casts oriented N70°E (or S70°W), and asymetric ripple marks indicating a current direction of N10°E to N15°E. Interbedded breccia shows evidence of channel filling and slumping, but no paleoslope directions were ascertained.

Unit ST-1 and ST-2

Two distinct Pleistocene terrace deposits crop out on the eastern side of South Island. The highest and smallest of the two, unit st-1, is a small remnant of a shingle beach or near shore deposit perched 55m above sea level east of Middle Peak (Plate III). The entire outcrop is 3m wide, 7m long and 1.5m thick, consisting of poorly-indurated conglomerate with a reddish brown sandy matrix. Clasts are locally derived, well-rounded pebbles and cobbles.

The other terrace deposits, apparently unrelated to the topographically higher unit st-1, were deposited on a wave-cut terrace 30m above present sea level at the south end of Puerta Cueva Cove. Here, moderately indurated mudstone, breccia, and a pocket of unconsolidated sand lie unconformably on west-dipping beds of unit s-4, s-5, and s-6. The unconformable contact is well defined on the cliff face, but elsewhere is only inferred due to soil cover. These rocks designated unit st-2 are approximately 20m in total thickness and have an inherent dip of 10° to the northeast. The lowest bed of unit st-2 is 1-7m of loose, fine to medium sand with numerous pelcypod and gastropod fragments deposited in a

Figure 16. Thinly bedded siltstone (unit s-6) overlying volcaniclastic breccia of Unit s-5 at north end of Seal Cove. View is to northeast.

beach or shallow subtidal environment. Evidently this sand is the remnant of a pocket beach that developed in a cove along the differentially eroded fault zone separating units s-5 and s-6 from unit s-3 at the southwest corner of Puerto Cueva Cove. This sand pinches out several meters to the east where 12m of overlying reddish brown mudstone with breccia and sandstone interbeds forms a sub-horizontal terrace at the south end of the cove.

Unit st-1 and st-2 are unrelated lithologically and stratigraphically, hence were deposited during different stands of sea level in Pleistocene time. An elevated sea cave south of north lighthouse about 35m above sea level may have been formed during the same sea level stand that aided deposition of unit st-2.

Unit LS

Unit ls landslide debris is located along the east side of the island south of north lighthouse. In the recent geologic past a combination of over-steepening by wave erosion along the shoreline, and the presence of a weak (fault) zone near the crest of the island, has caused portions of unit s-2 to slide eastward. A vertical scarp was created on the southwest side of the landslide, and a bulge in the shoreline developed as debris slid into the sea.

Geologic Structure

The most obvious structural features of South Island are its homoclinal, west-dipping strata and northeast-southwest trending normal faults. With the exception of the Pleistocene terrace deposits, the rocks of South Island dip 15-35°W and strike N20°E to N25°W. Folding is limited to drag near faults.

A dominant structural feature of the island is the large down-dropped block in the north-central part of the island. The fault on the west border of the block strikes N15°E to N20°E and dips 35 to 42° E, forming an arcuate trace over the island's surface (Plate III). A minimum of 150m of stratigraphic displacement has

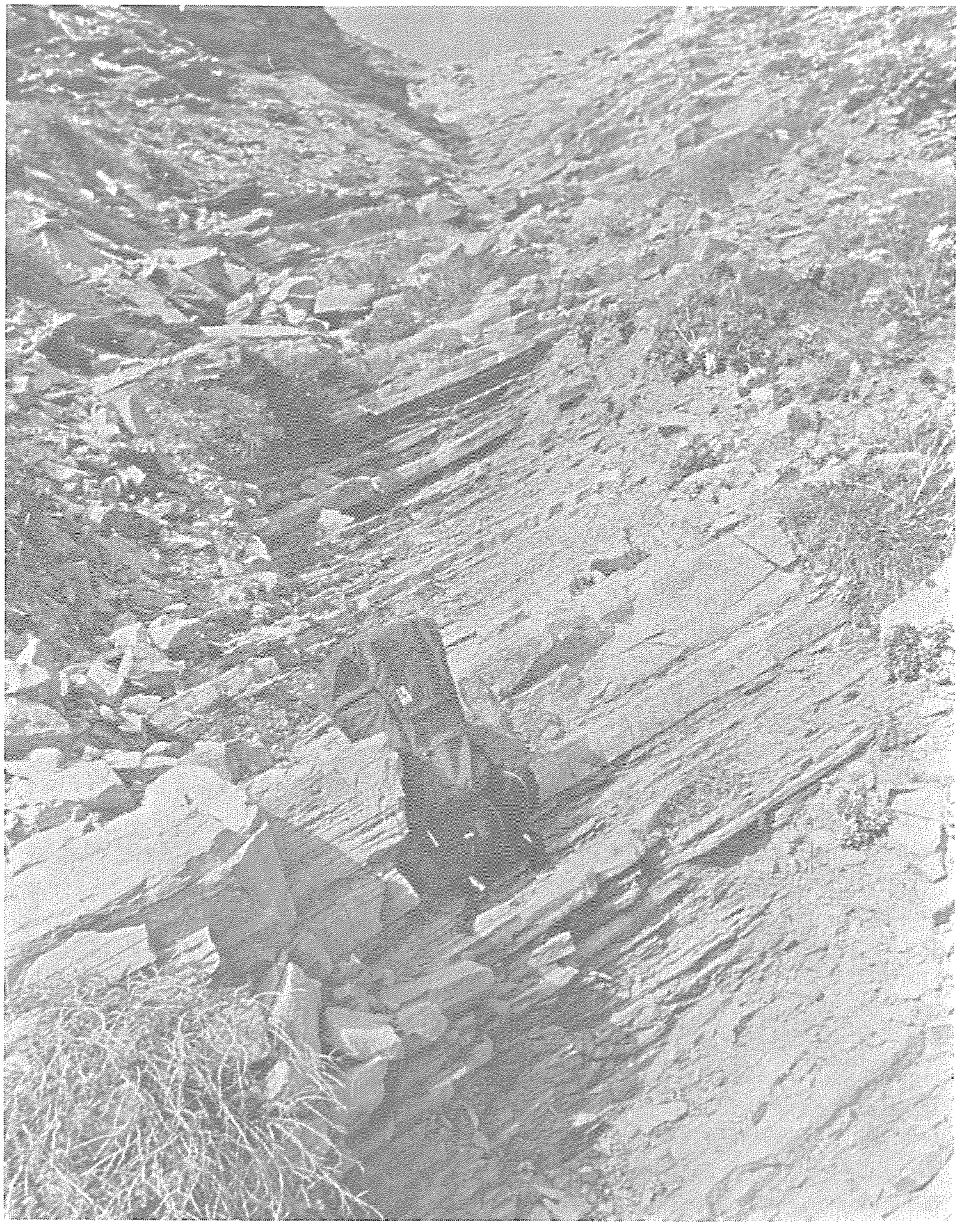


Figure 17. Interbedded siltstone and tuffaceous sandstone of unit s-6 west of Middle Peak. View is to the east.

taken place along this fault. Estimated displacement on this and other faults of the island are based on measured thicknesses of exposed rock units and only minimum displacement is indicated. The main fault trace makes a sharp contact between unit s-3 on the west and units s-5 and s-6 of the central graben. Unit s-3, being well-indurated, has been unaffected by the faulting as little as a few centimeters from the fault zone, but units s-5 and s-6 have been highly disturbed, up to 6m from the fault. Drag in unit s-6 rocks indicate that normal, down-dip movement was predominant.

The main fault at the eastern edge of the graben strikes about N15°E and has a relatively straight trace over the island due to an average dip of 80-85°W. An estimated 250-300m of stratigraphic displacement has occurred on this fault with major movement being down-dip and normal as shown by drag and slickensides near Seal Cove (Fig. 18). Many secondary faults are associated with the main trace; in fact on the east side of the island there are several faults as opposed to one major break.

The northern end of the island has five nearly parallel faults that strike N30°E and N35°E and dip 35 to 65°E. The southernmost of these faults separates unit s-1 and s-2 from s-3 with over 250m stratigraphic displacement. The southern two-thirds of the island has no major faults, and about half of the minor breaks trend northwest rather than northeast.

Age of South Island Rocks

Woodford (1925) proposed a Miocene age for South Island rocks on the basis of their lithologic similarity to the Miocene San Onofre Breccia near Oceanside, California. At both localities Catalina Schist-type clasts are incorporated in conglomerate and breccia beds. Later study by Emery and others (1952) confirmed Woodford's original age estimation by the discovery of Middle Miocene Foraminifera in fine-grained rocks from the northeast part of the island (units s-1 and s-3 of this report). In 1969 personnel of San Diego State University collected samples from units s-3 and s-6 of the present report which were analyzed by Texaco laboratories. Texaco paleontologists characterized Foraminifera and Nanoplankton collected on the west side of Puerto Cueva Cove (unit s-3), as definitely Middle Miocene and probably Relisian in age. They noted a strong resemblance to the Topanga Sequence in the southeast Los Angeles Basin.

Several bulk samples were collected by the present author and analyzed by Mobil Oil Company laboratories. Foraminifera recovered from siltstone and shale of unit s-1 were assigned a range of Saucesian to Lower Luisian of the Miocene. Arenacous species were most abundant, and all calcareous forms were limonite casts as similarly reported by Emery and others (1952). A unit s-3 sample collected from the siltstone beds west of Puerto Cueva Cove is apparently of Saucesian to Lower Mohnian age. Again all calcareous Foraminifera were replaced by limonite, and arenaceous forms were abundant. Fossil-based determinations of the present and previous studies indicate a Middle Miocene (Saucesian to Lower Mohnian) age for all South Island rocks, excluding terrace deposits which are assumed to be Pleistocene in age.

GEOLOGIC HISTORY

Mesozoic

During middle to late Mesozoic time much of the Pacific coast of North America was experiencing active subduction of the Farallon oceanic plate beneath the western continental margin. In southern California this offshore subduction resulted in landward andesitic volcanism (Santiago Peak Volcanics) and placement of the southern California batholith. By Late Cretaceous time the batholith had intruded into the Santiago Peak Volcanics along the coast, and into pre-batholithic rocks inland. It has been hypothesized that batholiths in general, rather than forming beneath thick piles of eugeosynclinal deposits, are emplaced as relatively shallow bodies beneath their own volcanic equivalents (Hamilton and Myers, 1966). Assuming that subaerial erosion takes place continuously with intrusion, plutonic rocks would be exhumed in a geologically short time.

Figure 18. Main fault east of Seal Cove separating unit s-6 siltstone (on left) and conglomeratic sandstone of unit s-2. Note drag and secondary faults in unit s-6. View is to northeast.

This model seems applicable to the northern Peninsular Ranges since rocks derived from the batholith are found in the Cretaceous Lusardi Formation of coastal San Diego County. Extensive erosion of the crystalline basement preceded depostion of Lusardi rocks, as they were deposited on a high-relief plutonic and metamorphic terrain (Peterson, 1971).

As outlined previously inthis report, the red beds of North Coronado Island are tentatively correlated as westward equivalents of the Lusardi Formation on the basis of (1) a nonmarine appearance, (2) the presence of Peninsular Range clasts and an absence of Eocene Poway Suite clasts, and (3) the proximity of similar red beds encountered in wells beneath Cretaceous sedimentary rocks along the San Diego coast. Whereas the Lusardi Formation is largely conglomeratic and was deposited by high energy streams and mudflows, North Island beds are medium-to coarse-grained sandstone, reflecting depostion by relatively slow currents. It is probable that during Late Cretaceous time a gently-sloping depositional plain extended from the present coastal area, westward to the Coronado Islands and beyond to the sea. The Coronado Islands vicinity may have been a low relief coastal plain where periodic flooding introduced sand and silt from the east. Sediments must have been exposed to the atmosphere much of the time to permit extensive iron oxidation. Citing examples of Recent deposits in the northern Gulf of California, Walker (1968) suggested that oxidizing conditions of marine-fluvial transition areas are especially conducive to development of redbeds if sufficient mafic minerals are available for alteration to limonite and hematite. The North Island redbeds may have formed in such a marine-nonmarine transition zone.

Subsequent to nonmarine deposition along the coast, but also in the Late Cretaceous time, the sea transgressed resulting in deposition of marine sandstone, shale, and conglomerate of the Point Loma and Cabrillo Formations (Kennedy and Moore, 1971). These sediments were deposited over Lusardi rocks in the immediate San Diego coastal area, and presumably offshore as well.

Paleogene

Except for the middle Eocene little is known of early Tertiary history of coastal southern California and Baja California due to gaps in the rock record. Paleocene rocks have not been found in San Diego County or northwestern Baja California. Evidently, humid, tropical climatic conditions prevailed in Paleocene and early Eocene time, since mid-Eocene sediments were locally deposited on thick lateritic soils (Peterson and Abbott, 1977). It is possible that a broad regional uplift and subaerial erosion characterized the region during the early Tertiary.

Deposition was extensive along the immediate coastal area by middle Eocene time when several river channels funneled sediment, including the exotic Poway Suite clasts, across the batholith from eastern sources (Minch, 1972). At this time several transgression-regression cycles resulted in an interfingering of marine and nonmarine rocks along the coast. Extensive marine deposition took place offshore at least several kilometers west of the Coronados, since re-worked Poway clasts (derived from the west) are common in Miocene rocks of Middle and South Islands. Eocene rocks have not been reported in situ in the immediate offshore area, but may underlie later Tertiary deposits.

Miocene

Since at least as far back as early Cenozoic time, the North American Plate and the active spreading center (East Pacific Rise) separating the Pacific Plate and the actively subducting Farallon Plate had been migrating toward one another in a relative sense. Toward the end of Oligocene time, about 27 m.y.b.p. the North American Plate had encountered the East Pacific Rise and Pacific Plate off southern California (McKenzie and Morgan, 1969, Atwater, 1970). This waning of subduction offshore was followed by tectonic disruption of the borderland in Miocene time.

Atwater (1970) presents two models for Cenozoic crustal interaction along the southern California coast. One theory assumes that a somewhat constant relative motion (right lateral strike slip) existed between the Pacific and North American plates as far back as the mid-Cenozoic. As the two plates juxtaposed, strike slip faulting occurred between two diverging ridge-trench-transform triple junctions, one migrating south, the other north. Due to a nonalignment in the plate juncture, oblique rifting took place resulting in crustal disruption of the Borderland. An apparent 100km+ right lateral offset of Eocene lithofacies in the Borderland substantiates this theory (Howell and others, 1974). Atwater's alternative hypothesis assumes the North American and Pacific Plates, though abutted, remained stable until about 5 m.y. ago when major strike slip motion began on the San Andreas and related fault systems. In this model, Miocene rifting had to occur independently within the North American Plate. Such an intracontinental spreading model is consistent with views of Yeats and others (1974) who state that a palinspastic reconstruction of the Borderland, so as to realign pre-middle Miocene sedimentary facies of the northern Peninsular Ranges, Santa Monica, and Channel Islands blocks, requires largely east-west crustal extension.

Whether Miocene crustal dilation of the Borderland occurred by east-west spreading or oblique rifting, the result was (1) widespread rifting and block faulting, (2) uplift and exposure of once-subducted Catalina Schist rocks, (3) subsequent erosion of highland areas and (4) the advent of extensive volcanism.

The sedimentary rock type most indicative of offshore Miocene tectonism is the San Onofre Breccia and its lateral equivalents. The initial deposition of San Onofre Breccia debris in Saucesian time (Yeats, 1973) indicates a beginning of major uplift and rifting in the Borderland. These rocks, noted for their coarse texture and abundance of Catalina Schist clasts, crop out at widely scattered localities from the Channel Islands, southward along the coast to the Coronado Islands (Fig. 19). At the type locality near San Onofre Mountain north of Oceanside, the San Onofre Breccia consists of sandy marine rocks and nonmarine mudflows containing Catalina Schist clasts up to 3m diameter (Woodford, 1925). Woodford postulated that the breccia debris was transported by streams, mudflows, and slumping from a high relief upland not more than a few kilometers to the west.

San Onofre-type rocks of the Coronado Islands show evidence of transport from a similar western highland source. It has been postulated that at least two separate Catalina Schist highlands existed off the local coast in the middle Miocene, one west of the Coronados, the other west of Oceanside (Howell and others, 1974).

Rocks of Middle and South Coronado Islands contain a faulted, unrepeated middle Miocene section over 600m thick. Present day geologic structure consists of west-tilted fault blocks bounded by normal faults exposing older rocks to the west. The uplifted southern half of South Island is an exception. Thus, the unit m-1 redbeds on the western margin of Middle Island appear to be the lowest stratigraphic Miocene rocks of the Islands. As evidenced by the fluvial nature of unit m-1 redbeds, the local depositional basin or trough was initailly above sea level. At this time a highland to the west or southwest was shedding a mixed suite of reworked Peninsular Ranges and Poway clasts and a small amount of Catalina-type greenschist and blueschist debris. As with all Miocene rocks of the islands, unit m-1 sand grains are 15 to 40% volcanic rock fragments. The highland evidently had only limited exposures of Catalina Schist bedrock at this time, but contained widespread outcrops of early Tertiary sedimentary deposits and Miocene extrusive rocks.

It appears that unit s-1, the lowest stratigraphic unit of South Island, is next highest stratigraphic unit to m-1. Units m-2 through m-5 of Middle Island are unlikely prospects, since all resemble various stratigraphically higher units of South Island. Prior to the time unit s-1 was deposited, the sea had transgressed over the area, and would remain at least through deposition of unit s-6, 550m upsection. This transgression could have been a eustatic sea level change, but the immediate trough or basin was in all probability a down-dropped low of structural

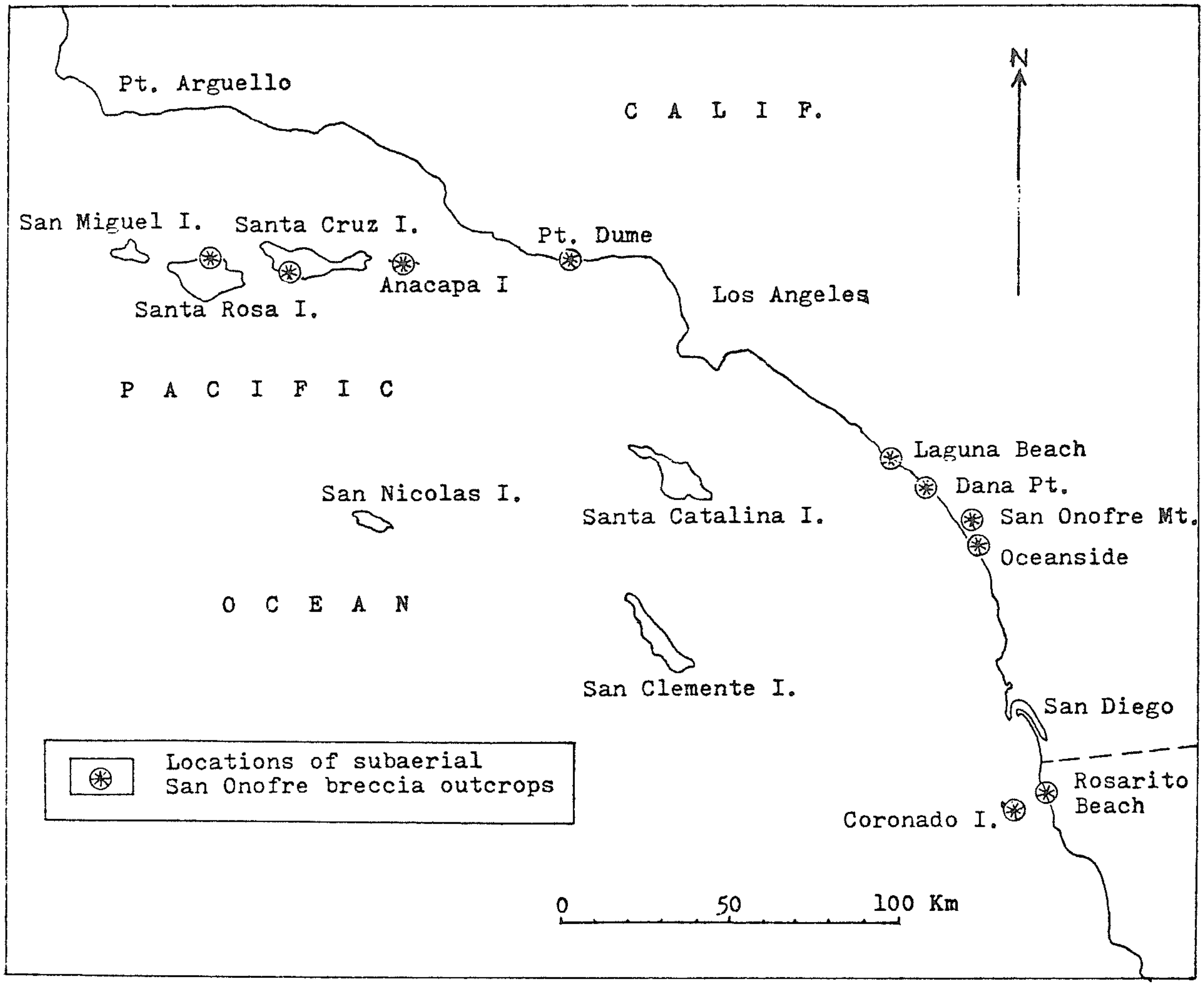


Figure 19. Distribution of San Onofre Breccia-type rocks of southern California and northwestern Baja California.

origin. Sandstone and shale of unit s-1 reflect a moderately quiet depositional environment. At this time, conglomerate debris similar to unit m-1, once carried to the area by streams, may have been deposited farther west near the shoreline as the sea transgressed onto the western highland. Locally quiet depositional conditions were temporary, since the western highland continued to rise relative to the immediate area. As the highland actively eroded, a subsea fan of coarse San Onofre-type debris (unit s-2) was prograding eastward (Fig. 20). The sudden introduction of this material to the Coronados area is reflected in the sharp, scoured contact between shale of unit s-1 and conglomeratic sandstone of unit s-2. Coarse clastic deposition continued for some time until over 250m of sandstone and conglomerate were deposited. High energy transport was prevalent during deposition of overlying units s-3 and s-4 as well, (collectively over 120m thick) but siltstone sequences up to 30m thick in unit s-3 indicate a change to alternating low and high energy transport and deposition. The Catalina Schist basement of the local highland was more widely exposed during deposition of units s-2,s-3 and s-4 as reflected in a high percentage of Catalina Schist clasts in these units relative to unit m-1 redbeds. Paleoslope and Paleocurrent indicators in units s-2,s-3, and s-4 show a major NNE current/slope component Perhaps the western highland was actually located to the southwest, or the Coronados area may have been a northern lobe of the subsea fan (Fig. 20). In any case, the highland was not far away, perhaps as close as a few kilometers and surely not farther than 15-20 km. A close proximity to the source area is indicated by large Catalina Schist boulders up to 1.5m diameter in units s-2, s-3, and s-4, the local concentration of fossil wood chips in siltstone of unit s-3, and the presence of red shale intraclasts in unit m-3 of Middle Island.

Following the main influx of San Onofre-type deposits, the Coronados area was blanketed by volcaniclastic rocks of units m-5 and s-5. Evidently, volcanism was rapidly becoming prevalent in the area, possibly reflecting an increase in regional crustal dilation. Paleoslope and current data were not ascertained fro the volcaniclastic breccia of unit s-5, but assuming these rocks were also derived from the west, the highland must have become at least partially masked by volcanic deposits. Unit s-5, resting conformably on San Onofre-type rocks of unit s-4, contains less than 5% Catalina Schist rocks and other nonvolcanic clasts in its lower portions, and an apparent absence of these clasts in the upper half of the section. It is doubtful that the highland could have eroded or subsided quick enough to account for the abrupt absence of Catalina Schist clasts after deposition of unit s-4. In fact the largest exotic slump blocks of the Coronados (up to 15m long) are found in the unit s-5 volcaniclastic breccia, indicating continued high relief in the area.

Deposition of silt and fine-to medium sand of conformably overlying unit s-6 marked an abrupt return to low energy deposition with only occasional influxes of volcaniclastic debris. No Catalina Schist clasts were found in unit s-6, but this may not represent a final masking or subsidence of the western highland. The limited outcrops of the Coronados cannot be assumed to represent the entire mid-Miocene depositional sequence in the area.

Miocene rocks of the nearby Mainland, represented by the sedimentary and volcanic Rosarito Beach Formation, crop out along the coast from La Mision, north to Tijuana (Minch, 1967), with lateral sedimentary equivalents in southwest San Diego County (Artim and Pinckney,1973, Kuper and Gastil, 1977). Though both the Rosarito Beach Formation and rocks of South Coronado Island have been dated as mid-Miocene, it appears the Coronados section is somewhat older than Miocene rocks of the Mainland. Differing lithologic properties of Catalina Schist debris and volcanic rocks of the Coronados and Mainland suggest noncontemporaneous deposition. The basal Mir Al Mar member of the Rosarito Beach Formation contains Catalina Schist clasts derived from the western highland, and overlying basalt was also derived from the west (Minch, 1967).

Catalina Schist material in the Mira Al Mar member of the Rosarito Beach Formation

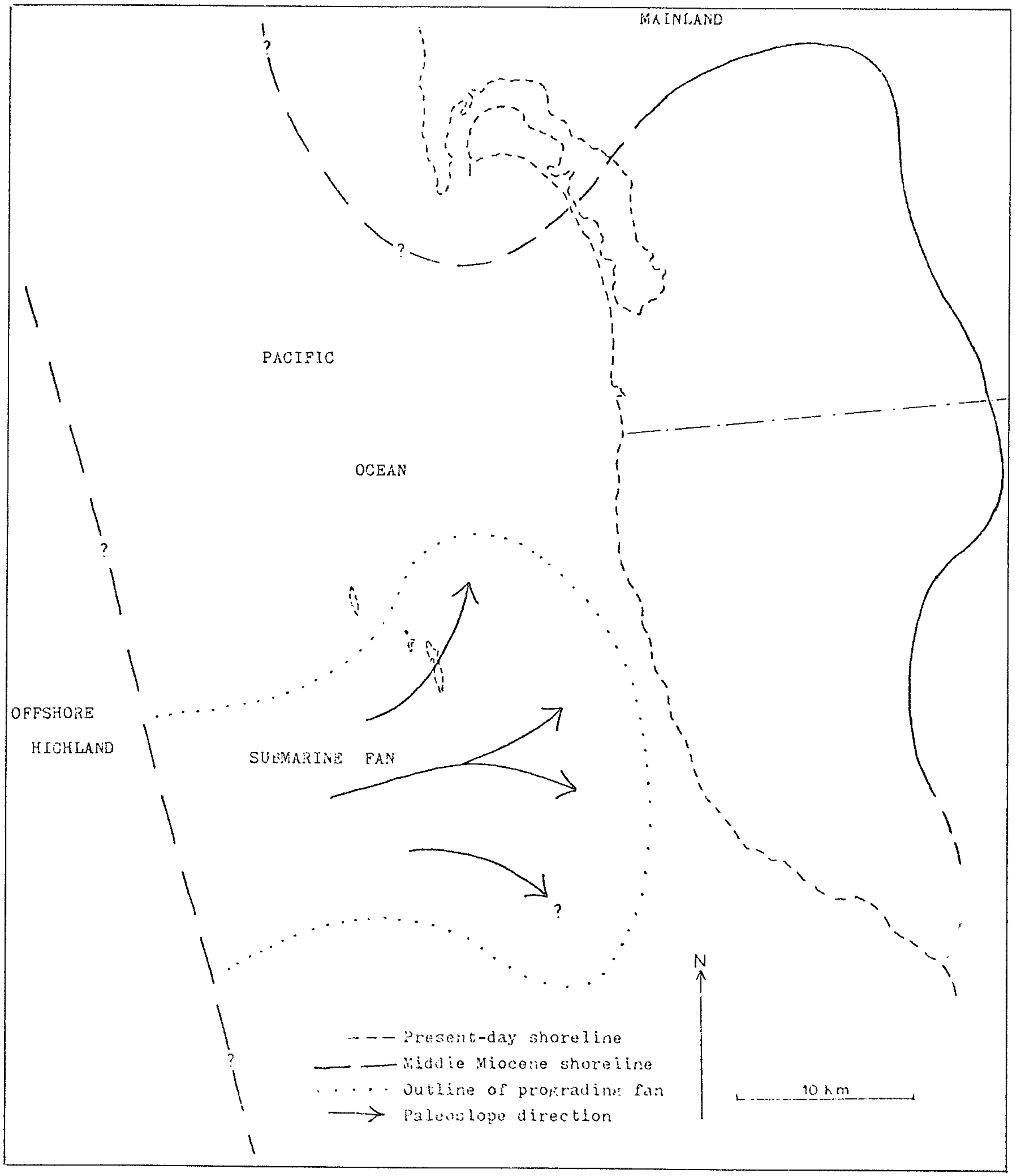


Figure 20. Proposed middle Miocene paleogeography of Coronado Islands and vicinity.

includes a large percentage of blueschist clasts (Minch, 1967). Conversely, greenschist clasts are dominant on the Coronados and blueschist is rare. Since both areas received detritus from the west, a proportionately greater area of blueschist (relative to greenschist) may have been exposed in the western highland during deposition of the Rosarito Beach Formation. Given these lithologic differences and employing the prograding fan model, it is inherent that Coronado Islands sediment was deposited prior to that of the Rosarito Beach Formation.

Volcanic rocks of the Rosarito Beach Formation are basalt flows with a high ferromagnesian content, whereas volcanic clasts of the Coronados are largely andesitic basalt, except in breccia beds of unit s-6 where basalt clasts predominate. It is postulated that this trend toward more basaltic volcanism, occurring after San Onofre fan-type deposition on the Coronados, continued with extrusion of the nearby Rosarito Beach basalts. Perhaps this was a time of increased crustal dilation and deeper rifting, thus allowing more basic magmas to reach the surface.

The bulk of Miocene sedimentation and volcanism occurred locally in the mid-Miocene. By Late Miocene time layered rocks of the Rosarito Beach Formation had undergone a period of major faulting (Minch, 1967). Faulting continued into the Pliocene and Pleistocene, but was less disruptive. Faulting of the Coronado Islands area and adjacent mainland was probably time equivalent, since both areas have a similar structural pattern, that is, west-dipping strata cut by northwest and northeast-trending normal faults that dip east. Strata of the Coronados dip steeper than Mainland rocks (25-35^{o} versus 5-15^{o}) and normal faults show greater stratigraphic separation, indicating more intense tectonic activity offshore. Though an analysis of regional crustal strain is beyond the scope of this paper, it seems that crustal deformation of the Coronados and nearby Mainland may be related to major faulting farther offshore, perhaps in the San Diego Trough or San Clemente Basin areas.

Pliocene and Pleistocene

By Pliocene time the horst-graben topography of the Continental Borderland was well developed, volcanism had waned, and major sedimentation was confined to embayments, nearshore shelves, and offshore troughs and basins. In the San Diego-Tijuana area, sandstone and conglomerate of the Pliocene San Diego Formation was unconformably deposited over Miocene and older rocks in a shallow marine Pliocene deposits, though not reported in the immediate vicinity of the Coronado Islands, were laid down on Coronado Bank 15km to the north (Emery and others, 1952). The shelf surrounding the Coronados is topographically higher than Coronado Bank, and may have been an area of nondeposition in the Pliocene or was subject to erosion in Pleistocene time. Faulting and tilting of the Coronado Island area undoubtedly contined through Pliocene into Pleistocene time.

Pleistocene to Recent geologic activity in the San Diego-Tijuana-Coronado Islands area has been marked by faulting, sea level fluctuations, fluvial to shallow marine deposition, and coastal erosion. In the offshore area there has been a continued influx of sediment into the San Diego Trough and San Clemente Basin (Shepard and Einsole, 1962), as well as some Quaternary deposition on Coronado Bank (Emery and others, 1952). Onshore, the most widespread Pleistocene deposits are of the Lindavista Formation (Hanna, 1926) that caps Pliocene and older rocks from northern San Diego to the Rosarito Beach area. The Lindavista is generally less than 15m thick and is composed of red sandstone and conglomerate deposited during a regression of the sea. A late Pleistocene transgression-regression of lesser extend left deposits over the La Jolla terrace as well as the Nestor terrace near San Ysidro. The red terrace deposits of South Coronado Island (unit st-2) are of comparable elevation to the Nestor and La Jolla rocks, but until more study is done on fossils of unit st-2, the correlation must remain tentative.

The San Diego-Tijuana-Rosarito Beach and offshore areas were tectonically active during Pleistocene. Displacement and/or tectonic warping of Pleistocene rocks has been documented near the Rose Canyon Fault on the northeast side of Mount Soledad (Peterson, 1970), on the east side of the Point Loma Peninsula (Kern, 1973), along the La Nacion fault system in the Chula Vista-San Ysidro area (Artim and Pinckney, 1973; Foster, 1973), and in the Rosarito Beach-Tijuana area (Minch, 1967; Flynn, 1970), Faulting in the offshore region is not well documented, but one would expect that appreciable Quaternary deformation has taken place between the coast and the major fault-controlled basins offshore. Coronado Bank has undergone deformation subsequent to being beveled by wave action in the Pleistocene, and the adjacent Loma Sea Valley may be of structural origin (Emery and others, 1952). Timing of the latest faulting on the Coronado Islands proper is not clear. On South Island, portions of unit st-1 were deposited in an eroded fault zone, suggesting a termination of movement by Late Pleistocene time, but unit st-2 at Puerto Cueva Cove is in direct contact with the fault forming the west side of the main down-dropped block. Due to soil cover and slope wash, it was unclear to the author whether unit st-2 was faulted or merely deposited against the well-preserved fault scarp on unit s-3. In any case, most movement on the fault occurred before unit st-2 was deposited, since it was essential that units s-2 and s-3 be in their present positon to shelter the Puerto Cueva Cove area and allow terrace deposition on the less resistant central fault block.

The southern California-northern Baja coastline has been subjected to active wave erosion at varying eustatic sea levels in Pleistocene to Recent time. Today, actively eroding sea cliffs are common on the coast and offshore islands, including the Coronados. In fact the mere existance of the Coronados has been dependent on the well-indurated, resistant nature of units n-1 of North Island, m-1 on the west side of Middle Island, and s-2, s-3 and s-4 of South Island. All other rock units of the Coronados, if not sheltered by these rocks would have since been beveled to wave-cut terraces.

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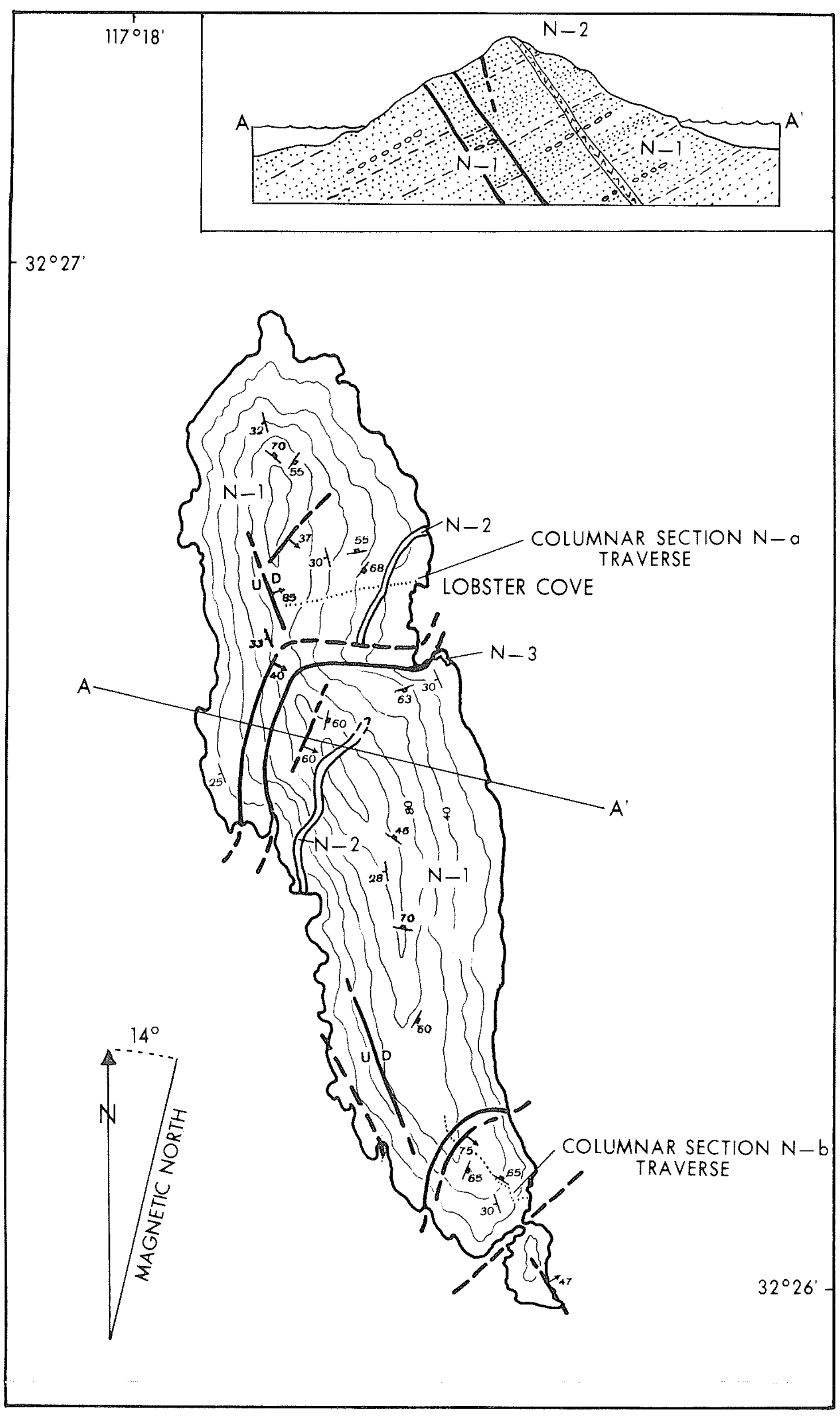
PLATE I



FORMLINE TOPOGRAPHY FROM AIR PHOTOS

GEOLOGY BY TOM LAMB, 1974

EXPLANATION

ROCK UNITS

N–3 PLEISTOCENE
CONGLOMERATE

N–2 MIOCENE(?)
ANDESITIC DIKES

N–1 CRETACEOUS(?)
RED SANDSTONE

GEOLOGIC SYMBOLS

GEOLOGIC CONTACT, DASHED WHERE INFERRED

FAULT, DASHED WHERE INFERRED

STRIKE AND DIP OF STRATA

STRIKE AND DIP OF JOINTS

COLUMNAR SECTION TRAVERSE

GEOLOGIC MAP and STRUCTURE SECTION of NORTH CORONADO ISLAND

NORTHWESTERN BAJA CALIFORNIA, MEXICO

SCALE 1:7000

0 0.5 1Km

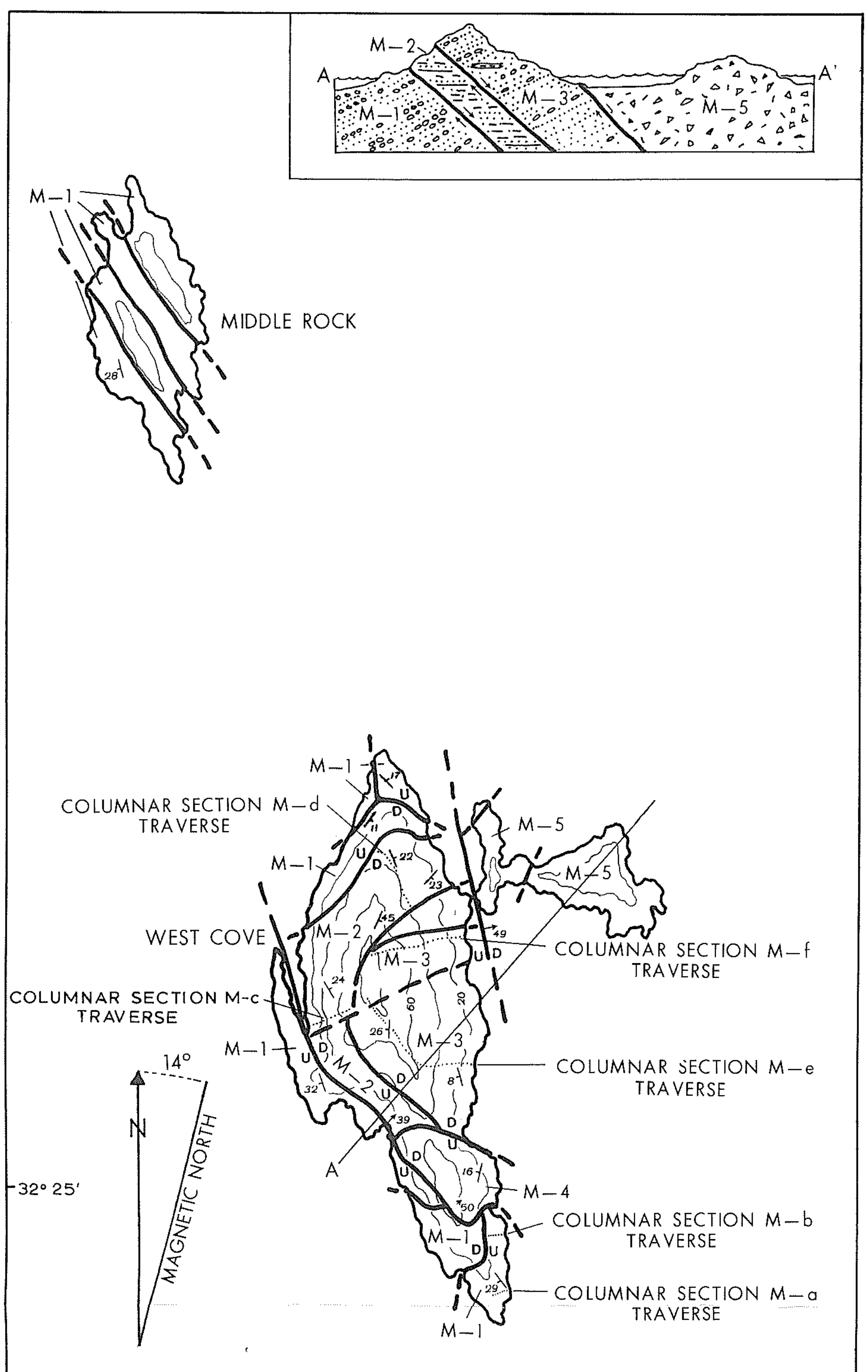
FORMLINE CONTOUR INTERVAL APPROXIMATELY 20 METERS

PLATE I

TOM LAMB

GEOLOGY OF CORONADO ISLANDS

PLATE II



FORMLINE TOPOGRAPHY FROM AIR PHOTOS

GEOLOGY BY TOM LAMB, 1974

GEOLOGIC MAP and STRUCTURE SECTION of MIDDLE CORONADO ISLAND

NORTHWESTERN BAJA CALIFORNIA, MEXICO

SCALE 1:5070

0 0.25 0.5 KM

FORMLINE CONTOUR INTERVAL APPROXIMATELY 20 METERS

EXPLANATION

ROCK UNITS

MIOCENE

- M-5 VOLCANICLASTIC BRECCIA
- M-4 SANDSTONE, SILTSTONE, SHALE, AND CONGLOMERATE
- M-3 SANDSTONE, SILTSTONE, AND CONGLOMERATE
- M-2 SANDSTONE, SILTSTONE, AND SHALE
- M-1 SANDSTONE AND CONGLOMERATE

GEOLOGIC SYMBOLS

FAULT, DASHED WHERE INFERRED

STRIKE AND DIP OF STRATA

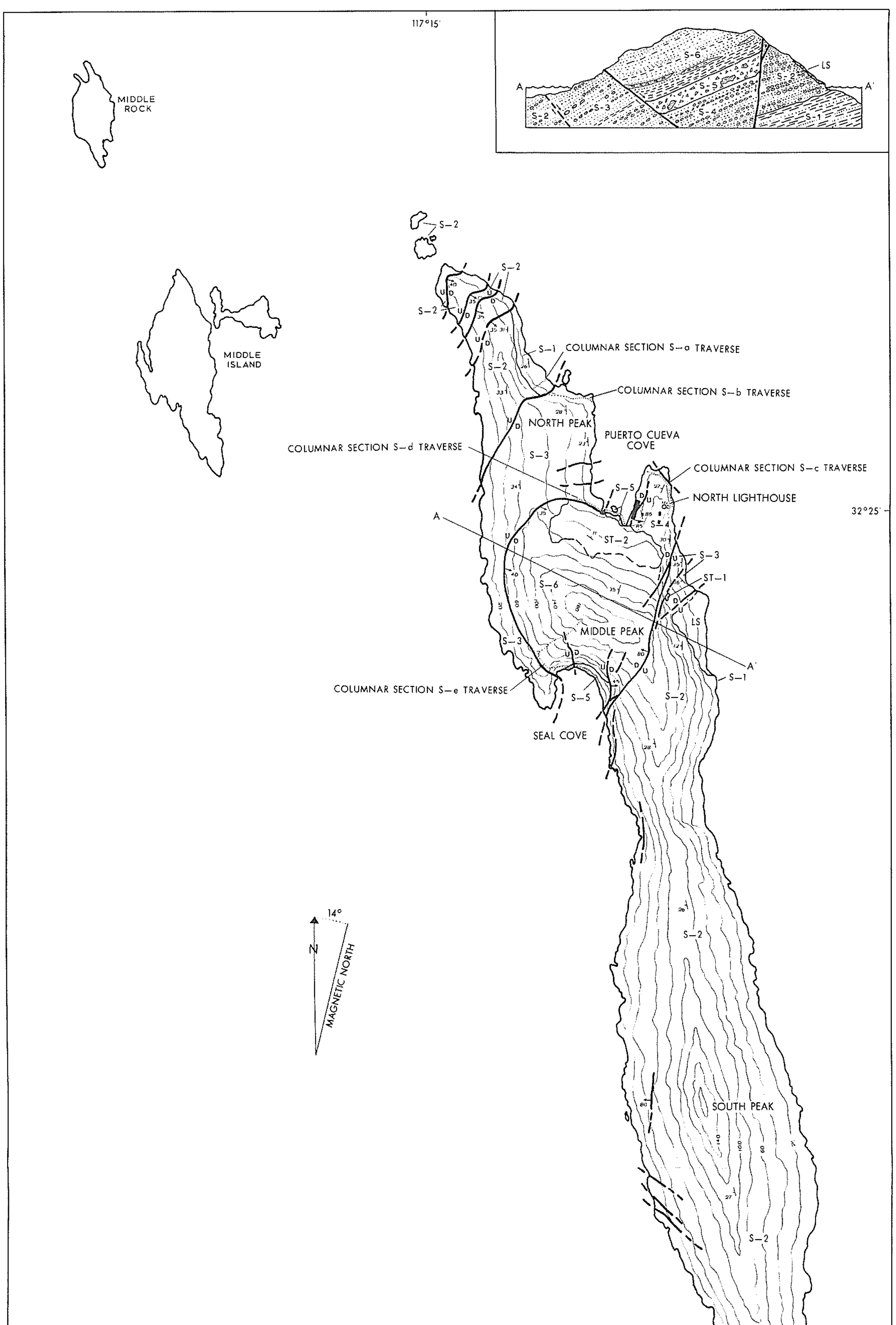
COLUMNAR SECTION TRAVERSE

PLATE II

TOM LAMB

GEOLOGY OF CORONADO ISLANDS

PLATE III



FORMLINE TOPOGRAPHY FROM AIR PHOTOS

GEOLOGY BY TOM LAMB, 1974

EXPLANATION

ROCK UNITS

LS	LANDSLIDE DEBRIS	RECENT
ST-2	MUDSTONE, BRECCIA, AND CONGLOMERATIC SANDSTONE	PLEISTOCENE
ST-1	CONGLOMERATE	PLEISTOCENE
S-6	SILTSTONE, BRECCIA, SANDSTONE, AND TUFFACEOUS SANDSTONE	MIOCENE
S-5	VOLCANICLASTIC BRECCIA	MIOCENE
S-4	CONGLOMERATE, CONGLOMERATIC SANDSTONE, AND VOLCANICLASTIC BRECCIA	MIOCENE
S-3	SANDSTONE, CONGLOMERATE, AND SILTSTONE	MIOCENE
S-2	SANDSTONE AND CONGLOMERATE	MIOCENE
S-1	SILTSTONE, SANDSTONE, AND SHALE	MIOCENE

GEOLOGIC SYMBOLS

GEOLOGIC CONTACT, DASHED WHERE INFERRED

FAULT, DASHED WHERE INFERRED

STRIKE AND DIP OF STRATA

STRIKE AND DIP OF JOINTS

COLUMNAR SECTION TRAVERSE

NONGEOLOGIC SYMBOLS

BUILDING

LIGHTHOUSE

GEOLOGIC MAP and STRUCTURE SECTION of SOUTH CORONADO ISLAND

NORTHWESTERN BAJA CALIFORNIA, MEXICO

SCALE 1:7000

0 0.5 1Km

FORMLINE CONTOUR INTERVAL APPROXIMATELY 20 METERS

PLATE III

TOM LAMB

GEOLOGY OF CORONADO ISLANDS

BIOLOGY

Tom Oberbauer
Integrated Planning Office
County of San Diego

Los Coronados Islands are biologically very important. They are important because biological resources on the islands influence the biological communities both locally, in the vicinity of the Islands, and regionally. They are important locally for the relatively great diversity of biological resources on them, but also regionally because the breeding populations on them are the origin of many of the birds and mammals seen throughout Southern California and Northern Baja California.

The most conspicuous resources on these islands are the large nesting populations of marine mammals including such notable species as Northern Elephant seals. However, the islands also support ten species of reptiles and amphibians including endemic varieties, and a fairly large native flora.

Breeding activities of these birds and mammals and the majority of the plant growth on the Islands occur during the spring months. But, many of the animals and plants are still visible in late summer and fall.

The biological resources presently found on Los Coronados Islands are partially the result of impacts from human activities. The islands have had a comparatively long history of exposure to human activities (Ellsberg, 1970; Osburn, 1909). Disturbing factors such as animal grazing, bird and mammal harvesting, and the introduction of feral animals have all occurred. As a result, some of the breeding birds and mammals have disappeared from the islands and a non-native, weedy plants have become established.

Ornithology

Birds are among the most visible animals on Los Coronados Islands. Because of their importance as bird nesting areas, the islands have been designated as a bird sanctuary by the Mexican government since 1924. Jehl (1977) recently summarized the avifauna of Los Coronados Islands. Though the islands are of rather small size, Jehl's information shows that at least 162 species of birds have been observed on them and 31 species are thought to have nested on them at least once. At one time, several sea birds had major breeding colonies on the islands including Cassin's auklet on North Island, Brandt's cormorant, Western gull, and California brown pelican (Jehl, 1977; Osburn, 1909; Grinnell, 1928). Presently, only the Western gull produces major colonies on the islands. The brown pelicans still nest on them but in variable numbers. In addition to the loss of major breeding bird colonies, two notable species of birds, the Bald Eagle, and Peregrine falcon have been extirpated from Los Coronados Islands as they have throughout much of North America. The Osprey may have also nested on the islands at one time. The loss of these birds may partially be due to the effects of organic pesticides, particularly DDT.

Los Coronados Islands has played an important role in the understanding of DDT and its effects on the reproduction biology of birds (Jehl, 1973, Anderson et al, 1975). It was found that nesting success of the California brown pelican was greatly reduced by the presence of high concentrations of DDE, a breakdown component of DDT, in the eggs.

Lack of nesting success was partially due to the fact that many of the eggs had greatly reduced shell thickness and could not support the weight of the incubating parent birds. Fortunately, the nesting success has been increasing in recent years.

Quite a few common terrestrial birds found on the San Diego mainland have also been found to nest on Los Coronados Islands including the House Finch, Chipping sparrow and Song sparrow. The Song sparrow is an adaptable species and the form found on Los Coronados has even been described as an endemic subspecies (Melospiza melodia coronatorum; Grinnell, 1928). However, several species that are very common within San Diego are conspicuously absent from Los Coronados, although they are only 13 kilometers from the mainland. Such birds as the Wrentit, Brown towhee, California thrasher, Scrub jay, and Bushtit are apparently too sedentary to fly out to the islands. The presence of the California quail, another sedentary bird on the South Island, appears to be the result of intentional introduction.

Coastal islands in the Southern California-Baja California region seem to be particularly notable for the presence of migrant birds in spring and fall. Coastal islands such as Los Coronados act as "vagrant traps" where birds that fly off course seek refuge. For this reason, coastal California islands have a disproportionally high number of migrant bird species seen on them, including species not normally found on the adjacent mainland. This sees to be true for Los Coronados where several species of warblers normally found in the Eastern United States have been seen.

Mammals

There is apparently only one indigenous terrestrial mammal on Los Coronados Islands, the White footed mouse. Like the Song sparrow , the White footed mouse found on Los Coronados Islands is considered a distinct subspecies, Peronyscus maniculatus assimilies (Huey, 1964). At various times, other terrestrial mammals such as feral house cats (Osburn, 1909), goats and rabbits (Ellsberg, 1970) have been introduced on the islands. Fortunately, probably because there are no permanent water sources, the introduction of biologically destructive goats was not successful. However, the introduction of rabbits apparently found on South Island, are also very harmful to the native vegetation.

The most prominent mammals to have utilize Los Coronados Islands are seals, sea otters and sea lions. These are all large animals ranging from 30 kilograms (60 pounds) for the male Sea otters to 2275 Kilograms (5000 pounds) for a male Northern elephant seal which may reach a length of 4.8 meters (16 feet). At one time, there were apparently large colonies of California harbor seals, Northern elephant seals, California sea lions, Guadalupe fur seal, and sea otters breeding on Los Coronados Islands. Oil and fur hunters greatly reduced the numbers of all of these mammals, reducing the sea otters and elephant northern seals to near extinction. But, since 1892, the Northern elephant seal population has climbed from less than 9 known individuals to a present population of 15-20,000 (Bostic, 1973).

Sea otters are beginning to be seem more frequently in Southern California waters. Presently, Northern elephant seals and California harbor seals can be seen on Los Coronados Island. California sea lions have a major colony on the west side of North Island. However, the sighting of a Sea otter as far south as Los Coronados is still an unusual occurrence and Guadulupe fur seals are still mainly seen only on Guadalupe Island.

Bats are also seen on the islands. Eleven species of bats have been recorded in the coastal area of northern Baja California and most have the capability of flying to Los Coronados Islands.

Herpetology

Los Coronados Islands have quite a diversity of reptiles and amphibians.

when compared to other Pacific coastal islands in the Southern California-Baja California region. Ten species of reptiles and amphibians have been found on the islands with four of them differentiated into subspecies that are only found on Los Coronados Islands. They are the Árboreal salamander (Aneides lugubris) on the South and Middle Islands, Pacific slender salamander (Batrachoseps pacificus) on all four of the Islands, the Side blotched lizard (Uta stansburiana hesperis) on the South and Middle Island, Los Coronados Island subspecies of the Western skink (Eumeces skiltonianus interparietalis; Stebbins, 1966) found on the North, South and Middle Islands, the Los Coronados subspecies of the Southern Alligator lizard (Gerrhonotus multicarinatus nanus; Fitch, 1938) on the South and Middle Island, the Coastal Whiptail (Cnemidophorus tigris multiscutatus) on the South island, the California legless lizard (Anniella pulchra) on the South and Middle Islands, the San Diego night snake (Hypsiglena torquata klauberi) found on the South Island, the Los Coronados island subspecies of the gopher snake (Pituophis melanoleucus coronalis) on the South Island, and perhaps most important for people traversing the islands on foot, the Los Coronados Island subspecies of the Southern Pacific Rattlesnake (Crotalus viridus caliginis; Klauber, 1956) on the South island. It is noteworthy that out of over 20 islands along the Pacific Coast of Southern California and Baja California, only 3 have rattlesnakes, South Los Coronados, Santa Catalina Island, and Cedros Island. It is unclear that the rattlesnake on Santa Catalina occurred there naturally, but the fact that the rattlesnakes on Cedros and Los Coronados have differentiated into local forms indicates authochthonous origins.

It has been suggested that the reptiles on the Channel Islands probably dispersed from the mainland during the Pleistocene, probably by chance overwater rafting (Savage, 1967). This seems to be substantiated by the fact that the reptiles present on the islands represent a depauperate subset of the mainland reptile fauna.

Botanical Resources

A list of plants occurring on Los Coronados Islands was compiled by Beauchamp (1978), based on information from the herbarium of the San Diego Museum of Natural History. Much of the following discussion pertains to that list.

There have been 113 species of plants reported from Los Coronados Islands. Of these, 103 have been found on the largest, South Island. Ninety three species seem to be indigenous to the Islands with the remainder introduced. This is comparable to the number found on other California Islands of similar size (see table 1). The slightly greater number of species on Los Coronados when compared to the other islands may be partially a result of the closer proximity to land.

Six of the species found on Los Coronados are insular endemics and not found anywhere on the mainland. Two species are endemic to Los Coronados Islands. They are Los Coronados bedstraw (Galium coronadoense) and Dudleya candida. Some of the more unusual plants found on Los Coronados Islands are the stonecrops in the genus Dudleya. Dudleyas for the most part, are succulent plants that are found growing on rock faces and rocky slopes. The genus consists of about 40 species. Four of these are found on Los Coronados. They include Dudleya lanceolata which is found throughout Southern and Northern Baja California. Dudleya attenuata ssp. orcuttii, which is found only in northern Baja California and Border Field State Parl, Dudleya anomala which is found only on Los Coronados Islands, Todos Santos Island, and Punta Banda on the Baja California mainland, and the endemic Dudieya Candida. There is another form of Dudleya found on Los Coronados sometimes referred to as Dudleya siemteres, however, it is considered a hybrid between D. candida and D. attenuata ssp. orcuttii. Another plant of interest on Los Coronados is the Malva rosa (Lavetera occidentalis). This is a shrub with large rose colored flowers that is found on several of the Pacific Coastal Islands off

TABLE I

Floristic statistics of some California Islands with land areas similar to Los Coronados Island:

Island	Area (Km^2)	No. Native Species and Varieties	No. of endemics	Distance to mainland (Km)
Anacapa	2.9	70	0	22
Santa Barbara	2.6	68	2	63
Los Coronados	2.5	93	2	13

From Philbrick, 1972; Raven, 1967, Beauchamp, 1978.

of Baja California. At one time, the form of this plant that grows on Los Coronados was considered a separate species.

Vegetation

The majority of the vegetation communities found on Los Coronados Islands are maritime forms of Coastal sage scrub (see Thorne 1976), similar to those on Point Loma. The dominat plants on the islands are mostly succulents and spiny shrubs. Dominat species are cacti such as jumping cholla (Opuntia prolifera), beavertail cactus (Opumtia oricola, O. littoralis), snake cactus (Bergerocactus emoryi), and shrubs such as California sagebrush (Artemisia californica), winged saltbush (Atriplex canescens), California boxthorn (Lycium californicum) and Flat-top buckwheat (Eriogonum fasciculatum). During the summer and fall, the vegetation takes on a drab brown and gray appearance. But, following the winter rains, the vegetation becomes green with succulent iceplant (Gasoul crystallinum, G. nodiflorum) and various herbaceous plants. Patches of color are provided by the yellow sea dalea (Coreopsis maritma), Encelia (Encelia californica), and Goldfields (Lasthenia chrysostoma, L. coronaria). Various other wildflowers also produce a colorful display during the Spring including Wild Hyacinth (dichelostemma pulchella), Mariposa lily (Calochortus splendens), and ground pinks (Linanthus dianthiflorus).

In spite of their small size and unobtrusive appearance, Los Coronados Islands contain a great diversity of biological resources. The breeding bird and marine mammal colonies and endemic reptiles and plants are not only significant to the islands, but are significant to the Southern California-Northern Baja California region as a whole. The resources on Los Coronados Islands are unique and efforts should be made to perpetuate their existance whenever possible, particularly in relation to their close proximity to large human population centers.

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ARCHAEOLOGY

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To set the stage for the discussion of the archaeological resources and their significance on the Islands a brief cultural overview of the San Diego regional area is presented. It is generally agreed that manifestations of three major prehistoric cultural traditions exist in San Diego County and northern Baja California: the San Diequito Complex, the western aspect of the Paleo-Indian tradition; the La Jolla Complex, a local expression of the California Milling Stone Horizon; and a Late Prehistoric Complex, in this specific region designated in the southern part of the County and northern Baja California as Yuman (Diegueno-Kumeyaay) and in the northern part of the County as San Luis Rey I (a preceramic horizon) and San Luis Rey II (a horizon beginning when ceramics came into general use). The historical culture associated with the two San Luis Rey phases is the Shoshonean speaking Luiseno.

The Paleo-Indian Stage found throughout North America prior to 9,000 years B.P. refers to an economy based primarily on the hunting of now extinct big game. In San Diego County, this stage was named and recorded in 1938 by Malcolm J. Rogers as the San Dieguito Complex.

The best known early cultural tradition in Southern California is termed the Milling Stone Horizon (Wallace 1955:214-230) It is a cultual tradition which occurs along the coastal strip from San Luis Obispo County into Central Baja California, and it is this tradition which is identified on North Coronado Island. Archaeologically, the Milling Stone Horizon exhibits a relatively homogeneous assemblage of artifacts including (Heizer 1964:123; Wallace 1955: 214):

1) crude percussion flaked choppers

2) relatively unrefined scrapers

3) hammerstones

4) manos and metates often with deep basins

5) few and rather large projectile points which suggest the use of the dart rather than the bow and arrow.

6) no ceramics

7) no C-shaped shell fish hooks

Over time, some areas were subject to ecological changes and outside influence which resulted in a number of localized variants or expressions including "Oak Grove" in the Santa Barbara area, "Topanga" in the Santa Monica Mountains of Los Angeles County and "La Jolla" in southern Orange County, coastal San Diego County and northern Baja California. Characteristic traits of the La Jolla culture include shell middens, flexed inhumations (often in association with "killed" milling stones, that is metates which have had holes punched through the bottom of the basin), manos and metates, fire hearths, a paucity of projectile points, and an abundance of crude percussion flaked scrapers, choppers and lithic waste. The quality and variety of lithic tool manufacture is less refined when compared to the preceding San Dieguito Complex and the Late Prehistoric cultures which followed the La Jollan culture. Because the economy of these early inhabitants included the gathering of marine shellfish as well as plant and seed processing, La Jolla sites are typically located near the bays and lagoons along the coast, which suggests a predisposition for a maritime technology.

While a maritime technology has never heretofore been identified as an attribute of the La Jolla Culture except by implication (Shumway et al. 1961:104), the technology was obviously available and was utilized by contemporaneous south coast California peoples, as is indicated by the following list of radiocarbon dates for the Channel Islands:

San Nicholas Island:

3300 (UCLA-165) years B.P.
3980 (UCLA-147)
5070 (W-981)

Santa Catalina:

3880 (M-434)

Santa Rosa:

7350 (M-1133)
5370 (L-446B)
4790 (UCLA-105)

San Clemente:

2120 (LJ-218)

Recently, Michael Axford of Mesa College has indicated he has received radiocarbon dates for San Clemente Island of considerable antiquity which are contemporaneous with the La Jolla occupation on the mainland (Axford 1978).

The recovery of a few pelagic fish remains from La Jollan middens and contemporaneous radiocarbon dates on other Channel Islands led this author to hypothesize that if the La Jollan peoples utilized a maritime technology, manifestations of their culture should be identifiable on the Coronados. The islands would have afforded an excellent locale for the gathering of bird eggs, infant birds, bird bones, shellfish, fish and sea mammals, since they are only seven miles from the coast of Baja California, where there are numerous La Jollan middens.

However, it must be remembered due to the lack of fresh water on the Islands no permanent settlements would have been feasable. The nature of the archaeological sites therefore should represent temporary and relatively small encampments, which were probably used by a small group of people repeatedly for many centuries. It would seem reasonable that heavy food processing implements (such as the mano and metate) would not be present as an abundance of other food resources are available on the islands. The group probably brought what ever staples they required for the trip with them.

Secondly, the types and amounts of artifacts on the islands should identify which of the two more recent cultures (i.e. La Jolla 8,000-3,000 B.P. or Late Prehistoric 3,000-European contact) were the peoples who were there. If Late Prehistoric peoples reached the islands the presence of pottery, C-shaped shell fish hooks, small arrow points and refined pressure-flaked stone tools would be expected. The pottery (canteens) would be almost requisite to transport water. If, however, only the earlier La Jollan peoples visited the islands none of the above should be found. Instead there should be stone tools more crude in nature. These are typically large precussion-flaked scrapers and choppers. Pottery, the bow and arrow and shell fish hooks were unknown in La Jollan times. It might be speculated that the stomachs of animals were used to transport fresh water. As seals are present on the islands and would have been much easier to kill than land mammals, these may have been the source. Furthermore, the crude La Jollan stone scrapers would be suitable for butchering.

In order to test the hypothesis, I examined Malcolm Rogers field notes and a small collection of artifacts recovered from North Island, which are currated at the San Diego Museum of Man. Reported below are his site notations:

<u>W-168 North Coronado Island:</u>

Culture appears to be Lit. II (La Jolla) but it is not probable that boats were built as early as this. We found no sherds (ceramics) but they have been reported from a small cave - Pirate's Cave. (An ex-boatman told me this cave was salted for tourists to collect from - even one skull was buried; Scattered camp debris on the more gentle slopes such as they are; water none; architecture-none as everything is greatly eroded due to the steep sides of the island; Not enough artifacts present to determine whether Lit II (La Jolla) or Y-II (Yuman-Late Prehistoric) is present or both. The stone for flaking (porphyritic cobbles) comes from a conglomerate of beach cobbles cemented in tuff at the base of the island. The largest midden patch of shell and charcoal was on a saddle midway on the island; but has slid down both sides from erosion. The principal tool present is the teshoa flake (a large percussion struck flake, generally minimally modified and characteristic of Milling Stone Horizon Sites).

W-169 South Coronado Island:

Culture: This has not been determined as it is the same as that of North Coronado Island; Area: Scattered evidence over the flatter parts of the island; Fishing camp type of intermittent visitations; water-none; History: Did not examine the island personally so history cannot be determined. Have been told that there are larger midden patches on this island than on North Island. The largest midden was on the site of the present Mexican Hotel grounds. (Rogers, n.d. courtesy of K. Hedges of the San Diego Museum of Man). Note; information within parentheses supplied by this author.

Having reviewed this information I carefully examined the artifactual collection which is composed of sea-mammal bone, shell, flakes and stone tools from both Islands. How Rogers acquired materials from South Island is not explained by his notes. The flaked stone tools exhibit sizes and shapes typical of the tool making pattern during La Jollan times. They are relatively large, crude, and unifacially percussion flaked. The flake scars on the tools suggest the use of a stone hammer to shape them, rather than an antler or bone. While Rogers was speculative as to whether the material could be attributed to the La Jolla Tradition (8,000-3,000 B.P.), which he called Lit. II, he did not at the time of his writing have the benefit of subsequent radiocarbon dates from other Channel Islands. Further it may be suggested that the "crude" character of the stone tools and the lack of artifacts attributable to the more recent cultures suggests that a maritime technology was utilized by La Jollan peoples sometime prior to 3,000 B.P. It is hoped that more careful examination of the archaeological sites on the Coronado Islands and possibly radiocarbon testing of shell will verify this hypothesis.

Acknowledgements: I thank K. Hedges of the San Diego Museum of Man for access to Malcolm J. Rogers' field collection and notes: S. Sapone for typing the manuscript; D. Flower and L. Roth for helpful suggestions.

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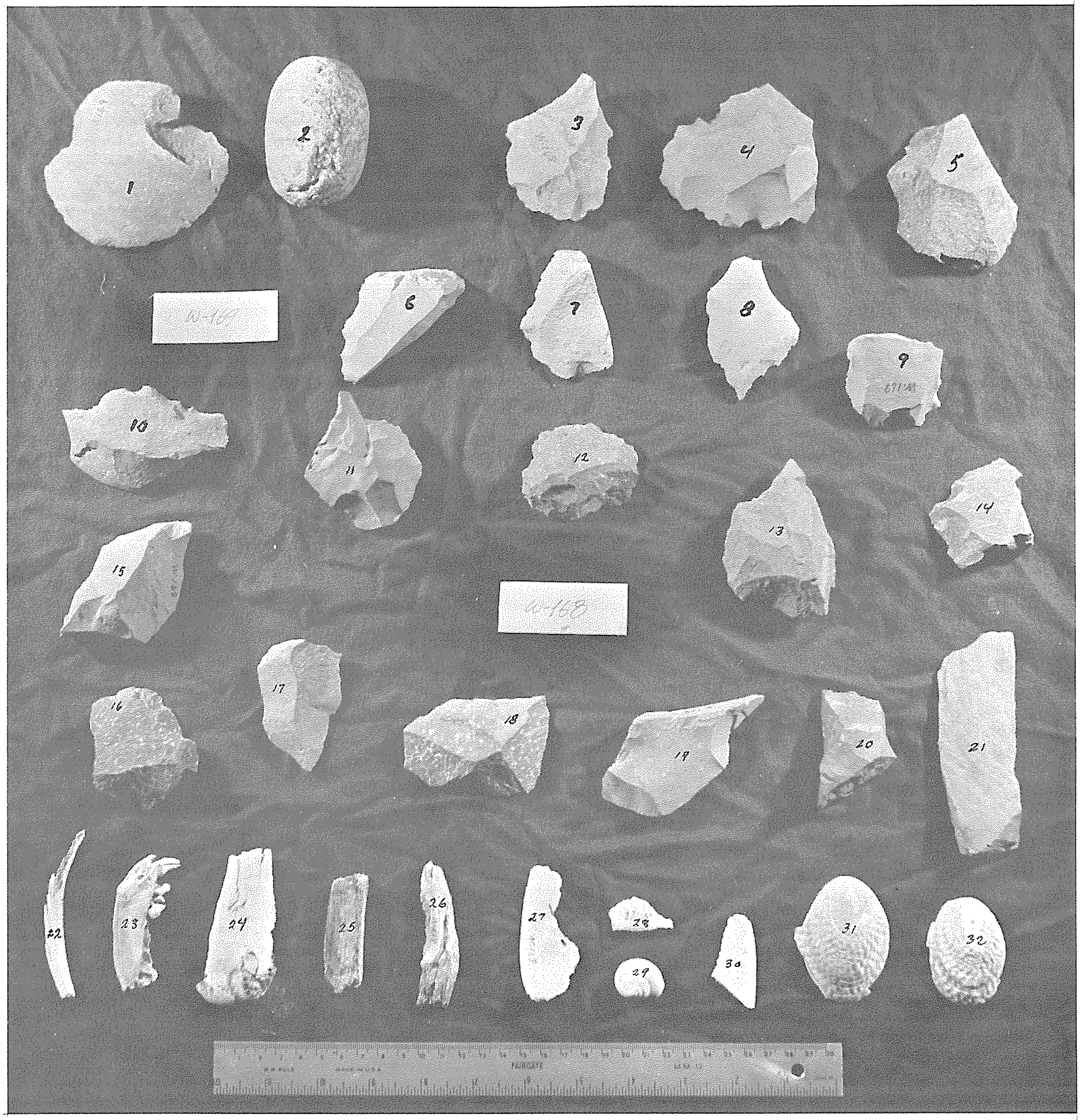

No. 1. Teshon Flake (w-169), No. 2 Possible Mono (w-169), Nos. 3,4,5,10,11,12 and 16 convex side scrapers, Nos. 6,7,8,9 and 14, side scrapers, Nos. 17,18 and 19 utilized flakes, No. 20, end scraper, No. 21 blade (typological) Nos. 23,24,24 and 26 sea mammal bone fragments, No. 27,28,29,30, haliotis sp fragments, No. 28 quartz flake, No. 29 small snail (sp ukn), Nos. 31 and 32 Acrnoea sp.

BACK COVER. Photograph of South end of North Island (1915). Photograph courtesy of Historical Collection, Title Insurance and Trust.


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