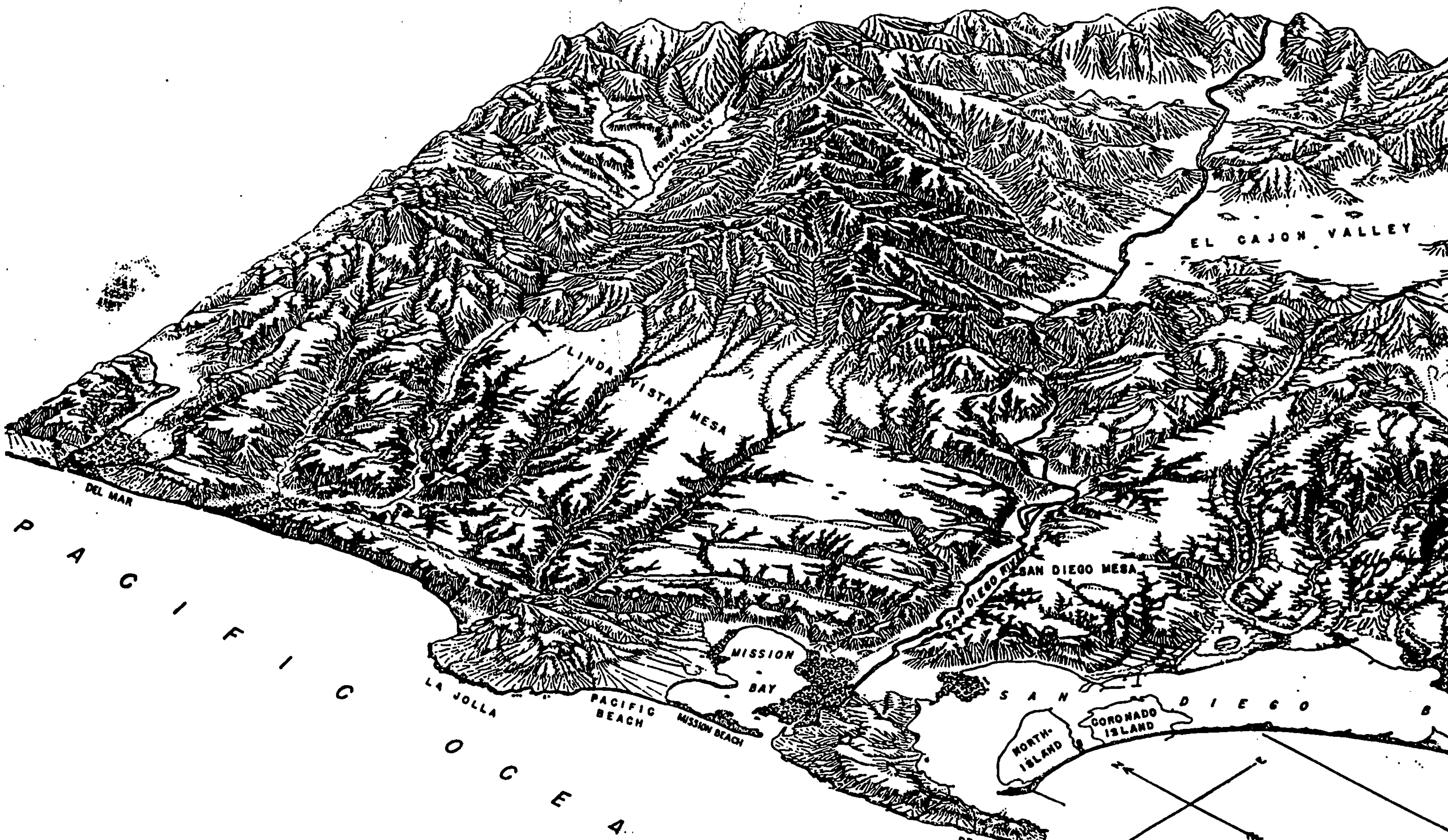
GUIDE TO SAN DIEGO AREA STRATIGRAPHY



PREPARED FCR AAPG-SEG PETROLEUM EXPLORAT
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COVER ILLUSTRATION FROM HERTLEIN AND GRANT, 1944

GUIDE TO SAN DIEGO AREA STRATIGRAPHY

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by

Gordon Gastil
and
Richard Higley

Department of Geological Sciences
San Diego State University

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DEPARTMENT OF GEOLOGICAL SCIENCES
SAN DIEGO STATE UNIVERSITY
SAN DIEGO, CALIFORNIA 92182
(714) 286-5586, 286-5587

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AN OVERVIEW OF 150 MILLION YEARS

The coast of the tropical Jurassic sea lapped against volcanic islands near San Diego. There was, then, no "west coast" of North America. Indeed there was no Atlantic Ocean or Pacific Ocean as we know them today. San Diego was part of an island arc lying just west of what is now central Mexico. From here shallow tropical seas extended eastward across Mexico and northern Africa. The islands of San Diego exposed cliffs of andesite breccia, and the beaches were almost devoid of quartz grains. Back from the shoreline stood tall trees resembling the modern redwood.

Where was the subducting trench which fed this ancient arc? From whence came the old ocean floor that was being consumed? Bits of early Jurassic ophiolite in the continental margin to the west may be a clue--but the pattern is lost.

Thousands of meters of volcanic-volcaniclastic strata, some with marine fossils, form the basement rock beneath our sedimentary coastal plain. To the east these rocks have been intruded by great volumes of granitic rock, metamorphosed and highly deformed, but at the head of Mission Valley, a few kilometers from the modern strandline, they can still be seen lying almost as they were deposited 150 million years ago.

Over the next 60 million years this trench-arc system proceeded to consume and digest an oceanic plate and generate magmas of gabbro, tonalite, and granodiorite composition. They rose to build a new sialic crust along the western periphery of the continent, hundreds of kilometers wide, almost from pole to pole. During most of this interval the coast lay further west on what we call the continental margin. By Upper Cretaceous time volcanic activity had ceased along the western coastline (although still very active a few hundred kilometers to the east). Short, steep drainages along a precipitous coast led into a deeply disected terrain of recently unroofed granitic and metamorphic rocks. Some of these great fans or debris-slides contained blocks the sizes of houses, or even hotels.

Along this narrow coastal belt only a few kilometers separated the conifers and duck-billed dinosauers from the precipitous sea stacks, the tumbled submarine slide deposits and the dark, bathyal shale. Occasionally a few centimeters of ash recalled that a trench was still active somewhere to the west, and an arc still erupted somewhere to the east.

By the end of the Paleocene the precipitous coastline had been somewhat worn down. San Diego was the apex of a delta lined with mangroves and nut palms. To the east braided rivers reached inland for hundreds of kilometers across a rolling, hilly upland. Tropical weathering had penetrated so deeply into the local bedrock that cobbles and boulders no longer reflected the local basement rock. Rather, the old Cretaceous canyons were now overfilled with clasts derived from southern Arizona and northern Sonora.

Then in the Oligocene the whole tectonic scheme seemed to change. The andesitic volcanism which had been moving steadily eastward for 120 million years was replaced, far to the east, by great floods of ignimbrite; basins and ridges began to form; and the rivers which had drained to the Pacific were diverted in other directions. In the Miocene the continental borderland rose for the first time, exposing pillow basalts, serpentine, and glaucophane schist, creating mountains that shed coarse detritus eastward onto the old coastal plain.

By middle Miocene time what was to become southern California was a series of ridges and basins. Granitic and metamorphic rocks were exposed to the east; andesite and basalt were erupting to the west in the continental borderland, to

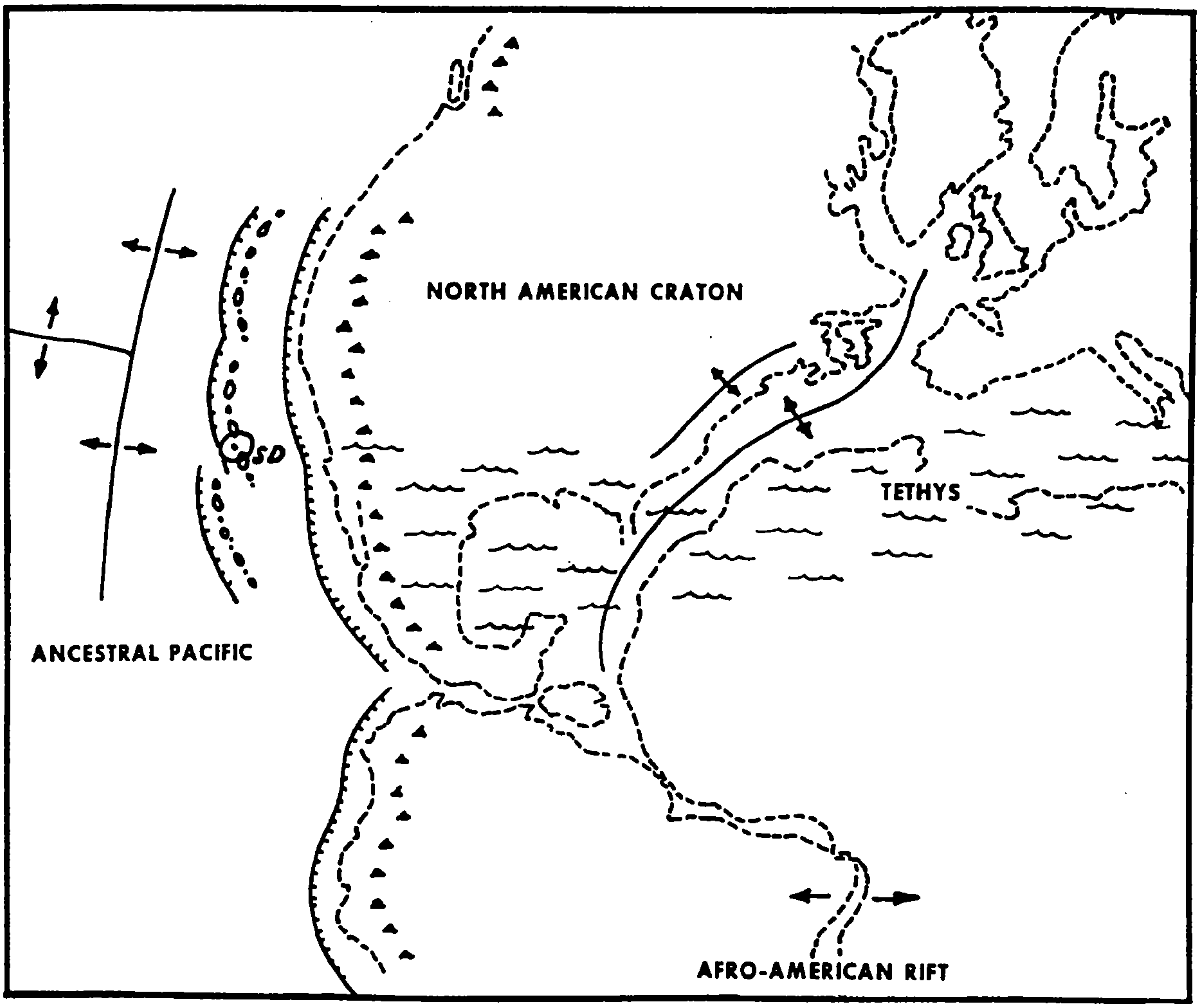


Figure 1. Cartoon showing hypothetical location of San Diego in the Jurassic.

the north in the Los Angeles basin, and to the south in northern Baja California. Great blocks of lithosphere were working against one another, and rapidly thickening sections of Tertiary strata were being upturned, compressed and folded. Within this arena of great activity the coastal plain near San Diego remained comparatively quiet. Ash and fine sandstone from the volcanic fields to the southeast interfingered with coarse, local detritus from the inland mountains, accumulating in shallow lacustrine and fluvial deposits. Local volcanism was limited to a few small dacite domes, and deformation was negligible.

In the Pliocene the borderland began to subside and with it the coastal plain near San Diego. Coastal currents from the north reworked the resistant Eocene boulders of rhyolite and quartzite, and the Oligo-Miocene breccia of glaucophane schist, and mixed them with newly quarried clasts of meta-andesite and granodiorite brought in by streams from the east to produce a complex sequence of nearshore conglomerates and sandstone, perhpas 300 meters in maximum thickness.

The early Pleistocene produced a broad terrace across the area, marked by a succession of regressional beach ridges. The complete leaching, the deep red stain, the lateritic soil formation on this surface suggests that there was a warm, high rainfall, probably forested environment. Mastodon remains suggest the fauna. During glacial time the river valleys cut progressively deeper into the coastal plain to depths over a hundred meters below modern sea level. The highest marine sea level during the interglacial time was on the order of ten meters higher than present.

In contrast to most of California in which the diastrophism of obducting plate convergence, arc volcanism-plutonism, and transform strike-slip motion has mangled and recrystallized Mesozoic, Tertiary and even Holocene strata, San Diego presents a sequence of flat-lying rock surfaces, representing a succession of coastal plains which alternately deposited and eroded across this area without significant vertical, compressional, or extensional movement.

Tectonically we can divide the San Diego area into a stable coastal plain and hinterland, and a less stable continental margin or "borderland" province. The boundary between these follows the Newport-Inglewood-Rose Canyon fault system south to San Diego Bay, thence southward just off the Mexican coast. East of this line post-batholith strata of all ages dip less than 5° except for a few meters adjacent to faults or rare intrusive plugs. West of this line even Pleistocene beds are tilted at greater angles. East of this line fault systems, such as the La Nacion-Sweetwater, are dip slip, largely normal, with maximum post-Miocene displacements of a few hundred feet. This is probably due to differential subsidence and compaction along the margin of the Pliocene San Diego embayment. It has been suggested that there is strike-slip displacement on the Rose Canyon fault (Kern, 1973). If so it is part of the motion between the North American and Pacific plates which is distributed across the continental borderland.

A FEW WORDS ABOUT THE STRATIGRAPHY

To this point we have written of events and deposits, but have not mentioned stratigraphic names. To some of you these may be old friends, to others they will be unfamiliar, at times confusing, and in the end perhaps unnecessary. Inevitably, the local geologists will use them in conversation, and we will do our best to set you straight.

The oldest stratified rocks we will see are andesitic breccia, tuff, and sandstone. These rocks show little hand specimen evidence of metamorphism, but scarcely a kilometer to the east they are intruded by granitic rocks of the southern California batholith. Although the outcrops we will visit do not contain fossils, the fossil ages we have in the county indicate the Portlandian stage (Fife and others, 1968). Pre-batholith volcanic rocks in San Diego County are referred to the Late Jurassic Santiago Peak Formation (Larsen, 1948).

The oldest post-batholith strata are the coarse, locally derived, nonmarine deposits named the Lusardi Formation by Nordstrom in 1967. The oldest marine strata of post-batholith age are the Campanian-Maestrichtian conglomerate, sandstone, and shale which outcrop on Point Loma, near La Jolla, and in a small area east of Carlsbad. In 1961 Milow and Ennis assigned these rocks to the Rosario Formation of Baja California (Beal, 1924). In 1971 Kennedy and Moore raised the name Rosario to group standing and subdivided the rocks north of the International boundary into the Lusardi, Point Loma, and Cabrillo Formations.

There are no Paleocene strata recognized in San Diego County, to the south in Baja California and to the west in the outer banks of the Continental Border-

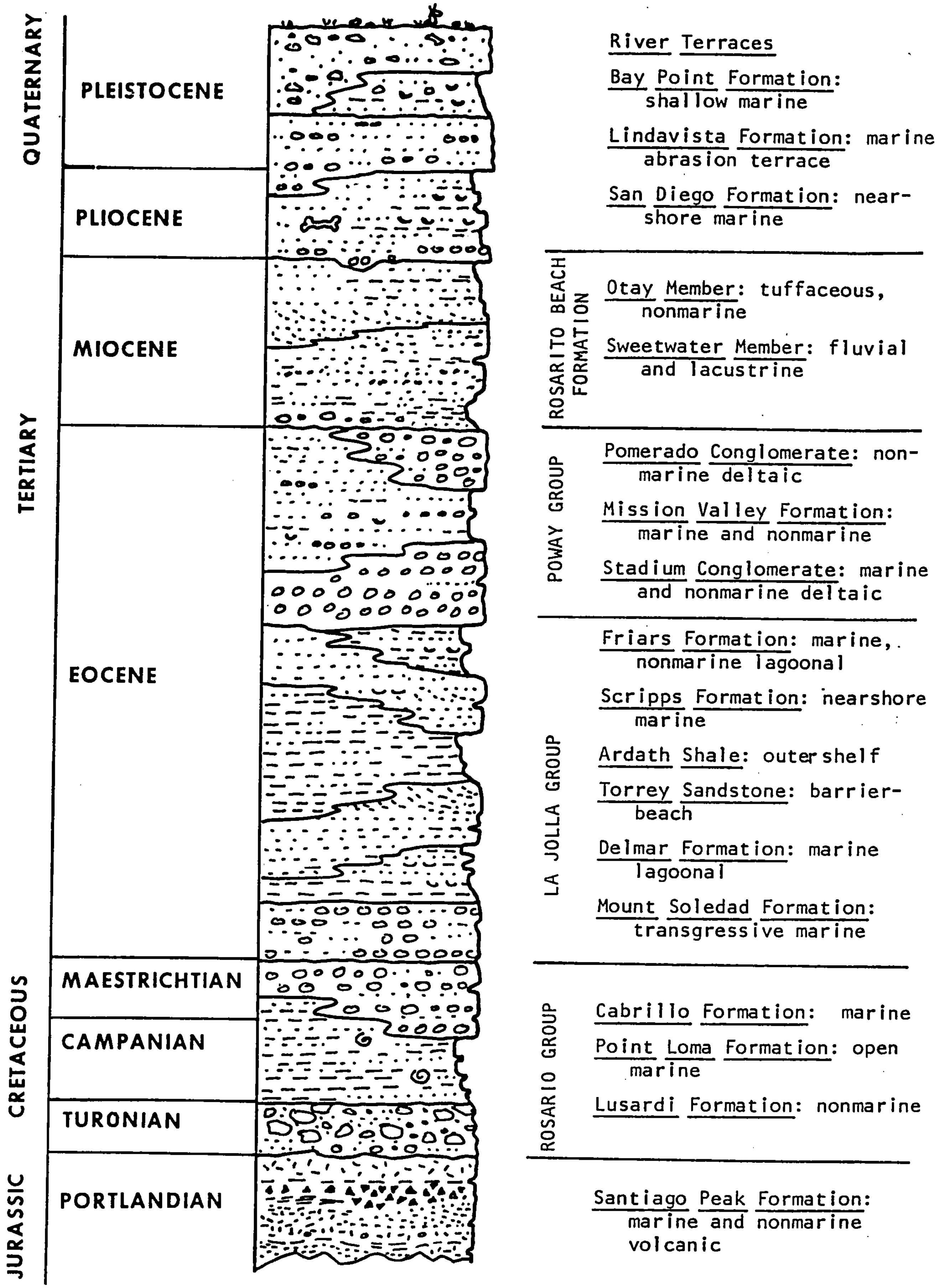


Figure 2. Generalized stratigraphic section of the San Diego area.

land. Kennedy and Peterson, 1975, indicate that Eocene strata range in age from Capay to Tejon Stage (Figure 8). Hanna (1926) divided the Eocene rocks into the lower La Jolla Formation (with the Delmar, Torrey Sandstone, and Rose Canyon Shale members), and the Poway Formation. In 1971 Kennedy and Moore raised the names La Jolla and Poway to group status, and divided each into several formations (see Figure 8). Briefly, the Ardath shale is an offshore deposit contemporaneous with the Torrey and Scripps bar and nearshore deposits and the backbar lagoon Delmar and Friars Formations. The Stadium and Pomerado Conglomerates are largely non-marine shoreward facies of a river delta contemporaneous with the marine and non-marine Mission Valley sandstone.

Wilson (1972) shows that north of Carlsbad the strata of the La Jolla Group equate to the Santiago Formation (Woodring and Popenoe, 1945). A few kilometers south of the International boundary Flynn named equivalent strata the Delicias and Buenos Aires Formations.

It was long believed that the only Miocene strata in the western part of the county was the middle Miocene San Onofre Breccia (Woodford, 1925) which outcrops as far south as Oceanside, and has been recognized in the Los Coronados Islands (studied in detail by Lamb, 1972). However, Minch (1967) discovered rocks of similar age and provenance just south of Tijuana, and named them the Rosarito Beach Formation. In 1973 Artim and Pinkney suggested that strata previously included in the lower part of the San Diego Formation (Hertlein and Grant, 1944) was correlative with Minch's Rosarito Beach Formation. Scheideman (1977) confirmed this correlation by mapping across the international boundary, and has proposed extending the name Rosarito Beach Formation to include the Miocene age strata in southwestern San Diego County. Kuper and Gastil (1977) have suggested that the formation names proposed by Artim and Pinkney (Otay and Sweetwater) be retained as members of the Rosarito Beach Formation.

The oldest stratigraphic name in the area is the Pliocene San Diego Formation (Dall, 1898). The consensus of opinion assigns it a late Pliocene (Wieander, 1970; Mandel, 1974).

The terraces of the San Diego-Tijuana area, are capped by an iron oxide cemented red conglomerate-sandstone named by Hanna (1926) "Linda Vista terrace materials." Kennedy and Peterson (1975) assign the name Lindavista Formation to this material and a latest Pliocene to earliest Pleistocene age. The age may actually overlap that of the underlying San Diego Formation.

Late Pleistocene strata include the Bay Point Formation (Hertlein and Grant, 1944) and several marine and non-marine terrace deposits. The Bay Point is considered to be an offshore bar or barrier deposit, and it is not clear which if any of the terrace deposits were contemporaneous with it. Kern (1977) indicates that most of the terraces post-date the Bay Point Formation. Kennedy and Peterson (1975) use the name Bay Point Formation to include most of the post-Lindavista strata in the San Diego area.

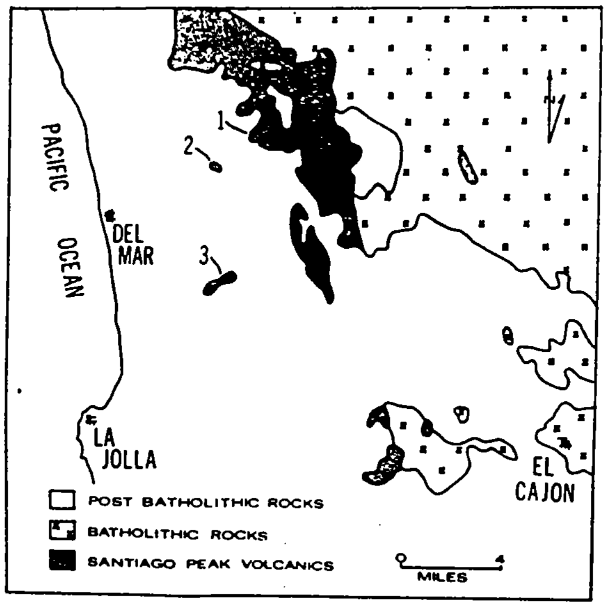


Figure 3. Generalized geologic map showing the distribution of the prebatholithic Santiago Peak Volcanics, the Southern California batholith, and postbatholithic rocks. Fossils were found in (1) Lusardi Canyon, (2) small canyon north of La Zanja Canyon, and (3) Los Peñasquitos Canyon (modified from Weber, 1963)

BACKGROUND INFORMATION ON THE STRATIGRAPHIC UNITS

SANTIAGO PEAK VOLCANICS

The coastal plain and adjacent mountains of western San Diego County are underlain by intruded and weakly metamorphosed volcanic and volcanoclastic rocks of basalt to rhyolite composition. Although the stratigraphy of these rocks has yet to be worked out, the fossils which have been found indicate a latest Jurassic (Portlandian) age.

Our field trip will visit the volcanic strata near the head of Mission Valley. Unfortunately no fossils have as yet been encountered in this area. To see the argillaceous and fossiliferous beds one needs to visit an area four to six miles east of Del Mar. Fife, Minch, and Crampton (1967) describe three localities as follows:

Lusardi Canyon

> *The slates and argillites contain large clasts and boulders of volcanic debris and numerous interbeds of volcanic rock, which locally contain clasts of slate. Numerous sedimentary structures indicate that the section is overturned; they include small-scale cross-bedding, beds grading from medium to coarse sandstones to fine siltstones and claystones, oscillation ripple marks, flame structures, rip-up clasts from grit- to cobble-size, and load casts. The main section of slates and argillites in the canyon overlies the volcanic rocks. These findings confirm Larsen's (1948) observation that the slates are interbedded with and overlie the Santiago Peak Volcanics. The slates superficially resemble the Bedford Canyon Formation farther north, but they cannot be equivalent, for the Santiago Peak Volcanics overlie the Bedford Canyon Formation.*
>
> *Collected from the slates were a few poorly preserved fossils, tentatively identified as belemnoids and* Buchia *sp. Although* Buchia *ranges in age from Upper Jurassic to Lower Cretaceous, many of its species have much narrower age ranges and thus a further search is warranted. Fragments of wood, tentatively identified as sequoia of Mesozoic age (Chester A. Arnold, 1965, personal communication with San Diego State College), have been found in the volcanic rocks and in the slates and argillites in this canyon. Wood fragments have been found also in the San Dieguito River Canyon to the north.*

Small Canyon North of La Zanja Canyon

> *Numerous graywacke and argillite beds and persistent thin stringers of argillites are interbedded with the volcanic sandstones and breccias. Within the breccias are boulders and clasts of argillite and graywacke. That this section is overturned is indicated by flame structures, graded bedding, and flute casts. Belemnoids and* Buchia piochii *are found in both the argillites and the rocks of volcanic derivation. According to Imlay (1959),* Buchia piochii *is diagnostic of the latest Jurassic (Portlandian). Neither this age nor the stratigraphic relationship of the small canyon's interbedded argillites, graywackes, and volcanic breccias supports Hanna's (1926) tentative correlation of the small-canyon strata and the Bedford Canyon Formation.*

Los Peñasquitos Canyon

All argillites, clasts, and volcanically derived metasedimentary rocks have the same general strike and dip and are continuous over the extend of the inlier. Fragments of the argillites and slates are found in both the metavolcanic and volcanically derived sedimentary rocks, and fragments of the latter are found in the slates and argillites. Distorted thin slate and argillite beds are traceable 20-30 feet through coarse volcanic breccia, which locally has an argillaceous matrix. Belemnoids are found in both the matrix and the thin distorted beds and in all other rock types except for the reworked clasts of volcanic rock in the breccia.

Numerous specimens of Buchia piochii *(Imlay, 1961, personal communication) were collected from the slate at several exposures. One exposure also yielded fragments of an ammonite. The Los Peñasquitos inlier appears to be interbedded with the Santiago Peak Volcanics.*

Some information on the petrology and chemistry of the weakly metamorphosed volcanic rocks can be found in Hawkins (1970).

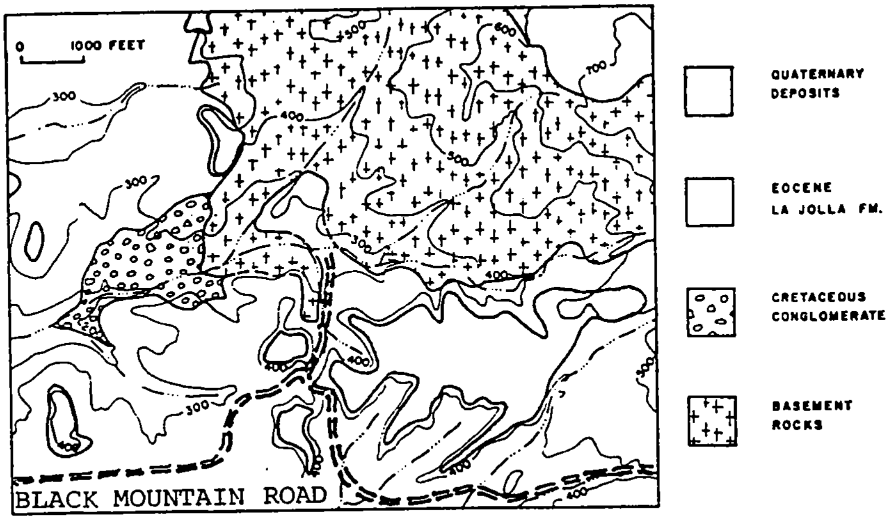
LUSARDI FORMATION

Beds of extremely coarse, poorly sorted, angular conglomerates of local derivation, lying with high relief unconformity on the batholith and pre-batholith terrane, and deeply weathered before burial, are exposed from Carlsbad, San Diego County, to the area southeast of La Mision in northern Baja California. They are found at 2000 feet elevation south of Alpine (Gastil and Bushee, 1961), east of Poway (Kennedy and Peterson, 1975), and near San Vicente Reservoir (Morgan, 1975).

The best exposures were described by Nordstrom in his Master's thesis (1967):

A previously undescribed conglomerate unit is discontinuously exposed over an area of twenty-five square miles near Rancho Santa Fe, California. This formation unconformably overlies the Late Jurassic to mid-Cretaceous basement rocks, and is unconformably overlain by the Eocene La Jolla [Group]. Although the unit is unfossiliferous, it is thought to be Late Cretaceous in age because of similarity in clast content and other physical characteristics to known Cretaceous units nearby and a distinct dissimilarity to other Cenozoic conglomerate units. On the basis of stratigraphic position and lithic character a gentative correlation is made with the Trabuco Conglomerate of the Santa Ana Mountains.

The unit is predominantly a reddish-brown boulder conglomerate with a sandstone-siltstone matrix. Clasts locally range up to 20-25 feet in diameter. The dominant clast types include plutonic rocks, volcanic and volcaniclastic rocks, hornfelses, and quartzites, which were derived from the nearby basement rocks. Thin lenses of well-sorted, medium- to fine-grained sandstone are



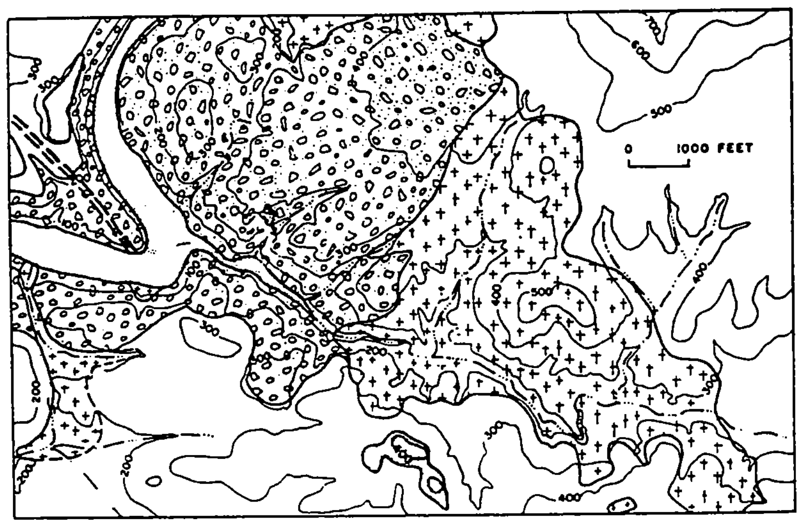


Figure 4 (after Nordstrom, 1967). Map showing the location of Cretaceous (Lusardi conglomerate on La Zanja Canyon. The road shown in the lower edge of the map is Black Mountain Road which can be reached by going east on Carmel Valley Road (see field guide, stop 11A).

Figure 5 (from Peterson and Nordstrom, 1970). Map showing exposure of Lusardi Formation at the confluence of Lusardi Creek and the San Dieguito River near Rancho Santa Fe. This locality can be reached by taking Via De La Valle east from Interstate 5 about 2.5 miles to Las Colinas, thence east about 0.6 mile to Zumalde Street which extends almost to the sharp bend in the San Dieguito River.

locally present in the otherwise massive conglomerate and appear to represent channel deposits.

The large size of the clasts, their local provenance, and the coloration of the unit suggest terrestrial deposition, possibly as a fanglomerate. Many of the clasts are soft and friable and readily disintegrate upon exposure; this condition indicates lengthly subaerial weathering at the site of deposition prior to deposition of the overlying unit.

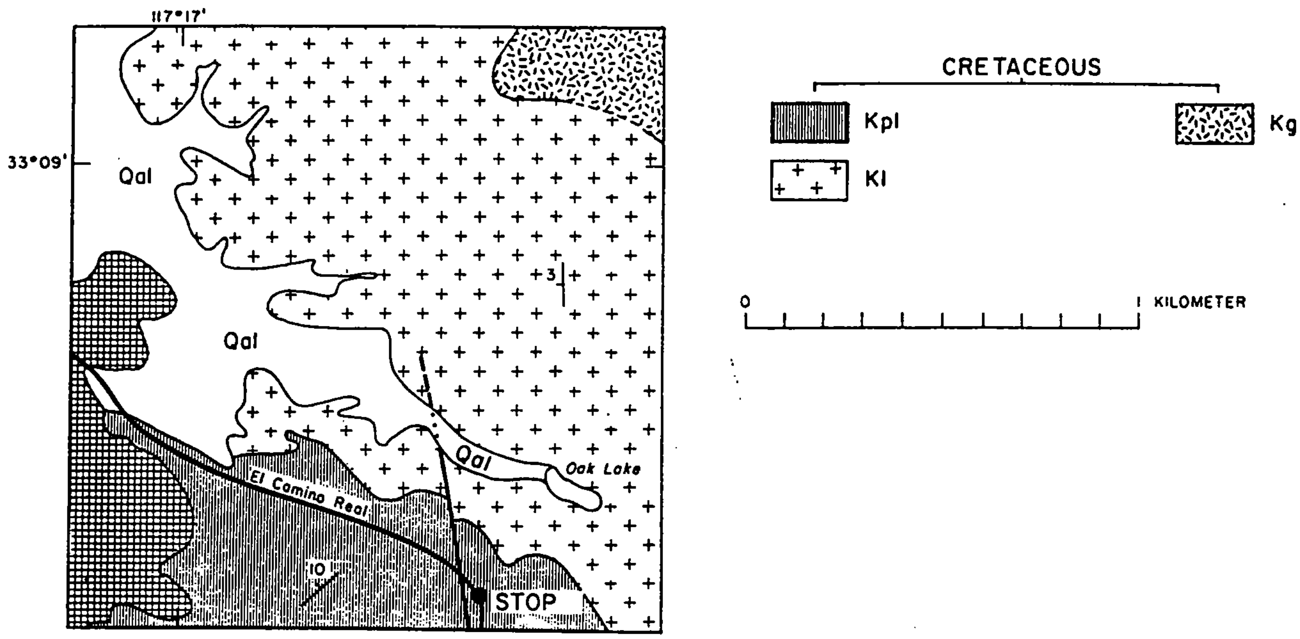


Figure 6 (from Kennedy and Moore, 1971). Map of the Lusardi beds underlying the Point Loma Formation east of Carlsbad. To reach this locality from Interstate 5 turn east on Palomar Airport Road approximately 3.3 miles to El Camino Real. At 0.8 miles north you reach Stop 2.

Although the rocks mapped by Nordstrom were not in contact with marine Cretaceous strata, the Lusardi beds east of Carlsbad are clearly overlain by the Point Loma Formation (Moore, 1971; Wilson, 1972; Peterson and Nordstrom, 1970).

Peterson and Nordstrom (1970) and Peterson (1970) stress the differences in the clasts that are found in the Cretaceous Lusardi Formation, derived from the local crystalline basement, and the Eocene conglomerates derived from an exotic source. This striking contrast will be seen in the ancient river gorges near San Vicente reservoir, in the Upper Cretaceous Cabrillo Formation conglomerate near False Point and in the conglomerates of the La Jolla and Poway groups.

POINT LOMA FORMATION

Marine strata of Campanian and Maestrichtian ages outcrop along the coast of northern Baja California as far north as Rosarito Beach, on Point Loma, La Jolla and Mount Soladad, and east of Carlsbad. North of the International boundary these rocks are divided into the lower, predominantly finer grained, Point Loma Formation and the upper, predominantly coarser, Cabrillo Formation. The measured thickness of the Point Loma Formation is 670 meters (Hertlein and Grant, 1944). The age is middle Campanian to lower Maestrichtian. The mixture of inner shelf and bathyal biofacies (Sliter, 1968) has heretofore led to the conclusion that shallow water deposits were reworked downslope by density currents.

Maytum and Elliot (1970) investigated the paleocurrent and slope indicators at Point Loma and La Jolla (Figure 7). Their descriptions of some of these structures are as follows:

Graded Bedding

> *Sandstone beds which exhibit this type of grain distribution are usually found sandwiched between thinly laminated clay-shale. Grading is locally common and seems best developed in the thinner sandstone beds. Most of the observed graded cycles occupy a vertical interval ranging from 0.5 to 1 meter. Generally the coarsest basal material is grit (2-4 mm) to coarse sand size (1-2 mm) and extends 10-15 cm into the bed. Medium to coarse arkosic sandstone occupies the middle of the cycle and grades upward into fine sandstone and siltstone. In ungraded beds medium to coarse arkosic sandstone predominates.*

Rip-up Clasts and Rip-up Structures

> *The clasts found in this area are clay-shale (and rarely sandstone) fragments suspended in the sandstone strata. They are very common in both the La Jolla and Point Loma localities. In some beds they occur as wildly separated, solitary fragments whereas in others they form a dense enough jumble to be classed as a shale-clast conglomerate or interformational breccia. The clasts in the Point Loma area are usually angular with some exhibiting the effects of minor marginal abrasion. In the La Jolla exposures, however, many inclusions are extremely deformed and rounded. Individual fragment size ranges from 1 cm "cubes" to tabular clasts 2 meters long and 10 cm thick. Stratigraphically clasts are concentrated in the basal portion of the sandstone bed.*
>
> *There is little doubt that the included clasts are fragments of stratigraphically lower beds. Some shale clasts with unusual lithologic characteristic (such as combined pyrite and carbonaceous fragments) matches with a similar shale bed slightly lower in the section. Also, numerous places were seen where, along strike, portions of 8-10 cm thick shale beds would abruptly disappear. Similarly, areas can be seen where sections up to 15 cm thick have "lifted out" of very thick shale units with the resulting void filled by the overlying sandstone. Related clast orientations commonly parallel other "current-formed" structures thereby indicating rip-up and realignment in a paleo-movement (down-current or slope) direction.*

Cross-Bedding

The cross-beds are all on a very small scale, seldom exceeding 6 cm in relief for any one "set." The entire structure extends no more than 10-15 cm laterally. The structures are numerous in the medium grain sandstone beds which are thinly interbedded with clay-shale. The individual structures are asymmetrical and therefore serve as paleo-current direction indicators because the foreset laminations (steep side) were developed on the downcurrent side of the ripple.

Groove Casts

These are best observed on the substratal surface of overhanging sandstone ledges on the sea cliff in the southeast corner of La Jolla Bay. A few, poorly preserved groove casts were found at Point Loma in the Sunset Cliffs area. They appear as rounded to sharp crested linear ridges at the sandstone-shale interface (the groove "mold" being in the shale and the ridge "cast" being in the sandstone). The relief of the casts ranges from slight protuberances of 5 mm to ridges over 6 cm high.

Flame Structures

These are variably sized, curved, pointed tongues of shale which project up into overlying sandstone beds; only a few of the flames are made up of fine-grain sandstone and sandy or silty shale. Amplitude of flames in the Rosario [Group] range from 2-15 cm and usually have a period of 15-60 cm. They are most commonly found in groups along strike. In cross-section and plan view many resemble linear ripple marks which have been pulled up, over, and streaked out into the overlying sandstone. Others look like a complex of interference ripples which have been deformed in the same way.

Convolute Laminations

The appearance of these paracontemporaneous deformational features is usually that of intense, but small scale folding. They are limited to a single sedimentation unit and are not generally faulted. The convolutions are very continuous laterally through and particular rock unit. They resemble elongate, but irregular corregated folds in plan view, with some fold axes extending the entire exposure of the bed (up to 6 meters). Convolutions are best developed in thinly laminated siltstone and sandstone beds. Amplitudes range from 2-12 cm with some thickening in the crests and troughs.

Convolute laminations are common throughout the studied [formations] of the Rosario [Group] at La Jolla and Point Loma. They form a significant source for the collected current data. Since mass movement along the convoluted bed occurred soon after deposition their common asymmetrical orientation points in a down current-slope direction.

Load Casts

In cross-sectional view the load casts resemble some of the convolute laminations with swellings in the individual bedding

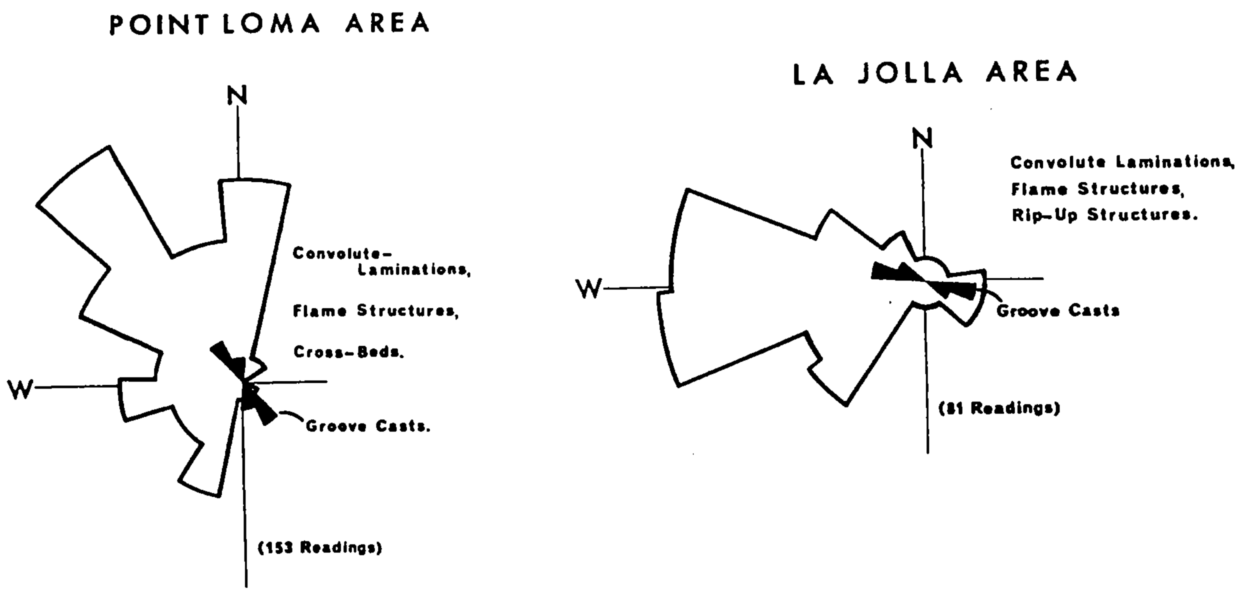


Figure 7. Composite rose diagram for the Point Loma and La Jolla areas (from Maytum and Elliot, 1970). Directionally oriented primary structures; convolute laminations, flame structures, and cross beds; indicate a northwesterly direction of transport or paleoslope at Point Loma and west at La Jolla. Bidirectional groove casts are also shown.

planes ranging from small, smooth bulges to highly contorted disturbances. On plan view, however, the casts are generally strictly localized and are not commonly oriented. These features show the deformational effect of relatively thick sandstone beds overlying shale. There appears to have taken place an alternating exchange of coarse and fine material between the beds with the lobes of shale pushing further up into the sandstone than the sand down into shale.

Intraformational Slump Structures

Two separate slump structures in the La Jolla area are recognized because of their probable indication of paleo-slope. The slumps take the appearance of displaced, rolled, and crinkled beds folded in with a complex of rock fragments of varying size and lithology. The nature of deformation, including small scale thrust faulting, leaves the impression that movement occurred when the beds were slightly more lithified than when such features as convolute laminations, flame structures, and rip-up clasts were formed. In the La Jolla area the slumps occur between undeformed beds which contain numerous sedimentary structures. Some of the blocks in the slumps themselves contain convolute laminations, flame structures, and rip-up clasts which pre-date the slump. These included fragments show marginal deformation (rounding) which indicates that they were in a semi-plastic state when the slump occurred.

Wensrich (1977) has re-evaluated the depositional environment as follows:

> *A wide variety of structures and interbed contacts suggest a combination of depositional mechanisms were responsible for sediment emplacement. The primary transportational mechanisms were by suspension settling and traction at Carlsbad, by grain flow and grain-fluidized flow at La Jolla, and by grain flow and suspension settling at Point Loma. The rocks of the Point Loma Formation have tabular geometry characterized by channels up to 200 meters wide, generally increasing grain size and standard sandstone: shale ratios from base to top, displaced shallow water fossils and associated alluvial fan and proximal submarine fan facies. Comparison with modern depositional systems indicate that the Point Loma Formation is composed of prograded sediments deposited at Carlsbad in the shelf transition zone, and at La Jolla and Point Loma in the oxygen-poor, bathyal depths of the upper-middle zone of a prograding submarine fan.*

Kern and Warme (1974) studied the trace fossils of the Point Loma Formation and also concluded that the formation was deposited in bathyal depths by grain-flow and pelagic processes.

Other relevant studies include the micro-fauna of the strata at Letterbox Canyon (Carsbad) by Liska (1964); a study of the Coccoliths in the Point Loma and La Jolla localities by Bukry and Kennedy (1969); a description of the Upper Cretaceous ostracodes from Cañon Del Morro (southeast of Rosarito Beach) by Holden (1970); a discussion of Cretaceous nannoplankton from the San Diego region by Wilson and Lipps (1970); and notes on the biostratigraphy of the Rosario Formation in northwestern Baja California (Mickey, 1970).

CABRILLO FORMATION

This is a massive sandstone and conglomerate unit of Maestrichtian age exposed on the southern tip of Point Loma, along the east side of Point Loma, in the La Jolla-Mount Soledad area, and west of Palomar Airport. The maximum measured section is 170 meters near False Point (Kennedy and Moore, 1971).

Jones (1973) concluded that the formation was deposited below wave base on a steep slope similar to the Recent La Jolla submarine fan and fan valley. Jones found that small-scale, cross-stratification, convolute bedding, flame structures, imbricate clasts, and channels indicate slope and current transport from the southeast at Point Loma and from the north at La Jolla.

The following descriptions of Cabrillo Formation sandstone and conglomerate are from Jones and Peterson (1973):

Sandstones

> *Two types of sandstone are distinguished in the field; 1) thin-bedded sandstone rhythmically alternating with mudstone, and 2) massive sandstone. The two types are associated and in many places grade from one type to the other. Both types are texturally submature and compositionally similar. According to the Folk classification (1968) the interbedded sandstones are predominantly fine- to medium-grained submature micaceous lithic arkoses whereas the massive sandstones range from fine-grained lithic arkoses to medium- and coarse-grained submature feldspathic litharenites.*

Table 1. Percentage of framework grains in sandstones from the Cabrillo Fromation at La Jolla and Point Loma. Modified after Jones (1973, table 2).

Mineral	Percent
Quartz	
Monocrystalline	28
Polycrystalline	7
Feldspar	
Perthite	4
Microcline	1
Orthoclase	5
Plagioclase	14
Rock Fragments	
Plutonic	2
Volcanic	9
Metamorphic	7
Mica	
Biotite	13
Muscovite	3
Miscellaneous	3
Carbon Fragments	4

Clast Type	Percent
Plutonic Rocks (39%)	
Granite	3
Syenite	1
Quartz Monzonite	9
Monzonite	3
Granodiorite	11
Quartz Diorite	6
Diorite	1
Gabbro	4
Aplite	1
Metavolcanic Rocks (39%)	
Rhyolite	1
Quartz Latite	1
Dacite	1
Andesite	20
Basalt	14
Tuff	1
Tuff Breccia	1
Metasedimentary Rocks (11%)	
Quartzite	8
Meta-arkose	2
Meta-conglomerate	1
Metamorphic Rocks (10%)	
Hornfels	4
Slate	2
Schist	2
Gneiss	2
Mudstone Clasts	3

Table 2. Composition and relative abundance of conglomerate clasts from the Cabrillo Formation at La Jolla and Point Loma. Modified after Jones (1973, table 3).

Average composition of the framework grains is tabulated in Table 1. The major components include quartz, feldspar, and rock fragments. Mica and carbonaceous material are common, and clay usually constitutes less than 5 percent of the rock. Accessory minerals include sphene, andalusite, sillimanite, garnet, hornblende, augite, and spinel. The individual grains are angular to subangular and are set in calcite cement.

Clearly the mineralogy of the Cabrillo sandstones indicates a mixed plutonic, volcanic, and metamorphic source terrane. The Peninsular Ranges to the east are made up of the Santiago Peak Volcanics (a mildly metamorphosed andesitic volcanic and volcaniclastic rock unit, the Julian Schist (metamorphic rocks of higher grade) and the Southern California batholith (a complex of intrusive and metamorphic rocks which ranges from granite to gabbro in composition). Hanna (1926), Larsen (1948), Merriam (1958), and many others have described these source rocks and their contained mineralogy in detail. The mineralogy of the Cabrillo sandstones is fully compatible with such a source terrane.

Conglomerates

Polymictic conglomerate units occur throughout the Cabrillo Formation. Representative outcrops are found in La Jolla in the sea cliff between Bird Rock and False Point and near the southern *end of Point Loma. At most outcrops the conglomerate is poorly sorted with clasts ranging in size from less than an inch to 10 feet in diameter.*

The clasts are grouped into three categories: 1) metamorphic rocks including gneisses, metavolcanic and volcaniclastic rocks, hornfels, and metasedimentary rocks, 2) plutonic rocks ranging in composition from granite to gabbro, and 3) mudstone and interbedded mudstone-sandstone rip-up clasts. A detailed clast identification was made for 1000 clasts obtained from outcrops of the Cabrillo conglomerates in La Jolla and Point Loma; the results of the identifications together with the approximate percentages of the different rock types is included in Table 2.

The Santiago Peak volcanics are a complex assemblage of andesitic flows, breccias, and tuffs, all of which have undergone low grade metamorphism (Hanna, 1926; Larsen, 1948). Less abundant rock types include metarhyolite, metaquartzlatite, metadacites, metabasalts, and a variety of immature metasedimentary rocks. All of these rock types are represented by clasts in the Cabrillo conglomerates and in roughly the same proportion as in the Santiago Peak Volcanics.

The plutonic rock clasts in the Cabrillo conglomerates range from granite to gabbro but are predominantly intermediate in composition. Description of the plutonic rocks of the southern California batholith together with the included higher grade metamorphic rocks (Merriam, 1946; Larsen, 1948; Engle, 1959; and many others) match, to a remarkable degree, the composition, variety, and proportions of plutonic clasts in the Cabrillo conglomerates.

The mudstone and interbedded mudstone-sandstone clasts are derived from two sources. Some of the clasts are derived from ripped-up mudstones within the Cabrillo Formation and are thus intraformational in origin. Others, particularly some of the larger ones strongly resemble the lithology of the underlying Point Loma Formation. A probable source within the Point Loma is indicated, although the mechanism whereby such clasts are derived from far down within the underlying formation is not fully understood at this time.

By an analysis of the sandstone and conglomerate petrology Peterson and Jones conclude that the Cabrillo Formation lacks rock types characteristic of continental borderland sources, bears no resemblance to the Poway suite of clasts (characteristic of Eocene conglomerates in the San Diego Area), and is entirely consistent with a local provenance in the granitic and metamorphic basement rocks of San Diego County.

POST-ROSARIO EROSION SURFACE AND PALEOSOL

A striking feature of the Peninsular Ranges of southern California and Baja California is the ancient surface which caps even the highest portions of the range (Gastil, 1961; Gastil and others 1975; Lower, 1977). The crystalline rock underlying this old surface is commonly decomposed to depths of 25 to 50 meters. Deposits of the Eocene Ballenas Gravels (Minch, 1973) are concordant with or slightly incised into the surface.

In a number of places where rocks of Cretaceous and older age lying beneath this ancient surface have been protected by overlying strata of Eocene age, we see, not only deep decomposition in the older rocks, but the preservation of a laterite type paleosol. Perhaps the best preserved exposures are those mapped by Flynn (1970) along the divide between Arroya Rosarito and Valle Cuero De Venado, southeast of Tijuana. Peterson, Pierce and Abbott (1975) describe this locality as follows:

> *Here the paleosol is developed on granodiorite. The total profile exceeds 100 feet in thickness. The lower portion grades from unaltered granodiorite to spheroidal boulders of granodiorite, separated by grus, to progressively more weathered grus horizons 50 feet thick and consists entirely of kaolinite, quartz, and minor amounts of iron oxide. It is severely depleted in all soluble compounds (Abbott and others, 1976). There is no evidence of a zone of accumulation. It is overlain by middle Eocene marine sedimentary rocks [Delicias Formation; Flynn, 1970].*

In the area east of Carlsbad (Wilson, 1972) paleosol development can be seen on the granitic basement rock (just southeast of Calaveras "crater"), on the Santiago Peak metavolcanic rock (in a field across the canyon to the southwest of Calaveras "crater," and on the Lower Maestrichtian Cabrillo Formation (Peterson and Abbott, 1975) just northwest of Palomar Airport. The description of this locality by Peterson and Abbott includes the following:

> *In the west pit of the Pacific Clay Products Company, the upper part of the Cretaceous rocks are severely weathered to the extent that their original character is almost totally obliterated. However, careful observation of the relict texture in some of the less altered portions indicates that the parent rock was dominantly a granule to small boulder conglomerate. Most of the clasts are altered to the extent that they no longer retain their original mineralogy or individual character, but rather resemble well-rounded ovoid to spherical "ghosts" in outcrop and differ from one another only in subtle shades of color. Only some extremely resistant clasts, such as quartz, quartzite, and highly silicified tuffs, are locally well preserved, but they form only a minor part of the total clast population. Although the original rock types cannot be deciphered in most cases, we interpret the total population of clasts to belong to the Peninsular Ranges suite characteristic of Cretaceous conglomerates (Peterson, 1970). Poway clasts are not present. A Poway clast, if severely altered, might be reduced to clay, but the clay would have residual quartz grains. The altered clasts near Palomar Airport have none. Thus we interpret these highly altered conglomerates at the top of the section to be the Cabrillo Fm. of latest Cretaceous age.*
>
> *In the eastern quarry (or east pit), the clay rich upper part of the Point Loma Fm. is exposed in the deepest part of the pit. We regard this as partially decomposed Point Loma, and thus would place it either in the C profile of the paleosol or consider it to be largely unaltered parent rock. Above this horizon is the main level of the quarry. Outcrops are poor as this was the level of mining and the pit is largely depleted of the kaolinite portion of the paleosol. However, small outcrops of reddish-mottled, white kaolinitic*

there is an overlying residual cap of ironstones, small siliceous pebbles and quartz sand. The maximum A horizon thickness is 10-15 feet.

The A horizon sample contained only two minerals: quartz and kaolinite (B axis disordered form). Regardless of whether the parent rock was the mudstones of the Point Loma Fm. or the conglomerates of the Cabrillo Fm., the units were so weathered in the A horizon of this profile that they yielded only the two minerals plus scattered blotches and small nodules or ironstones.

The residual cap over the A horizon consisted of a mixture of quartz, hematite, goethite, and a small percentage of magnetite. Possible clay minerals and aluminum oxides are also present, but their quantity is probably minor as their peaks did not project out from the background noise of the X-ray pattern.

The age of the paleosol on the old erosion surface in northern Baja California and San Diego County is post-Lower Maestrichtian (Cabrillo Formation) and older than the lowest Eocene strata (Delicias and Del Mar Formations). The Delicias and Del Mar have both been assigned to the Middle Eocene (Flynn, 1970; Kennedy and Peterson, 1975). The basal Mount Soledad Formation of the La Jolla group has been assigned to the Ypresian Stage (Lower Eocene), but has not been mapped in contact with the paleosol. In Riverside County (Woodring and Popenoe, 1954) the Lower Paleocene lower member of the Silverado Formation overlies a surface of deep decomposition on upper Cretaceous siltstones.

We believe then, that the rugged range of Mesozoic crystalline rock which shed the locally derived clasts of the Turonian (?) Lusardi Formation and the Lower Maestrichtian Cabrillo Formation, had become a very worn down surface by Paleocene time, still dotted by mountains but crossed by extensive drainages which (as you will see in the pages to come) probably reached eastward into central Sonora.

Peterson, Pierce and Abbott (1975) derive the following climatic implications:

The development of the pre-Eocene lateritic paleosol implies that a warm, humid, tropical climate existed during its formation. Modern laterites are predominantly located within 20 degrees of the equator in the western hemisphere, within 15 degrees of the equator in Africa, and mostly within 30 degrees of the equator in the Asia-Indonesia-Australia region (McNeil, 1964). We interpret the Late Cretaceous-Paleocene-Early Eocene paleoclimate to be similar to that of the modern equatorial belt. Rainfall probably exceeded 50 inches per year and the average annual temperature was probably in the vicinity of 20-25° centigrade (Maignien, 1966). A lush rainforest type of vegetation probably predominated. claystone are locally evident. Above the kaolinitic horizon, which is about 6' thick, is a residual cap consisting largely of ironstone concretions and some minor amounts of small resistant siliceous pebbles and quartz sand. We regard the kaolinitic horizon as the A horizon of the profile. The B horizon is not evident; either it is not exposed or is very poorly developed. We might add that B profiles in many lateritic soils are poorly developed and that it is likewise poorly developed in the paleosol south of Tijuana (Abbott et al., 1976). The residual cap probably represents a concentration of plinthitic ironstones together with admixtures of Eocene and possibly

Pleistocene sediments.

Exposures of the A horizon are much better in the west pit. The C horizon and parent rock are not exposed. The A horizon here varies from bright white to moderate red to dark reddish brown to gray and grayish red, purple mottled whitish outcrops. Close inspection of some of the less weathered portions revealed that the parent rock was dominated by conglomerate, and we would interpret the A horizon here to be developed on the Cabrillo Fm. As in the east pit,

LA JOLLA GROUP

The ages and depositional relationships between the Eocene formations of the San Diego area are indicated by Kennedy and Peterson in their 1975 diagram (Figure 8).

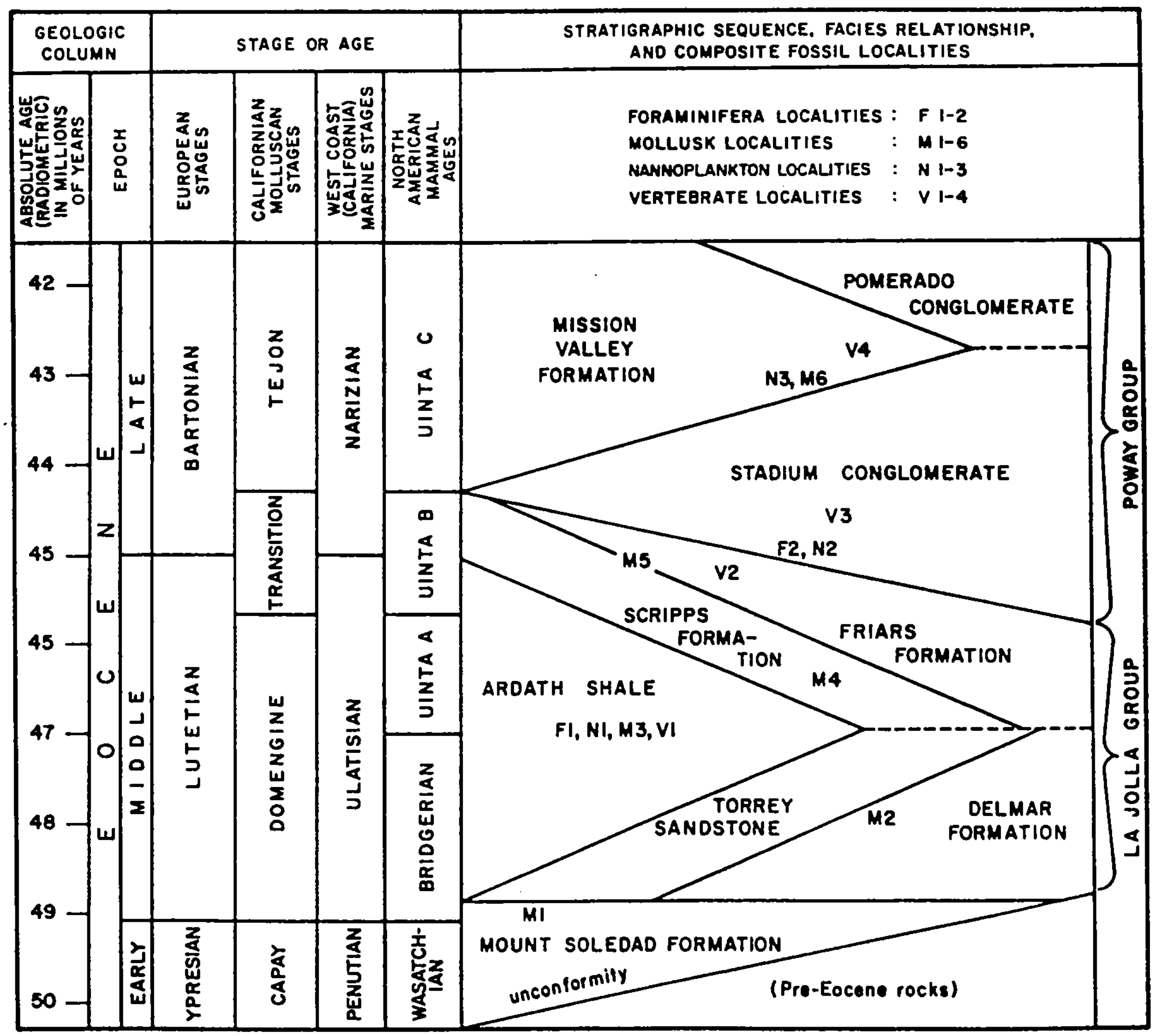


Figure 8 (from Kennedy and Peterson, 1975). Relationship of biostratigraphy to lithostratigraphy in the Eocene rocks of the San Diego area.

They visualize the La Jolla Group as a transgressive regressive triplet of open marine, bar-nearshore shelf, lagoon facies along a steadily submerging coastline. The Mission Valley Formation of the Poway Group is regarded as a second cycle of transgression and regression by the nearshore shelf facies.

Mount Soledad Formation

Kennedy and Moore (1971) designate the type section as a natural ampitheater 400 m west of the intersection of Ardath Road and Interstate 5 (just east of the cross on top of Mount Soledad). At its type section it is 70 meters thick and consists almost entirely of cobble conglomerate.

Delmar Formation

The type section is at a short canyon 2 km south of the Del Mar railroad station and the total section is estimated to be 60 m (Hanna, 1926). Kennedy and Moore (1971) describe the formation as "dusky-yellowish-green sandy claystone interbedded with medium-gray, coarse-grained sandstone...with...hard layers composed almost entirely of *Ostrea idriaensis* Gabb and other brackish-water mollusks."

Torrey Sandstone

The type locality is along Torrey Pines Grade where the old Coast Highway climbs from Sorrento Valley through Torrey Pines State Park. The maximum thickness is approximately 60 m (Kennedy and Moore, 1971). Williams (1972) summarizes the Torrey Formation as follows:

> *The Torrey Sandstone within the Del Mar Quadrangle can be divided into five subfacies on the basis of sedimentary structures. Gradationally underlying the Ardath Shale is subfacies A which is characterized by almost parallel, gently southwestward dipping lamina and thin beds. This subfacies rests diasiemically on the Delmar Formation and was probably deposited in upper foreshore to shallow neritic environments. Gradationally underlying subfacies A to the northeast is subfacies B. Subfacies B, which was probably deposited as backshore, beachridge and berm deposits, is characterized by much irregularity of structure and grain size with a trend toward northeastward dips. To the north, subfacies C, characterized by abundant small scale cross-lamination, intervenes between subfacies B and the Delmar Formation. Subfacies D is characterized by tabular fining upward sequences and by large channels. Bimodal cross-bedding and oyster fragments attest to the tidal origin of the channels. Subfacies E is characterized by large scale tabular sets of cross-beds and probably formed in a tidal inlet environment.*
>
> *The association of environments, indicated by the subfacies, is compatible with a northwest or north-northwest trending barrier beach complex. The relationship between the Delmar Formation and subfacies A, B and C indicates transgression with some subsidence followed by a suddenly accelerated rate of subsidence or rate of deposition. The volumetric dominance of rocks deposited in tidal channels and tidal inlets is due to the nature of the transgression and the relative preservation potentials of the deposits involved.*

Ardath Shale

The type section of the Ardath Shale is the east side of Rose Canyon, 800 m south of the Ardath Road intersection with Interstate 5, with an estimated thickness of 70 m (Kennedy and Moore, 1971). They describe it as uniform, weakly fissile, olive gray silty shale with the upper part containing thin beds of medium-grained sandstone similar to thicker ones in the overlying Scripps Formation, and concretionary beds with molluscan fossils.

Scripps Formation

The type section is on the north side of the mouth of Blacks Canyon, about 1 km north of the Pier at Scripps Institute and consists of 67 m of pale yellowish brown medium-grained sandstone, 1 to 5 m cobble conglomerate beds, and several siltstone interbeds near the base (Kennedy and Moore, 1971).

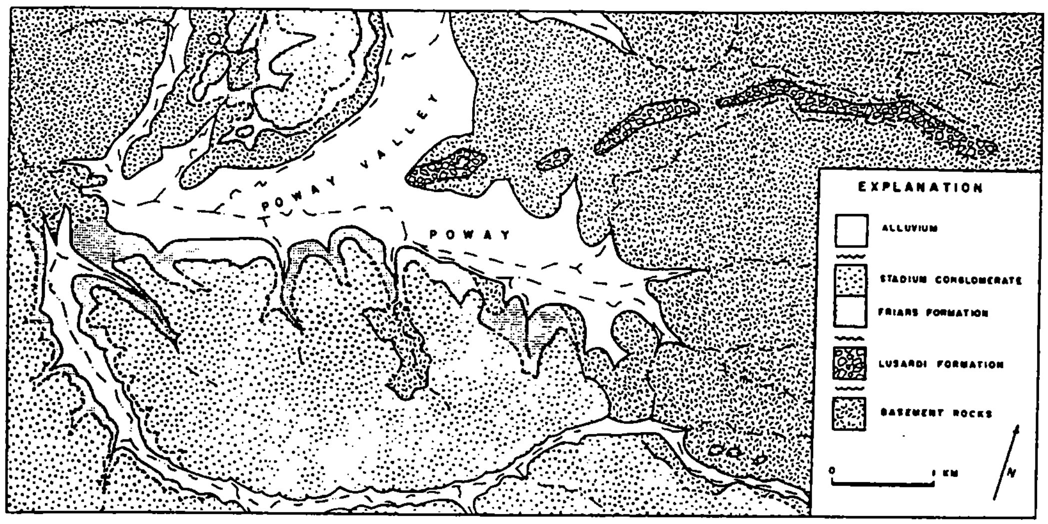


Figure 9 (from Peterson, 1971). Geologic map of the Poway area.

Friars Formation

The type section is on the north wall of Mission Valley just below San Diego University High School where it is 35 m thick (Kennedy and Moore, 1971). They describe the formation as a "yellowish-gray, medium grained, nonmarine friable sandstone containing several dark greenish-gray sandy claystone beds."

Fink (1976) reported:

> *At all sites observed by the author the Friars Formation is made up of a lower muddy unit and an upper sandy unit. The lower unit is a green to greenish-gray and reddish-brown fine sandy mudstone which exhibits popcorn weathering. The mudstone grades upward within a few centimeters into the overlying white to gray muddy fine sandstone. Mudstone lenses up to 20 m long and 3 m thick are present in the upper sandy unit.*

The Friars Formation appears in some localities to be gradational upward into the Stadium Conglomerate of the Poway Group. It extends much further inland than any other formations of the La Jolla Group and at many localities it rests on a high relief crystalline basement surface (Peterson, 1971).

FORMATIONS EQUIVALENT TO THE LA JOLLA GROUP SOUTHEAST OF TIJUANA

Flynn (1970) described the Eocene strata south of the international boundary:

> *The Delicias Formation, which rests unconformably on the Rosario Formation and older rocks, includes a lower mudstone member, at least at its type locality, and an upper sandstone member. Approximately 40 meters of greenish mudstones and siltstones with interbedded thin sandstone beds and locally concentrated conglomerates occur in the lower mudstone member in the type area of the Formation. The upper sandstone member consists of a 50 meter succession of brown to tan, fine- to medium-grained, yellow-weathering sandstones with interbedded greenish mudstone and siltstone.*
>
> *Fossil beds are common in the sandstone member where characteristic species are:* Ostrea *sp.*, Potamides carbonicola, Scolimytilus *sp.*, *and* Pelecyora *sp. (San Diego State College fossil locality 181). This association indicates a restricted marginal marine (? brackish) depositional environment comparable to that represented by the Delmar Sandstone of the La Folla Formation.*
>
> *The Buenos Aires Formation is separated by an angular unconformity from the underlying Delicias Formation. A 70 meter thick conglomeratic lower member contains cobbles and boulders of quartzite, porphyry, volcanic breccia, dacite, and granitic rocks in a matrix of brown to tan sandstone and sandy mudstone. An overlying 60 to 80 meter thick arenaceous member includes white to tan sandstones which grade laterally into brown sandstones and mudstones. Concretionary sandstone beds are common throughout the section.*
>
> *An abundant but poorly preserved molluscan fauna occurs in upper sandstones of the Buenos Aires Formation north of Rancho Delicias.* Tellina soledadensis *Hanna*, Turritella uvasana applinae *Hanna*, Ficopsis remondii crescentensis *Weaver and Palmer, and* Ectinochilus macelentus *(White) are among the species recognized in that fauna. This is a Middle Eocene assemblage which occurs in Hanna's (1926) Rose Canyon Shale Member of the La Jolla Formation and in equivalent sections further north.*

It is important to note that the conglomerate clast population is exotic, but different than that found in the Eocene strata north of the International Boundary.

POWAY GROUP

As defined by Kennedy and Moore (1971) and amended by Peterson and Kennedy (1974) the Poway Group consists of three interfingering formations, in sequence: the Stadium Conglomerate, the Mission Valley Formation, and the Pomerado Conglomerate. The Ballenas Gravels (Fairbanks, 1893; Minch, 1972) are an eastward fluvial correlative of the conglomerates of this Group.

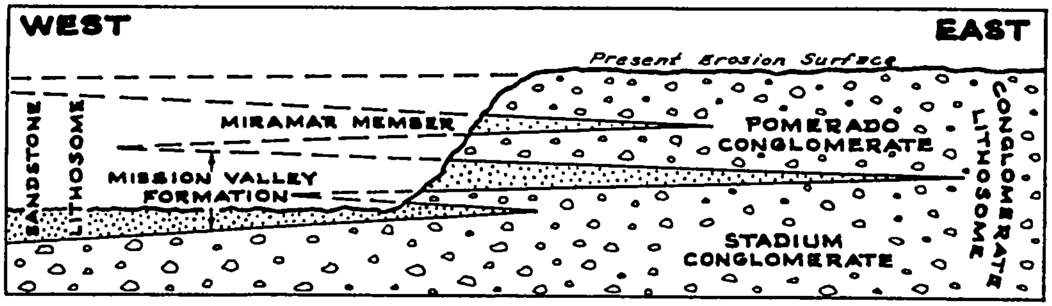


Figure 10 (from Peterson and Kennedy, 1974). Generalized diagram of relationship between sandstone lithosome (Mission Valley Formation and Miramar Sandstone Member of the Pomerado Conglomerate) and conglomerate lithosome (Stadium Conglomerate and Pomerado Conglomerate).

Stadium Conglomerate (after Kennedy and Moore, 1971)

The type section is on the north wall of Mission Valley, about 1 km west of Murphy Canyon Road (State 15). It begins at Friars Road and continues northwestward to the rim of the valley. At its type locality it is chiefly a cobble conglomerate. The matrix is a rather friable dark yellow-brown, coarse-grained sandstone. Similar sandstone occurs as scattered crossbedded lenses averaging 5 m long and 1 m thick.

Mission Valley Formation (after Kennedy and Moore, 1971)

The type section is along the south wall of the valley on the west side of Route 163 at its intersection with Interstate 8. Here, it is 58 m thick and largely composed of friable, light olive-gray, fine-grained sandstone containing several half-meter concretionary layers containing molluskan fossils. A greyish-red sandstone layer containing silicified wood is present near the middle of the formation. The top third of the formation contains several thin beds of pebble and cobble conglomerate.

The formation is laterally equivalent to both the Stadium and Pomerado Conglomerates, and Peterson and Kennedy (1974) recognize a Miramar Member within the Pomerado Conglomerate (see Figure 10).

The formation has been studied in detail by Jones (1973). Excerpts after Jones' description of the 30 m section at Collwood and Montezuma Road are as follows:

> *The section consists primarily of medium- to fine-grained, poorly to moderately sorted feldspathic litharenite. Some of these sandstones have framework grains cemented by calcium carbonate whereas others consist of framework grains and protomatrix. The framework grains consist of 57 percent quartz, 15 percent feldspar (two-thirds plagioclase, one-third potassium feldspar), and 28 percent lithic fragments. The lithic fragments are 70% fine-grained volcanic (devitrified) rocks; 17% are acid plutonic rocks; 1.2% sedimentary rocks; and 1.2% schistose metamorphic rocks.*

Jones also describes muddy sandstone units, reddish purple and brown colored sandstone units, and paleosol horizons.

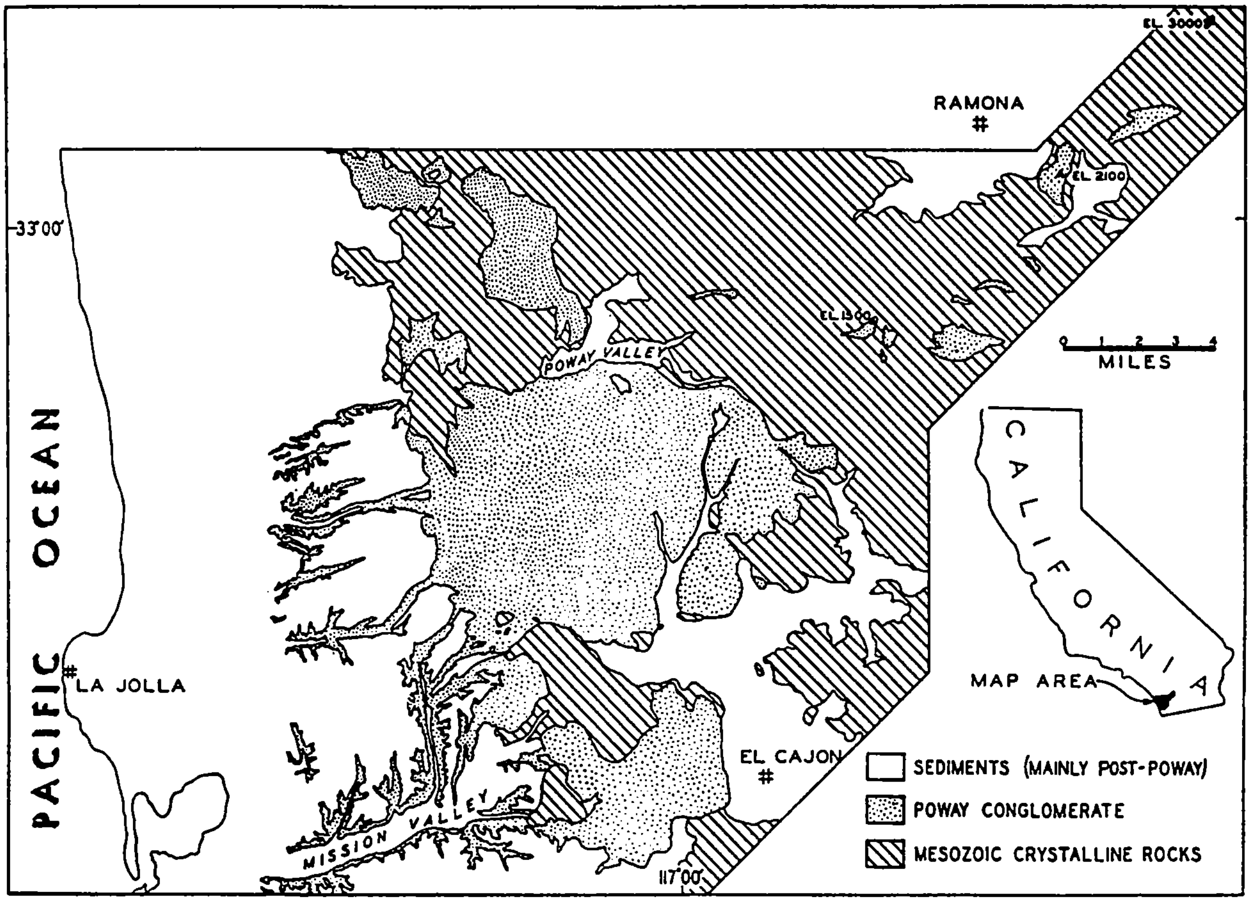


Figure 11 (after Bellemin and Merriam, 1958). Geologic map showing distribution of the Poway Group conglomerates.

Pomerado Conglomerate (after Peterson and Kennedy, 1974)

The type section is located along the roadcuts of Pomerado Road and Sycamore Canyon access road between San Diego and Poway. It is gradational with the underlying and interfingering Mission Valley Formation and consists of Poway-type conglomerate and lenses of medium-grained, soft, friable sandstone resembling that of the Mission Valley Formation.

Basin Analysis of the Poway Group

The following is the abstract of an as yet unpublished paper by Howell and Link:

Eocene conglomerate strata in the San Diego area were deposited as a narrow, west-trending progradational system that changed facies from fluvial channel, to alluvial fan, to coastal plain-fan delta, to paralic, to shelf and sub-sea channels. Continuing this system westward are the large Eocene sub-sea fan deposits that include inner, middle, and outer subfan and basin plain facies of the southern California borderland. In all environments 81 to 96 percent of the conglomerate clasts are distinctive, well-rounded, siliceous, metavolcanic stones (Poway clasts) that range up to 60 cm in size and average 6 cm; 2 to 13 percent *are quartzite; and 0 to 12 percent are locally derived, Peninsular Ranges, crystalline basement (granitic and volcanic) rocks that decrease rapidly in size and abundance from east to west. The composition, shape, and average size of the metavolcanic and quartzite clasts are constant in all environments, while the less resistant granitic clasts show the effects of progressive abrasion with increased transport distances.*

Three major sedimentologic trends characterize the Eocene conglomerate: (1) There is a uniform decrease in conglomerate abundance and thickness with a corresponding increase in finer-grained strata from east to west. (2) The non-marine and shallow marine conglomerate facies have both organized and disorganized beds, with no grading. The clasts are framework-supported, imbricated, and dip up-current. The long axes of the clasts are oriented perpendicular to the paleoflow or distributed randomly. Associated sandstone beds contain caliche horizons and are generally crossbedded. (3) The deep-water marine conglomerate is generally organized and the beds are normal to inverse graded. The clasts are matrix-supported, imbricated, and dip up-current. Long axes of clasts are oriented both parallel and perpendicular to paleocurrent trends, and angular, mudstone, rip-up clasts and reworked marine fossils are included in the clast populations.

The Poway Group conglomerate extends as far northwest as Rancho Santa Fe where it is only 8 m thick (Kennedy and Moore, 1971) and as far south as Encanto (Kuper and Gastil, 1977; Kennedy, 1977) where the base is not seen. The apex of the fluvial delta was north of Lakeside near the Tri-Way quarry. Northeast of this point we find discontinuous patches of conglomerate left by the feeder river. The map by Bellemin and Merriam (1958) shows these deposits extending to an elevation of 3000 feet about seven miles northeast of Ramona. Another deposit probably belonging to this river course was found by Sharp (written communication, circa 1970) east of the Elsinore fault and south of Borrego Valley.

Minch (1974) has remapped these deposits and compared them with the other exotic clasts deposits on the elevated erosion surface and with possible source areas in Arizona and Sonora. In 1974 Minch wrote as follows:

Several river courses are defined by the distribution of the gravels (Fig. 12). They are from north to south referred to here as (1) the Santa Rosa River, (2) the Ballenas River, (3) the Jacumba River which joins with (4) the La Rumorosa-Las Palmas River, (5) the Campo Nacional River and (1) the El Rodeo River. Cobble imbrication studies of these gravels have indicated a western to southwestern direction of transport for the Ballenas, Jacumba, La Rumorosa-Las Palmas, and El Rodeo Rivers.

The composition of the gravels in each river is somewhat different. The Santa Rosa River has not been studied in detail; however, it does contain reddish rhyolite to dacite porphyries and quartzites. The Santa Rosa, Ballenas and La Rumorosa-Las Palmas Rivers all contain greenish epidotized meta-volcanic and epiclastic meta-sedimentary clasts similar to the Santiago Peak Volcanics plus quartzites and "Poway type" reddish rhyolite and dacite porphyry clasts. The Jacumba River contains the greenish epidotized meta-

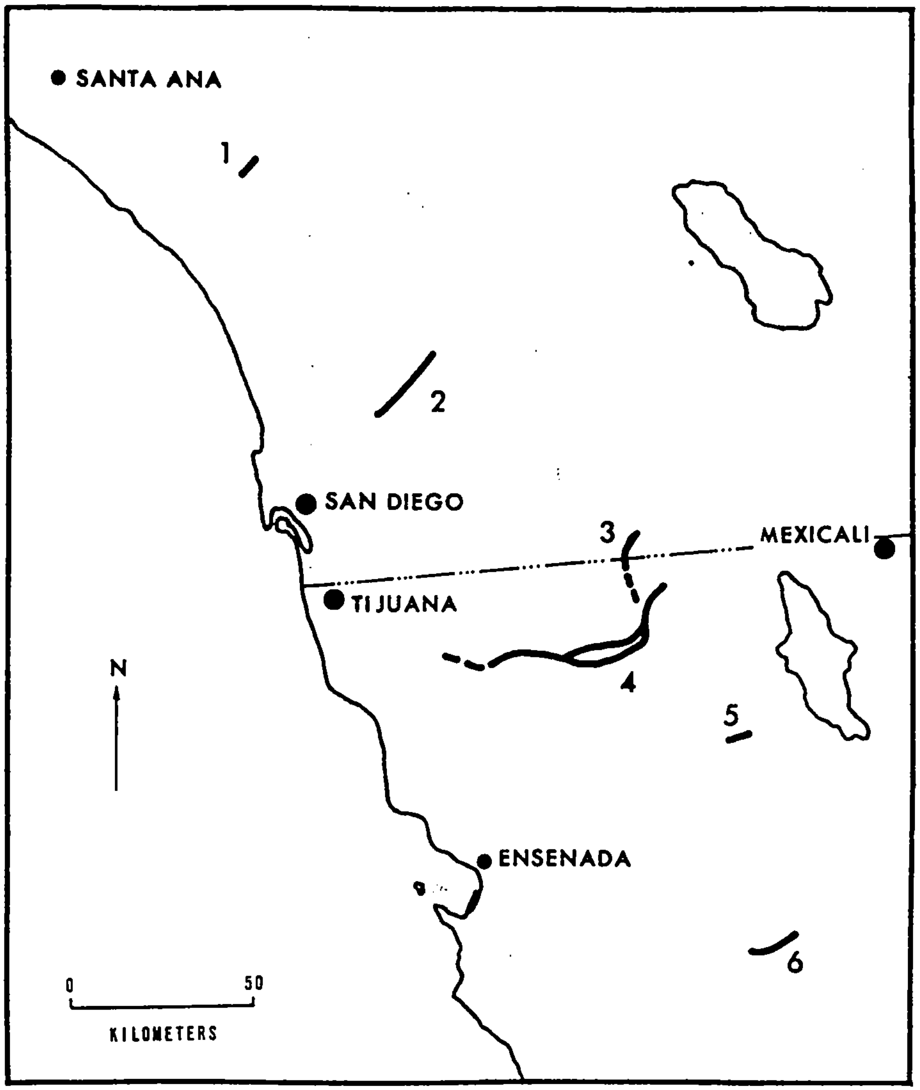


Figure 12 (after Minch, 1970). Early Tertiary paleography of a portion of the Peninsular Range. (1) Santa Rosa River, (2) Ballenas River, (3) Jacumba River, (4) La Rumorosa-Las Palmas River, (5) Campo Nacional River, (6) El Rodeo River.

volcanic and meta-sedimentary clasts, quartzites, and an abundance of granitic clasts. However, it contains no "Poway type" clasts. This assemblage is similar to that of the upper Cretaceous conglomerates in the San Diego area. The Campo Nacional and El Rodeo Rivers contain an entirely different suite of clasts which include gray to black quartzites, cherts, slates, argillites, gneisses and green-chlorite schists.

Lillegraven (1973) has made extensive investigations of the Eocene vertebrate fauna near San Diego. He writes that the fauna and associated plants indicate a less lagoonal environment for the Friars Formation and a less marine environment for the Mission Valley Formation than indicated by Kennedy and Moore (1971).

EOCENE CLIMATE

Peterson and Abbott (1977) find that the depositional framework, the character of deposits, and the pre- and post-depositional weathering of the clasts point to a semi-arid climate during the later Eocene. In regard to the deposition environment they write:

> *The finer grained body of rock (represented by the Friars and Mission Valley formations together with finer grained tongues within the principal conglomerate units) is intricately interfingered with the conglomerates, which is interpreted as overbank accumulations along main channel systems and also as back-fillings of tributary stream valleys leading down the main river system (Peterson, 1971; Peterson and Kennedy, 1974). In addition, the westernmost portions of the Friars Mission Valley formations contain some shore marine rocks probably deposited in distal delta bar and strandplain environments.*
>
> *The geometry of the coarse conglomerate rock unit together with the manner in which it is intertongued with the finer rocks suggests two major pulses of gravelly debris that built two major alluvial fan complexes. The total character of this type of depositional environment strongly implies semiarid to arid paleoclimatic conditions during sedimentation.*

Regarding the caliche:

> *The Upper Eocene nonmarine section contains numerous beds, lenses and nodules greatly enriched in calcium carbonate (Pierce and Peterson, 1975). These accumulations are absent in the marine Eocene formations. The carbonate rich layers and nodules contain up to 80% calcite; they characteristically also contain detrital sand grains and clay minerals scattered throughout the calcite. In outcrop the carbonate-rich layers typically are massive, soft, white and friable. They range in thickness from a few centimeters up to one meter. The calcium carbonate beds and nodules are interpreted as parts of differentially developed ancient soil horizons. These caliche-bearing paleosols are of the same age as the host formation inasmuch as they follow stratification. In contrast, Quaternary caliches in the San Diego area conform to the modern topography (Pierce, 1974; Pierce and Peterson, 1975).*

And in summary:

> *The total character of the nonmarine Eocene deposits of southwestern California and northwestern Baja California indicates a semiarid climate during deposition. Specifically, the caliche-bearing paleosols, the immature vermiculite-smectite-chlorite-illite clay mineral suite, the long-distance transport and ultradurable character of the coarse Eocene conglomerates, and the* in situ *salt-fractured clasts all imply conditions of aridity. Taken together, and coupled with the absence of humid paleoclimate indicators, the case for a semiarid paleoclimate becomes even stronger.*
>
> *The caliche in particular is a good paleoclimate indicator inasmuch as modern caliche forms only in arid and semiarid climates (Leeder,*

1975; Birkeland, 1974; Hunt, 1972). Steel (1974) concluded that caliche would not form in areas that have in excess of 63 cm of rainfall per year and that a strongly evaporative dry season would probably be essential. Based on the sea surface temperatures during late Eocene time (Savin et al., *1975), we estimate that the average annual Late Eocene temperature would probably be at least slightly higher than the present temperature (16°C); we estimate 18-20°C. This relatively high annual temperature suggests that the thick caliche beds formed under rainfall conditions nearer to the maximum for caliche formation. Our estimate is about 50-60 cm per year. The latitude (ancient or modern) implies that most of the rainfall occurred in the winter months, as at present.*

The semiarid interpretation for the later Eocene deposits is not particularly surprising inasmuch as the Eocene paleogeography is much the same as the modern. Deposition occurred close to sea level, the mountains to the east were not very high, and to the west was the unobstructed Pacific Ocean (Clark et al., *1975; Howell, 1975). The climate was warmer and probably had a higher annual rainfall but otherwise was much like the modern. However, the later Eocene climate contrasts markedly with the humid tropical climate present in the Paleocene-Early Eocene interval and indicates a pronounced climatic change occurred at about mid-Eocene time.*

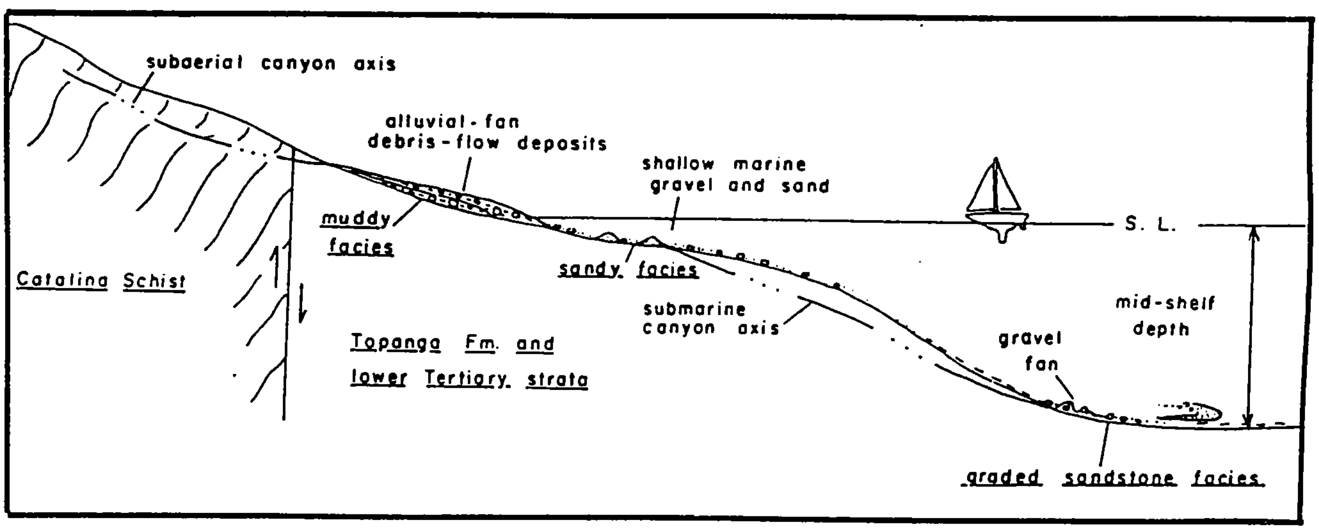


Figure 14 (from Stuart, 1975). Model showing the distribution of depositional environments characteristic of the three lithofacies of the San Onofre Breccia exposed in the Laguna Beach area.

DISTRIBUTION OF MIOCENE STRATA

It is uncertain whether Oligocene of Miocene strata were ever deposited in west-central San Diego County, if so they were removed before the deposition of the late Pliocene San Diego Formation. Miocene strata are preserved in northern and southern San Diego County and on the continental borderland to the west.

SAN ONOFRE BRECCIA

This Miocene formation extends as far south as Oceanside and its close correlative has been long recognized in the Los Coronados Islands (Woodford, 1925; Emery and others, 1952). Although we will not reach it on our field trip we include as a sidetrip a locality chosen by Moore (1972) (Figure 13).

Stuart (1974) describes this formation as follows:

The San Onofre Breccia has been subdivided in this study into three lithofacies distinguished on the basis of breccia and conglomerate matrix types, bedding characteristics, gross lithology, and mappability. These lithofacies are: (1) the graded sandstone facies, *(2) the* sandy facies, *and (3) the* muddy facies. *Mappable subdivisions of the three principal lithofacies can be recognized locally.*

Table 3 - Lithofacies of the San Onofre Breccia (from Stuart, 1974)

I.	<u>Muddy facies</u>:	red-brown and gray, mud-matrix breccia beds characterized by inverse grading and very poor matrix sorting; pebble- to boulder-size clasts; thin intercalations of calcareous, laminated sandstone; tuff and tuffaceous sandstone; rarely fossiliferous in laminated sandstone beds.
	Camp Pendleton area	Gray unit: as above, with gray matrix color. Red-brown unit: as above, with red to red-brown color.
II.	<u>Sandy facies</u>:	massive or crudely graded, gray, calcareous, sandy breccia and conglomerate; commonly with cross bedded, gray, calcareous, conglomeratic sandstone; fossiliferous
	Main outcrop area	Upper unit: very limey pebble to cobble conglomerate and conglomeratic sandstone; some intercalated mudstone. Lower unit: calcareous pebble to large boulder conglomerate and breccia, and conglomeratic sandstone; locally cross bedded.
III.	<u>Graded sandstone facies</u>:	gray, calcareous, graded sandstone; calcareous, massive and graded conglomeratic sandstone; massive and graded breccia-conglomerate and breccia with sandy, calcareous matrix and pebble- to boulder-size clasts; mud-matrix sandy breccia-conglomerate; gray, sandy mudstone; fossiliferous.

Sandy Facies

Sandstones and conglomerates in the upper unit of the sandy facies are both massive and layered. Imbricate clast fabrics and broken fossil fragments are present in some beds and pebble and sand sorting are moderately good. These characteristics are evidence that the sands and gravels were sorted, transported, and deposited by vigorous marine currents. The massive beds, however, may be resedimented current-deposited beds in which the previously formed structures and fabrics were disrupted.

Muddy Facies

The muddy facies consists primarily of muddy, inversely-graded breccia beds characterized by sharp, low-relief basal contacts, imbricate and open framework clast fabrics, and poor matrix sorting. These structures and textures are similar to those associated with the Recent debris-flow deposits at Wrightwood, California (Sharp and Nobles, 1953; Johnson, 1970). This similarity and the proximity shown by the muddy facies in the Laguna Beach sequence of lithofacies are evidence that the muddy breccias are probably subaerial debris-flow deposits. Sandy laminated and cross-bedded layers at the top of some muddy breccia beds are evidence that the debris-flow deposits were partly reworked after sedimentation by traction currents.

Debris flows are generated when muddy debris becomes water saturated and then mobilizes rapidly and flows downslope. These flows contain high concentrations of sediment, and typically move by laminar-flow mechanisms (see Johnson, 1970). High particle concentration and high fluid visposity and density give the flow shear strength; thus, when the shear stress within the flow is less than its shear strength, the debris solidifies. In this way the clast fabric and poorly sorted clast and matrix textures which formed during flow are preserved.

On the basis of associated fauna Stuart concludes that the muds were deposited in mid-neritic (mid-shelf) depths of water; beds of graded sandstone as a subaerial alluvial fan deposit; and the sandy facies as a near-shore marine deposit. In Figure 14 Stuart illustrates the sequence of facies: "Muddy alluvial fan deposits prograded into a marine basin where they were reworked by waves and currents, with the residual sands and gravels being deposited in shallow water (sandy facies). Some of these beds were mobilized and resedimented in deeper water."

One of the most significant features of the San Onofre Breccia and its correlatives on the Los Coronados and the Rosarito Beach Formation is the petrology of the clast population. Stuart summarized these rock types as follows:

Clast Types

Clasts within the sedimentary rocks of the San Onofre Breccia exposed on Camp Pendleton consist primarily of blueschist, greenschist, quartz schist, mafic plutonic rocks (saussurite gabbro of Woodford, 1925), amphibolite, serpentinite and related alteration rocks, vein rocks, and pre-San Onofre sandstone (see Platt, 1972 and 1973, for discussion of Catalina Schist rocks).

The blueschists are characterized by the high pressure minerals lawsonite, omphacite, and glaucophane. Lawsonite and omphacite, however, are the diagnostic minerals of the blueschist facies. These rocks also contain quartz, albite, green and colorless amphibole, and epidote, but not all of these minerals occur in equilibrium assemblages. Blueschists are typically fine-grained and most appear to be metamorphosed igneous rocks.

The greenschists are fine- and medium-grained rocks which consist primarily of quartz, muscovite, chlorite, epidote, green and colorless amphibole, and albite. Glaucophane, epidote, and albite

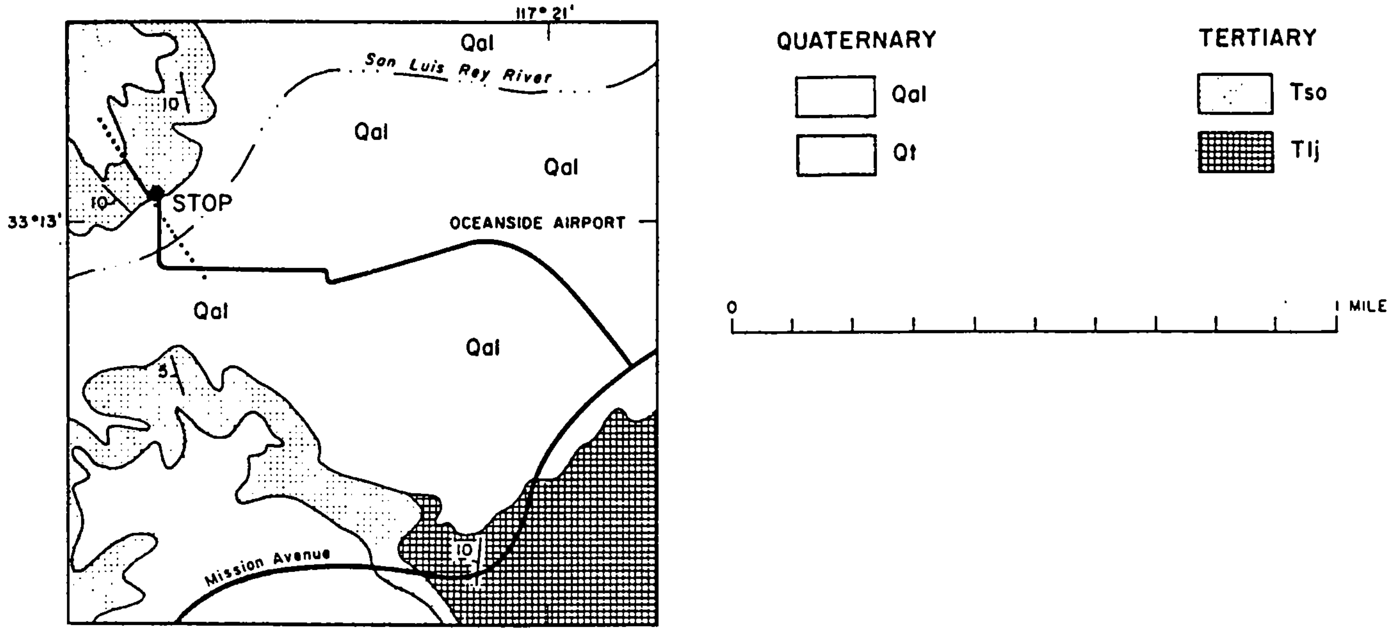


Figure 13 (from Kennedy and Moore, 1971b). San Onofre Breccia east of Oceanside. To reach this locality, turn from Interstate 5 east onto Mission Avenue (State 76). In 1.9 miles turn north onto Airport Road. In 0.7 miles turn left onto gravel road leading to St. Charles Priory high on the bluff; 0.4 miles reaches the exposure.

(lawsonite and omphacite are absent) are abundant in a massive to schistose blue rock termed glaucophanic greenschist by Platt (1973). Because diagnostic blueschist facies minerals are not present, it is grouped with the greenschists. Greenschists had both sedimentary and igneous origins.

Quartz schists are medium-grained, well-layered rocks that consist of quartz predominantly with laminae of muscovite and layered or scattered occurrences of glaucophane-crossite. Quartzose layers are commonly interlayered with greenschist facies albite-epidote-rich layers, some graphitic, which suggests a sedimentary origin for the rocks. They may have been bedded cherts.

Saussurite gabbros are highly altered (probably deuteric alteration) coarse-grained plutonites which have retained their original igneous texture. They consist of felty growth of green amphibole that has been altered from pyroxene, and an unresolvable mass of sericite, albite, and clinozoisite. Orientation of the original grains in some samples suggests that they may be igneous cumulates. Platt and Stuart (1974) speculated that these rocks may be analogous to the Coast Range ophiolite in central and northern California.

Amphibolites are massive to banded, medium-grained rocks. They consist of garnet, zoisite, albite, and colorless to green amphibole. One type contains green diopside and may be eclogite.

Serpentinites are pale green to yellow brown, massive, and commonly contain sprays of talc. Alteration rocks occur between the serpentinite intrusions and country rocks in the Catalina Schist out-

crops on Santa Catalina Island (Platt, 1973), and similar clasts occur in the San Onofre Breccia. The alteration rocks are massive to weakly schistose. One type consists of actinolite, chlorite, and talc; another consists of tremolite and calcite.

Clasts of coarse-grained quartz-albite, epidote, and calcite rock are common in all San Onofre Breccia deposits. Veins of this type are common in metamorphic rocks on Santa Catalina Island.

LOS CORONADOS ISLANDS

On a clear day you can see these islands 25 km to the southwest. Lamb (1972) has described the rocks of these islands in great detail. One interesting feature of the Miocene conglomerate in the Los Coronados is the fact that it includes scattered Poway-type clasts among a predominant population of blue-schist and related clast types. This suggests that Eocene deep water fan deposits were included in the uplifted western source area.

ROSARITO BEACH FORMATION (after Minch, 1970)

In its type area the Rosarito Beach Formation consists of 1155+ feet of basalt flows and interbedded sedimentary and pyroclastic rocks (Figure 1). Over half of the section in the type area is composed of olivine basalts which were derived from sources to the west in the Continental Borderland.

Glaucophane schists, serpentinites, and cherts, also derived from the west, are found as clasts in the lower part of the section southwest of Tijuana. These rocks, similar to the San Onofre breccia of Woodford (1925), consist of a basal fossiliferous sandstone, a middle fossiliferous sedimentary breccia, and an upper sandstone-shale-limestone sequence. Both sandy and earthy matrix breccias are present.

The sedimentary interbeds in the middle and upper parts of the section are composed of tuffs which were associated with the basalts, tuffaceous sandstones, and sandstones which were derived from Eocene strata in low hills to the east.

Basalts dominate the Rosarito Beach Formation south of Rosarito Beach. In La Misión Valley over 500 feet of basalt contains only one 2- to 6-foot layer of tuffaceous sandstone. In the La Misión area a sequence of tuffs, fossiliferous sandstones, diatomite, and sandy feldspathic breccias overlie the main basalt sequence.

A meager, poorly preserved marine fauna occurs in the lowest part of the section southwest of Tijuana in Canyon San Antonio de los Buenos (Table 1). This fauna has been identified as Miocene-Pliocene in age (W. O. Addicott, 1966, written communication) and as definitely not Pliocene on the basis of echinoids from another locality (E. C. Allison, 1966, oral communication). On this basis a Miocene age was assigned to the Rosarito Beach Formation in the Tijuana area (Minch, 1967).

Several localities from the vicinity of La Misión have yielded a well-preserved fauna consisting of diatoms, radiolarians, foraminifers, mollusks, sharks, rays, bony fish, marine mammals,

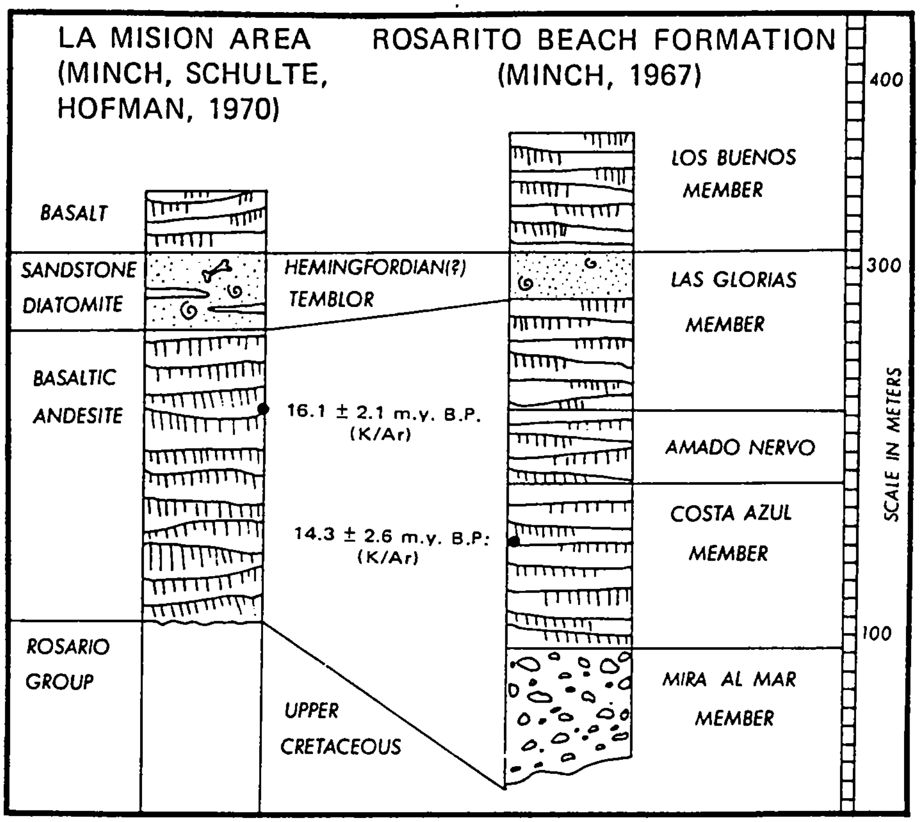


Figure 15 (from Gastil and ohters, 1975). Columnar section of Rosarito Beach Formation.

Rock Type	Northern sandy breccia (130 Counts) %	Southern sandy breccia (111 Counts) %	Earthy breccia (121 Counts) %
Serpentinite	22.3	14.4	10.7
Glaucophane schist	18.5	20.7	26.4
Glaucophane quartz schist	11.5	6.3	12.4
Bedded chert	17.6	4.5	7.4
Quartz-albite	3.1	11.7	4.1
Miscellaneous schist	3.8	3.6	9.9
Saussuritized gabbro	7.6	8.1	5.8
Gabbro	3.1	13.5	1.7
Granitic rock	3.1	6.4	7.4
Rhyolite	4.2	4.5	6.6
Quartzite	3.1	3.6	2.5
Graywacke	2.0	2.7	5.0
Totals	99.9%	100.0%	99.9%

Table 4 (from Minch, 1967). Cobble count in the Mira al Mar Member of the Rosarito Beach Formation.

MIOCENE ROCKS SOUTHEAST OF SAN DIEGO

In 1973 Artim and Pinckney realized that non-marine strata heretofore mapped as the lower part of the Pliocene San Diego Formation were actually correlative to the Rosarito Beach Formation south of the international boundary. They named these strata the Sweetwater and Otay Formations.

Scheidemann (1977) mapped the area straddling the border, connecting the Rosarito Beach Formation mapped by Flynn (1970) with the rocks identified by Artim and Pinckney. Figure 16 shows Scheidemann's map of the area southeast of the Tijuana Airport. Figure 17 is Scheidemann's interpretation of the relation between the stratigraphy on opposite sides of the border.

The area in which Artim and Pinckney recognized Miocene strata has subsequently been mapped by both Kennedy (1977) and Kuper (1975). Kuper and Gastil (1977) attempt to resolve the nomenclature problem by recognizing the "Sweetwater" and "Otay" as members within the Rosarito Beach Formation. Their description of these units follows:

Sweetwater Formation

> *The Sweetwater "Formation" consists of four lithologic facies: angular conglomerates, gritstones, mudstones, and sandstones. The angular conglomerate facies ranges in size from pebble and sand matrix to giant boulders, angular to sub-rounded. The clasts consist largely of the weakly metamorphosed volcanic-volcaniclastic rocks of the adjacent Santiago Peak Formation, with lesser amounts of granodiorite and gabbro. Locally, as southeast of Jamul, the matrix is poorly sorted, clay-rich, and in some places iron oxide stained. The most extensive exposures are found in Proctor and Otay Valleys. Local lenses occur within the gritstone facies further to the northwest. The most easterly exposures north of the international border are found capping ridges 8 kilometers southeast of Jamul (approximately 350 to 400 meters above sea level). These deposits were first mapped by San Diego State field classes under the direction of Ellis Roberts during 1949-50.*
>
> *The gritstone facies is found as lenses in the angular conglomerate and as massive beds up to 16 meters thick in the central part of the area, and as thin interbeds in the mudstone further west and north. It is the most distinctive facies and is second to the mudstone in abundance. The gritstone has been found in all localities of the Sweetwater with the exception of the furthest northwest exposures. The color ranges from bright white to tan. It is a lithic arkose in composition, with half-centimeter grains of quartz feldspar, and rock chips being the predominant components. Within the Paradise Valley area, this facies is in part well cemented with silica and forms resistant exposures. A particularly resistant exposure just north of Paradise Valley Road was pictured by Hertlein and Grant (1944). Sediments within this facies are massive and poorly sorted and resemble sheetflood deposits. The gritstone facies commonly overlies and interfingers with the mudstone facies.*
>
> *The non-gritty, relatively well-sorted sandstones appear in the eastern and central areas as lenses near the base of the mudstone facies. To the northwest, muddy sandstones are gradationally*

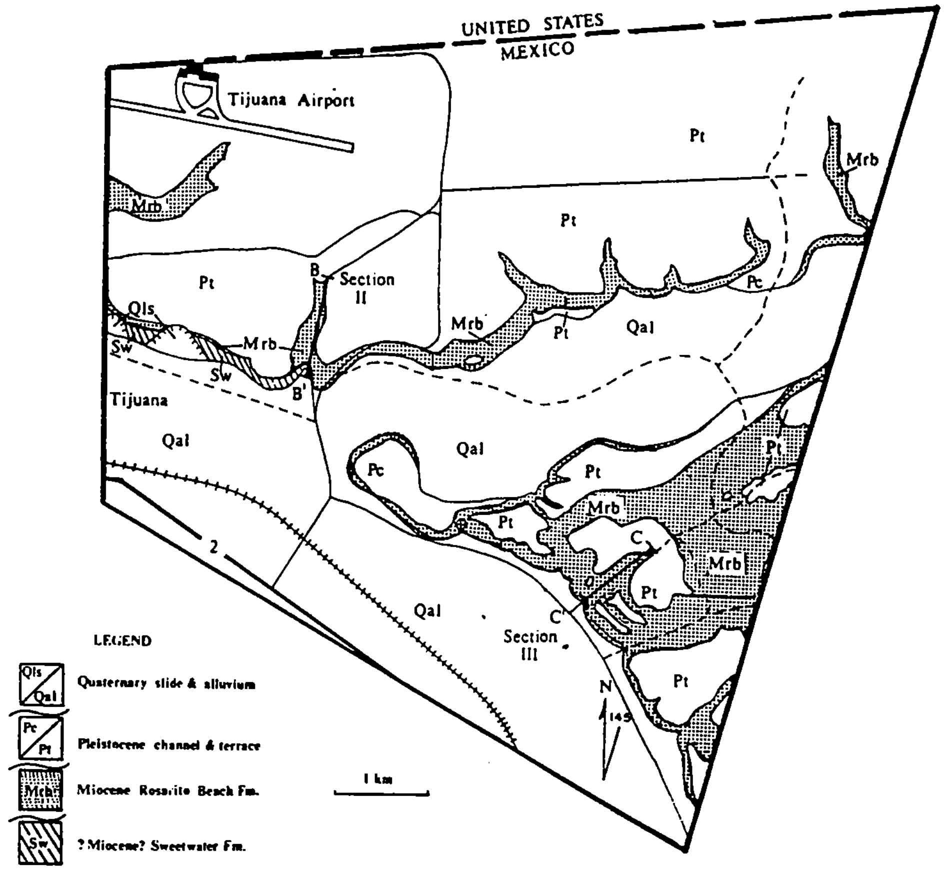


Figure 16 (from Scheidemann, 1977). Geology of the Otay Mesa and Tijuana River Valley area immediately south of the international boundary.

interstratified with sandy mudstones. The appearance of the sandstone facies is in some places only a short stratigraphic distance above the Mission Valley Formation which adds to the confusion between the Mission Valley and Sweetwater units.

The mudstone facies varies from brown, brick-like mixtures of clay, sand, and grit to relatively clean pink, expansive claystones, resembling horizons in the overlying Otay. Massive mudstone units measure as much as 26 meters in thickness. Even the waxy, conchoidally fractured pink clays generally contain appreciable silt and are commonly studded with visible granules of quartz. Along the northern margin of the area, from 54th Street and Highway 94 on the west, to Casa de Oro on the east, the mudstone is the dominant facies.

The erosional beveling of pre-Pliocene strata along the sub-San Diego Formation erosional surface removed part to all of the Sweetwater "Formation" from Bonita north.

Otay Formation

The unit which Artim and Pinckney (1973) named Otay "Formation" is essentially identical to that identified as Rosarito Beach Formation by Scheidemann (1976). It consists of very pale grey, massive to

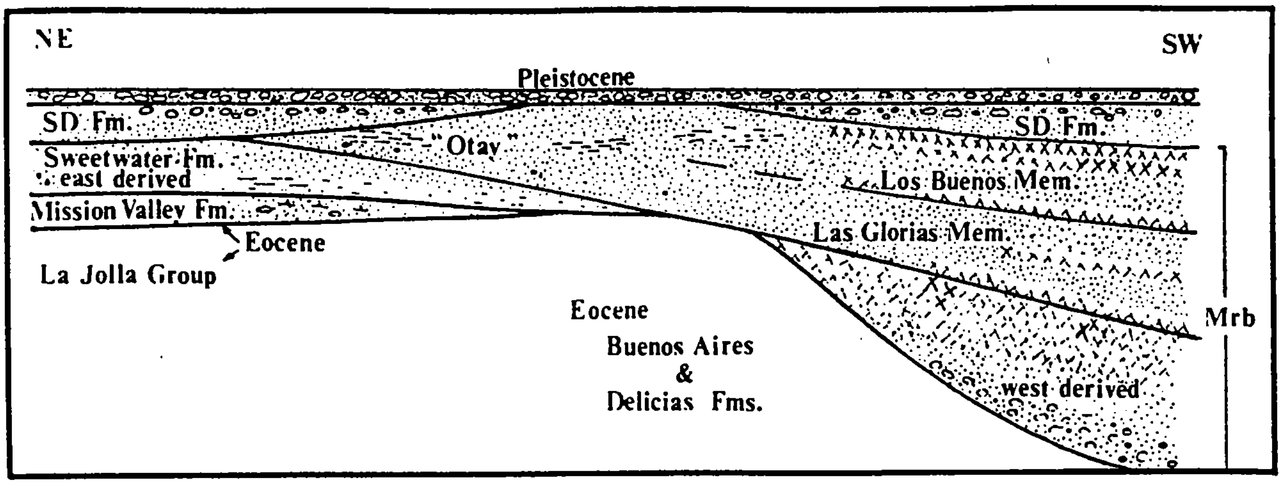


Figure 17 (from Scheidemann, 1977). Diagrammatic representation of relationship between Cenozoic stratal units from northeast to southwest across the international boundary.

thin-bedded sandstone with beds of bentonite clay up to 2 meters in thickness (Cleveland, 1960). The sandstone varies from a gritty, angular, commonly cross-laminated, feldspathic litharenite in the lower portion to a well-sorted, fine-grained, lithic arkose in the upper portion.

Artim and Pinckney (1973) describe the Otay "Formation" as: "Predominantly of...white, volcanically derived tuffaceous, fine sandstone with thin bentonite interbeds." Although the present authors have not done adequate petrographic work to confirm the volcanic derivation of the sandstone, volcanic lapillae and coarser volcanic clasts are found within the sandstones immediately south of the international border. This, together with the ash-derived bentonite clay (Cleveland, 1960) gives credence to the belief that an appreciable contribution was from local Miocene volcanism.

From a distance, the contrasting pale tan and pale grey colors of the Sweetwater and Otay "Formations" clearly distinguish their contact. Detailed examination, however, shows their lithology to be gradational, and a precise identification of the contact difficult. An excellent example of this gradation is found on the road which leads from Otay Valley Road north to the sanitary land fill area.

The conglomerate of the Sweetwater Member can be easily distinguished from both those of the underlying Eocene formations and those of the westerly derived Miocene units. Sweetwater clasts are almost entirely derived from the granitic and metavolcanic basement rocks found in place a few kilometers to the east. Even though the member unconformably overlies Poway group strata, Poway-type clasts are extremely rare. No clasts diagnostic of the western source area have been collected. No conglomerate has been found in the Otay member north of the international boundary. Southeast of Tijuana Airport it includes fragments of contemporaneous volcanic rock.

Both Scheidemann (1977) and Kuper and Gastil (1977) believe that the sediment of the Sweetwater Formation was derived under arid conditions from the Peninsular Ranges to the east and deposited under alluvial fan and playa conditions in a subaerial basin northeast of the volcanic centers of the Rosarito Beach Formation. The predominantly playa or lacustrine Otay Member contains an intermixture of detritus from the crystalline rocks to the east and the Miocene volcanic rocks to the southwest.

SAN DIEGO FORMATION

This formation is recognized from Mount Soledad and scattered localities north of Mission Valley south to the vicinity of Rosarito Beach. Correlative deposits are found all along the west coast of Baja California (Gastil and others, 1975; Mina, 1957). Hertlein and Grant (1945) described the San Diego Formation as 1250 feet thick, consisting of soft yellow and gray sandstone, locally micareous and marly. As Hertlein and Grant included the rocks of the Rosarito Beach Formation in the San Diego, presumably several hundred feet of this assigned thickness should be deleted.

Over much of the Mesa area south of Mission Valley and east of Balboa Park the formation consists of a few to 50 meters of fossiliferous fine-grained yellow-white sandstone with lenses of well-rounded cobble conglomerate. In places there are basal channels incised into the underlying formations. The conglomerates have a high percentage of Poway-type clasts, but there are a much higher percentage of Peninsular Ranges (eastern source) granitic and metamorphic rocks than are found in Eocene conglomerates, and there are rare clasts of glaucophane schist (western source). In places the fine-grained marine sandstone interbeds with red gritstones of probable lacustrine origin.

The best studied localities lie to the west: just north of Playa Tijuana, Balboa Park, the southern slope of Mount Soledad, and Pacific Beach. Recent studies are summarized by Wicander (1970) and Mandel (1974). Wicander concluded (largely on the basis of northern localities) that the formation was deposited in cool water in a littoral to sublittoral environment that became progressively shallower up section, no later than Late Pliocene.

Mandel (1974) concluded that the localities near the Mexican border were deposited in a sublittoral environment which was warmer and perhaps later than the northern deposits. According to Mandel: "The difference between latest Pliocene and earliest Pleistocene depends upon whether or not one included in the Pleistocene the short warming period that preceded glaciation." Allison (1964), on the basis of a horse tooth, had suggested that part of the formation might be earliest Pleistocene. The San Diego Formation has yielded a varied fauna of birds and marine vertebrates, particularly cetaceans (Barnes, 1973).

We hypothesize that the Sweetwater-La Nacion fault system, to the south, and other faults and fold boundaries, further northwest, were active during the late Pliocene time and formed a hingeline, producing a marine basin to the southwest but maintaining a stable terrace to the northeast and east. During early San Diego time marine erosion cut the sub-San Diego surface across the mesas to the east and filled in older drainages. Thicker deposits accumulated west of the hingeline. During the later deposition the cut surface submerged slightly, allowing the accumulation of fine-grained marine sandstone across the entire terrace. At this latest stage fluvial deposition interfingered with marine.

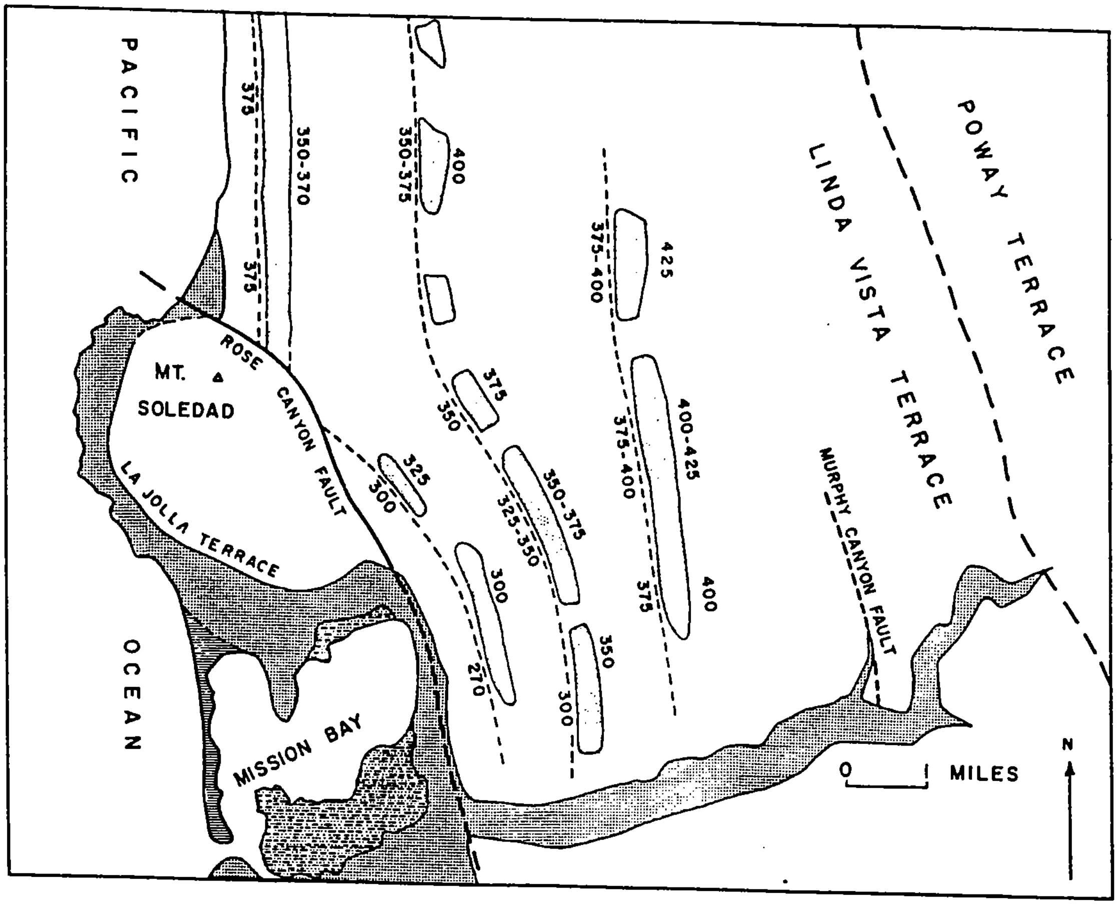


Figure 18 (after Peterson, 1970). Lightly stippled area is the Beach Ridge facies of the Lindavista Formation. Heavy stipple is Bay Point and other younger Pleistocene formations. Short dash lines are the shorelines of successive regressional stages of the Linda Vista Terrace.

LINDAVISTA FORMATION

Kennedy and Peterson (1975) describe it as follows:

The Lindavista Formation was named by Hanna (1926) for exposures at the Lindavista railroad siding in the La Jolla quadrangle (Lat 32° 53; N.; Long 117° 11'W.). The formation consists of nearshore marine and nonmarine sediments deposited on a 10 kilometer-wide wave-cut platform (Lindavista Terrace of Hanna, 1926) following the deposition of the middle or late Pliocene San Diego Formation (Hertlein and Grant, 1944) and prior to the deposition of the fossiliferous late Pleistocene (Sangamon) Bay Point Formation (Kern, 1971). A molluscan fauna from the Lindavista Formation, including the extinct species Pecten bellus*, not known from the late Pleistocene, suggests an early Pleistocene or late Pliocene age of these rocks (G. Kennedy, 1973). The Lindavista Formation is predominantly composed of moderate reddish-brown interbedded sandstone and conglomerate. Ferruginous cement, mainly hematite, gives the Lindavista Formation its characteristic color and a resistant nature.*

Both the coarse-grained and fine-grained rocks of the Lindavista Formation have been largely derived from the older sedimentary rocks within the San Diego embayment. Where iron staining, so common to the Lindavista Formation, extends downward into the underlying Eocene rocks, the two become difficult to differentiate.

Peterson (1970) describes the Linda Vista Terrace as follows:

The next lowest terrace, the Linda Vista Terrace, is very well preserved and only partially dissected within the area of study (Figure 18). It ranges in altitude from about 300 feet along the western extent to about 500 feet toward the east where it terminates against an old seacliff; the position of the shoreline is indicated by a heavy dashed line on Figure 18. The Linda Vista wave-cut platform truncates Late Lindavista Formation (equals Sweitzer Formation in some reports), a thin (generally less than 50 feet), bright red, unfossiliferous unit predominantly composed of moderately indurated sandstone and conglomerate. I interpret this formation as a regressive deposit laid down on the Linda Vista surface as the sea retreated. Although the Lindavista Formation is unfossiliferous, it post-dates the San Diego Formation (Pliocene) and the Poway Terrace (Early Pleistocene?) and pre-dates the La Jolla Terrace and associated Bay Point Formation (Late Pleistocene). This stratigraphic and geomorphic position indicates a mid-Pleistocene age for the Lindavista Formation.

One of the distinctive features of the Lindavista Formation is the set of beach ridges that cross it (Nordstrom, 1967). These are illustrated by Peterson in Figure 18. They are typically about one half kilometer wide and 2 to 16 meters in elevation. An excellent exposure of the vividly red Beach Ridge facies can be seen along Clairemont Mesa Boulevard just west of State 15. The upper surface of these deposits is covered with iron-oxide cemented concretion one to two centimeters in diameter. These features are illustrated by Peterson (1970) in Figure 18.

The fact that Hertlein and Grant (1944) and George Kennedy (1973) considered the age of the Lindavista (Sweitzer) Formation might be as old as latest Pliocene is not inconsistent with Peterson's interpretation of the relationship between the Lindavista and San Diego Formations (oral communication, 1977). If the wave cut platform beneath the easternmost portion of the Lindavista Formation represents the last time that the waves eroded this far inland, each of the beach ridges represents a hesitation point as the land emerged and the sea retreated. During this discontinuous regression marine sediment presumably contined to accumulate in deeper water seaward. Thus the abandoned beach lines and thinly covered wave platform deposits could be contemporaneous with the uppermost portion of the San Diego Formation west of the wave-cut areas.

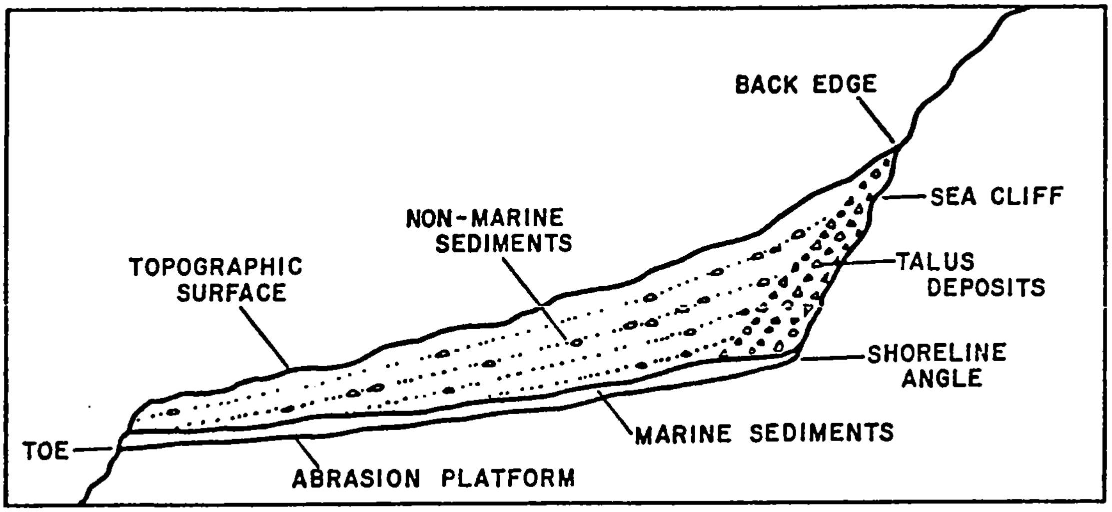


Figure 19 (from Kern, 1977). Illustration of the critical features of the coastal terrace.

BAY POINT FORMATION

No stratigraphic sequence in the San Diego area has had more detailed attention than that given to deposits of upper Pleistocene age. Kennedy and Peterson (1975) and Kennedy (1977) use the name Bay Point Formation (Hertlein and Grant, 1939) to include, not only the offshore bar facies of the type area (Crown Point in Mission Bay), but both the marine and non-marine deposits on marine abrasion platforms up to 60 m above sea level. Kern (1977) says that the geologic and chronologic relationships between the thin beds on abrasion platforms and the thicker sections such as that at Crown Point are not entirely clear.

Kern (1977) writes of the Upper Pleistocene marine terraces as follows:

> *The Nestor terrace abrasion platform was cut 120,000 years B.P. during a marine stillstand 6 ± 4 m above present sea level. Fossil marine invertebrates on this platform reflect slightly higher than present shallow-water marine temperatures, consistent with the slightly higher level of the sea and smaller volume of glacial ice. The 105,000-year B.P. stillstand 12 ± 3 m lower than present sea level may be recorded in a single very small unfossiliferous terrace remnant. The Bird Rock terrace abrasion platform was cut 80,000 years B.P. during a stillstand 14 ± 2 m lower than present sea level. Fossil marine invertebrates on this platform reflect slightly lower than present shallow-water marine temperatures, consistent with the slightly lower level of the sea and larger volume of glacial ice. General, rather uniform tectonic elevation of the entire San Diego coastal area has amounted to 19 to 24 m during the past 80,000 years for a rate of uplife of 24 to 30 cm per thousand years. Just south of the Rose Canyon fault the Nestor platform was elevated tectonically by approximately 23 m between 120,000 and 80,000 years B.P. and another 31 m during the subsequent 80,000 years to a total 54 m in 120,000 years, or 45 cm per thousand years.*

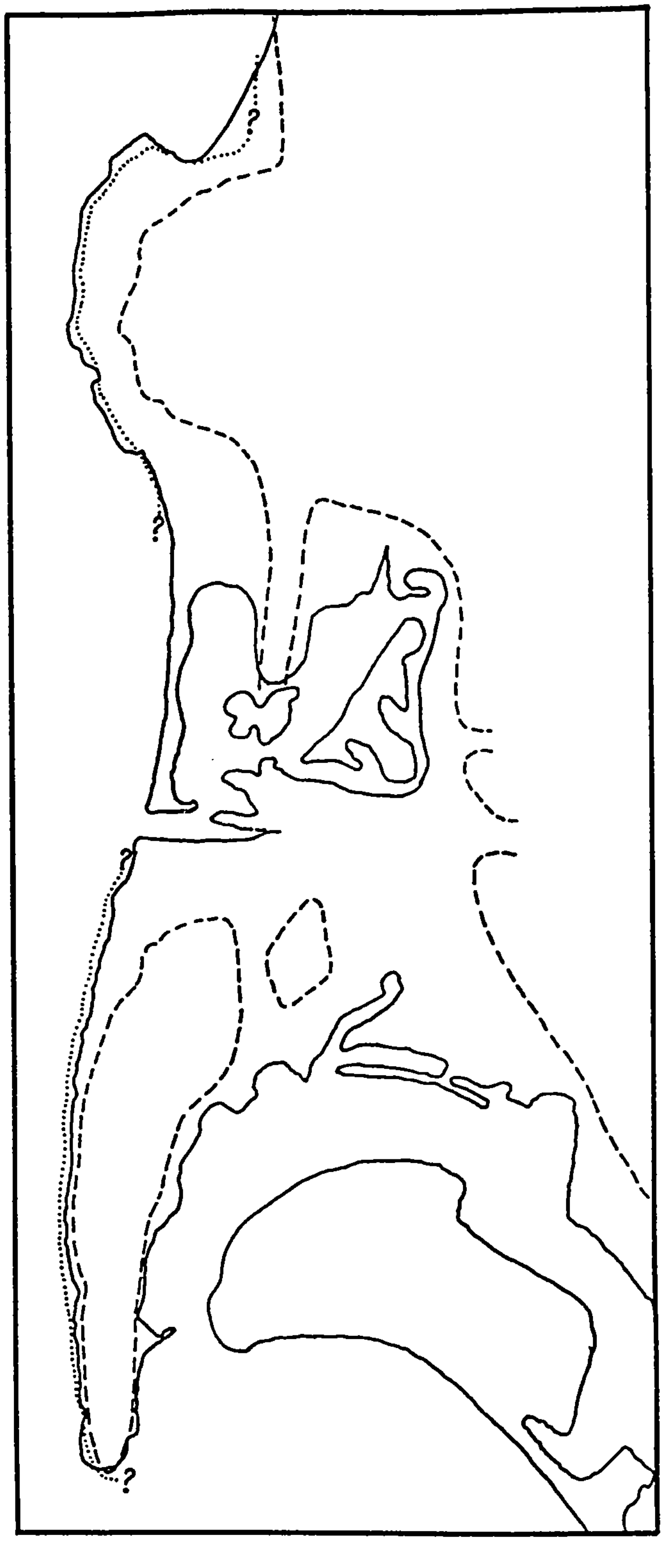


Figure 20 (from Kern, 1977) illustrates the positions of Upper Pleistocene coastlines. The dashed line represents an interglacial level of 2 to 10 meters above present sea level about 120,000 years B.P., corresponding to the Nestor Terrace. The questioned dotted line represents an interglacial high about 80,000 years B.P. when the sea rose to a level 9 to 15 m below present sea level. This shoreline may correspond to the Bird Rock Terrace.

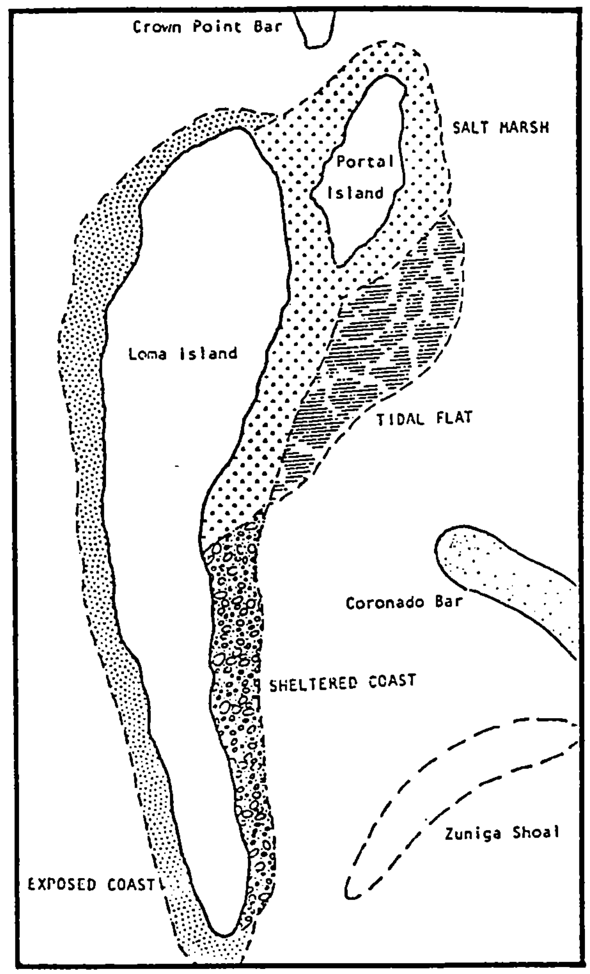


Figure 21 (from Bowersox, 1974) shows storm beach facies along the western exposed coast of Point Loma, coarse poorly sorted fluvial deposits along the sheltered east coast, salt marsh and tidal deposits northeast of Loma Island, with bars and shoal facies in the area now occupied by North Island.

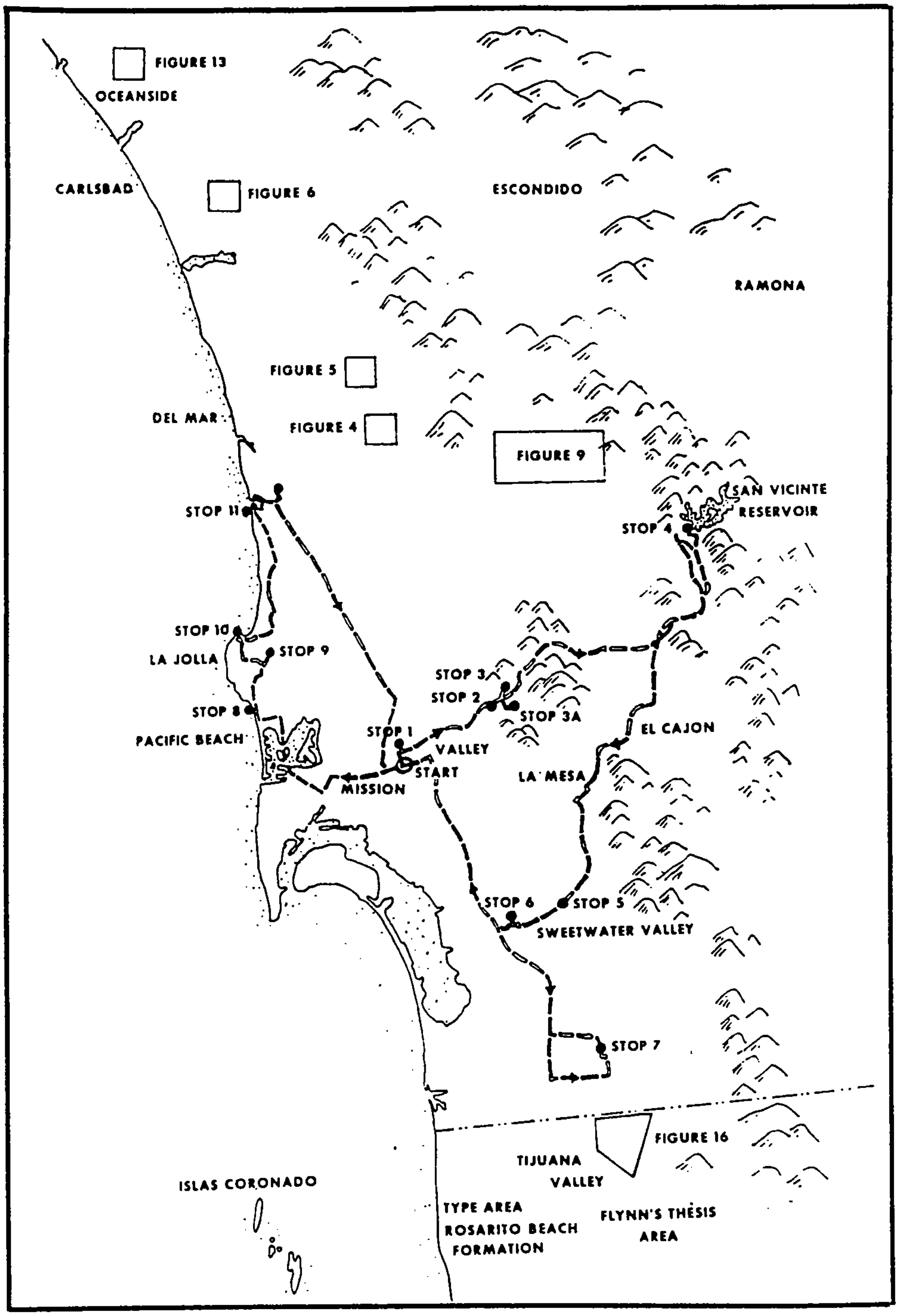


Figure 22. Route map for the stratigraphy of the San Diego area field trip.

THE DESIGN OF THE FIELD TRIP

In this trip we will attempt to see each of the stratgraphic formations exposed between the international boundary and Torrey Pines. A field trip guide by George Moore (1971) will take you to the San Onofre breccia near Oceanside and other points north of our traverse. Field trip guides by Allison and others (1970) will take you to the Rosarito Beach Formation and other rocks south of the international boundary. For a more detailed study of the Miocene rocks in southwestern San Diego County, see field trip guide by Ferrand (1977).

Ideally we should begin by looking at the oldest strata in the area and work upward. Unfortunately the exposures are not located in a manner that makes this practical. Try to imagine that we are making three traverses across the area, one from west to east, a parallel section to the south from east to west, and another from south to north. The eastward traverse begins in the interbedded marine sandstone and conglomerate of the Poway Delta and leads east across high-relief, buried mountains, to the narrow gorges through which these exotic boulders issued (see Figure 23). The westward traverse begins on basement rock, crosses Eocene and Miocene strata to the La Nacion and Sweetwater faults, west of which Pliocene and Pleistocene strata are exposed (Figure 24).

Figure 25 shows (with exaggerated vertical scale) how Miocene strata are preserved in a pre-Pliocene structural trough centered near the international boundary.

A third section through Mission Bay and La Jolla parallels our route north across the Rose Canyon fault to Torrey Pines (Figure 26).

ROAD LOG TO STRATIGRAPHY OF THE SAN DIEGO AREA FIELD TRIP

Cumulative mileage	Added		
00.0			Start from the Town and Country Hotel, drive north on Fashion Valley Road.
1.5	1.5		Turn east on Friars Road.
2.2	0.7	STOP 1	Turn right into property of Conrock Sand and Gravel Company. Continue to right through an underpass which leads to the north side of Friars Road. The cliffs to the north expose the upper Eocene Stadium Conglomerate. Some sandstone horizons in this area contain marine fossils. We are located near the east edge of the Del Mar quadrangle. Return to the same gate from which we left Friars Road.
3.8	1.6		San Diego Stadium on your right--home of the San Diego State Univeristy Aztecs. To the north the cliff exposes about 30 meters of Friars Formation overlain by 40 meters of Stadium Conglomerate. At the top of the cliff, perhaps difficult to see, are a few meters of Mission Valley Formation, overlain by the Pleistocene Lindavista Formation. You are near the west edge of the La Mesa quadrangle.

Cumulative mileage	Added		
4.6	0.8		We have crossed over State Highway 15, Mission San Diego de Alcala is over the hill to our right. The old river terraces on our right have recently been excavated for artifacts of paleolithic man.
5.3	0.7		Junction with Mission Gorge Road, continue northeast. The transition from marine to non-marine facies in the Poway delta occurs at about this longitude.
6.3	1.0	STOP 2	Turn off to the right and park on a large bare lot, just west of Teledyn Micronetics. Friars Formation sandstone and green mudstone is unconformably overlain by a river terrace, presumably correlative with the exposures seen near the Mission.

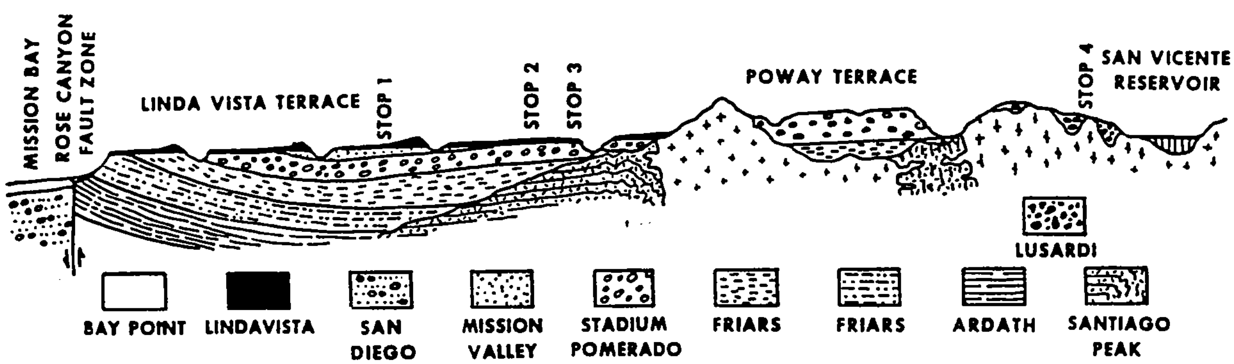


Figure 23. Cartoon geologic section from Mission Valley to San Vicente Reservoir.

7.1	0.8	SIDE TRIP	Princess Street, turn right
7.4	0.3		Fontaine Street, turn left
7.7	0.3	STOP 2A	Lina Place, turn around and park on north side of Fontaine. Viewpoint here shows (to the east) the exhumed mountains of batholithic and prebatholithic rocks. You are located almost in the center of the La Mesa quadrangle. On the north horizon you can see the Lindavista and Poway terraces. At the head of the gorge you can see beds of Jurassic volcaniclastic strata dipping gently to the west. To the southeast you see Del Cerro, an exhumed mountain of meta-volcanic rocks.
8.3	0.6		Return to the intersection of Princess and Mission Gorge Road, turn right (get into left lane for left turn).
8.4	0.1	STOP 3	Enter McCoy's rock quarry, stop at the office. The quarry is to the east of the office and can be entered only by permission. Note the dikes which cut the volcanic sequence. Note that among the fragments in the volcanic-volcaniclastic breccias there are some plutonic rocks. Return to quarry

gate. (Log distances do not include distances within quarries). Turn east on Mission Gorge Road.

8.9	0.5		Climbing hill through Friars Formation; brown and green, weathered meta-volcanic rock, grading into fresh meta-volcanic rock, then Lindavista Formation terrace.
9.9	1.0		Turn left onto Father Junipero Serra Trail (Gorge Road). For the next mile and one half we follow a deep gorge deeply incised by the San Diego River into granitic rocks.
11.9	2.0		Pass Padre Dam on the left. Constructed of terra cota brick laid with cement fired from local caliche, it was used by the Franciscan fathers to divert water into a tile flume.
12.5	0.6		Junction with Mission Gorge Road, turn left. We have now passed into the El Cajon quadrangle, for which there is no published geologic map.
16.4	3.9		Turn left onto Woodside Avenue, then right under State Highway 67, and thence onto 67 East.
19.7	3.3		End of Freeway, continue north on State 67. You are passing the town of Lakeside on your right.
22.8	3.1		Junction of State 67 and Vigilante Road.
23.1	0.3	SIDE TRIP STOP 4A	Continue on State 67. Turn immediately right into Triway sand and gravel quarry. Here the apex of the Poway fan is being excavated and large boulders of the adjacent granitic rocks can be seen in the conglomerate.
23.4	0.3		Return to State 67 and Vigilante Road, turn left.
24.2	0.8		Turn left onto Moreno Avenue.
24.4	0.2		Enter San Vicente Reservoir Property, gate generally open during daylight hours.
24.5	0.1		Just before reaching the locked gate (to the dam) turn left onto narrow paved road.
25.4	1.0	STOP 4	San Vicente Reservoir fishing camp. In the parking lot you can see the walls and the floor of the partially exhumed gorge which fed the apex of the Poway fan. Notice blocks of the foliated granodiorite from the channel walls within the Poway conglomerate.
25.7	0.2		(approximate distance) Returning up the hill, park at the top and walk down the hill toward the south.
by foot	0.2	STOP 4B	Here you encounter an unexhumed portion of a still older gorge, that which carried boulders to the Lusardi Formation during the Upper Cretaceous. Note that no clasts of Poway type are found in this conglomerate. Peterson (oral communication, 1977) reports that the Lusardi channel deposit could be seen beneath the Poway apex in the Triway quarry when it first opened. This overlying relationship can be seen on State Highway 67 about 1.5 miles north of the Triway Quarry.

Cumulative mileage	Added	
26.3	0.6	Return to Reservoir gate, turn right on Moreno Avenue
28.6	2.3	Return to Highway 67, turn left.
29.4	0.8	Return to Freeway, continue west and southwest.
34.8	5.4	Turn right onto Interstate 8 (toward San Diego). You are now passing through El Cajon Valley and the City of El Cajon. The floor of the valley is a discontinuously alluviated pediment across granitic and metamorphic rocks. The mesa to the west of the valley is underlain by Friars Formation and Stadium Conglomerate, capped by Pleistocene terrace material. The weakness of the Friars Formation has caused a history of sliding.
37.9	3.1	Turn left (actually from the left lane) onto State Route 125 (toward State 94); you are now passing through the City of La Mesa, and through the contact zone of the granitic and meta-volcanic rocks.
39.9	2.0	Turn (right lane) onto Spring Street, and turn left (left lane) under Freeway.
40.3	0.4	Turn right onto Broadway. We now enter northeast corner of National City quadrangle (Kennedy, 1977; Kuper, 1976).
41.1	0.8	Turn left onto Sweetwater Road. Going south we are following a "contact valley" between the metavolcanic Santiago Peak Volcanics to the east and the post-batholithic flat-lying section to the west. The road cut exposes the light grey sandstone of the Eocene Mission Valley Formation. It is overlain by the mudstone and gritstone of the Sweetwater member of the Rosarito Beach Formation and the predominantly yellow Pliocene San Diego Formation. We are passing east of the City of Lemon Grove.
43.3	2.2	Cross Jamacha Road, continue south. To the west the weak mudstones of the Sweetwater Formation have caused slides, producing a hummocky topography at the foot of the valley wall.

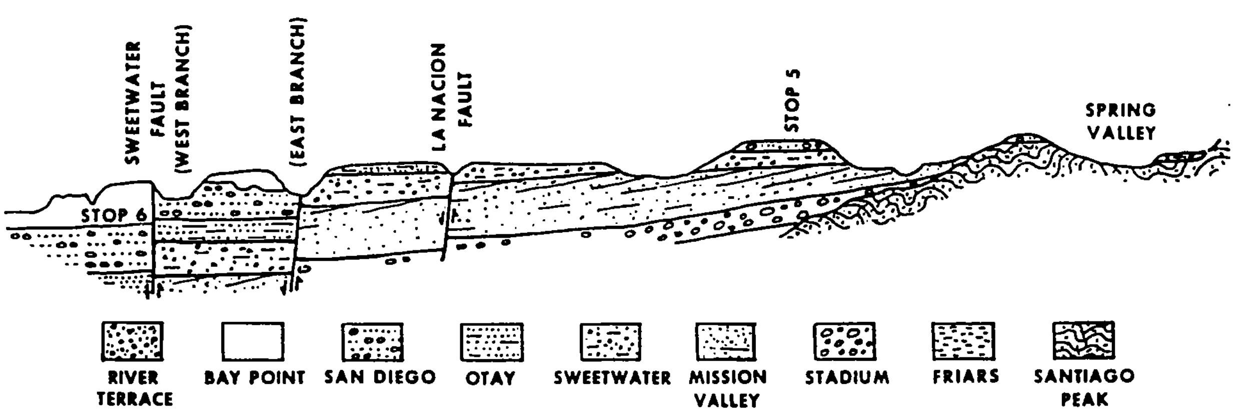


Figure 24. Cartoon geologic section along South Bay Freeway from Sweetwater Valley to Interstate 805.

44.1	0.8		Cross Jamacha Boulevard-Paradise Valley Road (S17). The road you are on becomes South Bay Freeway (State 54). We are now crossing an exhumed hill of metavolcanic rock.
45.1	1.0		Signal, Sweetwater Road crosses South Bay Freeway.
45.3	0.2		Light grey sandstone of the Eocene Mission Valley Formation laps onto weathered metavolcanic basement. A few blocks of the weathered volcanics have fallen into the sandstone.
45.6	0.3	STOP 5	Area to park on the right side of the highway. Walk west to a large roadcut. Examine the strata on both sides of the cut and climb to the top of the cut on the south side of the road. From this vantage view the cut to the north. Notice that the massive mudstones in the upper part of the cut are separated by an almost horizontal line from the inclined sandstone below. The lower formation is the Eocene Mission Valley, containing thin cobble horizons and iron placers. The upper few feet are stained by iron oxide. The iron oxide stain parallels the buried erosional surface. The overlying formation is the Sweetwater.
46.3	0.7		Additional road cuts showing the same Mission Valley/ Sweetwater contact.
47.0	0.7		Cross La Nacion fault. White exposure in the roadcuts west of this point are the Otay Member of the Rosarito Beach Formation.
48.4	1.1		Turn right onto Reo Drive, and immediately turn left onto Valley Road. We have now crossed the east branch of the Sweetwater fault, dropping the Pliocene San Diego Formation down to road level. To the north we can see the San Diego Formation overlain by Pleistocene deposits on a high relief unconformity.
48.7	0.3		Turn right onto Calle Abajo, Paved road ends in 0.2 miles; park at end of road.
49.0	0.6	STOP 6	West fork of Sweetwater fault. Upper Pleistocene deposits faulted against Pliocene San Diego Formation.
49.3	0.3		Back to Valley Road, turn right.
49.6	0.3		Proceed west on Sweetwater Road, and pass under Freeway.
50.1	0.5		Turn left(south) onto Interstate 805.
52.1	2.0		Passing roadcuts of marine Pliocene San Diego Formation.
55.4	2.3		Passing Telegraph Canyon. The yellow cuts up the canyon to the east are San Diego Formation. We are now entering the Imperial Beach quadrangle.
56.6	1.2		Roadcuts expose deposits of Upper Pleistocene age.
57.3	0.7		Turn (from right lane) to cross overpass and take the road east toward Brown Field.
57.7	0.4		Crossing the La Nacion fault (down to west). The light grey sandstone is Miocene Otay Member. The overlying yellow to grey sandstone is the Pliocene San Diego Formation.

Cumulative mileage	Added		
60.4	2.7		You are on Otay Mesa; turn left onto Heritage Road.
60.7	0.3		Turn left onto Otay Valley Road.
61.1	0.4		Junk Yard. From this point you can reach the type section of the Otay Member by circling behind the junk yard and following a dirt trail one mile northwest. Here on the east wall of Chester Canyon there is a natural ampitheater exposing the entire formation.
		STOP 7	We will park at this point and instead of visiting the type section we will walk 0.9 miles down Otay Valley Road.
on foot	0.1		Pleistocene/San Diego Formation contact. The mesa-capping Pleistocene formation is composed of coarse, angular, locally derived boulders.
61.3	0.4		San Diego/Otay contact.
61.7	0.2		Otay/Sweetwater contact. This is the first place we have had an opportunity to see the Sweetwater gritstone. The gritstone is the characterizing facies of the Member.
61.9	0.2		End of the section. Looking across Otay Valley toward the north we can see an elevated river terrace, and to the northeast an exhumed mountain of metavolcanic rock. Continue north.
62.6	0.7		Red Sweetwater claystone exposed in roadcut is lower in the section than gritstone exposed south of the valley.
62.8	0.2		Low in the roadcut we can see the Sweetwater/Mission Valley contact.

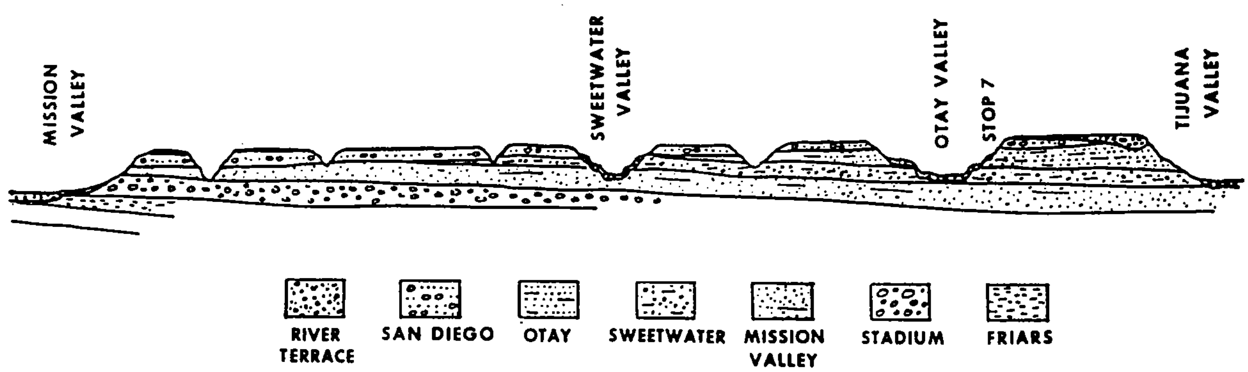


Figure 25. Cartoon geologic section east of La Nacion fault from Mission Valley to Tijuana Valley.

63.1	0.3	Elevated river terrace overlying sandstone of the Mission Valley Formation. Note the strong development of iron placers in the Mission Valley.
63.4	0.3	View of bentonite clay pits in hills south of the valley. The bentonite, derived from volcanic ash, occurs in the Otay Member and was mined for use in oil well drilling.

64.3	0.9		Turn north onto Interstate 805.
78.1	13.8		Turn from right lane onto Interstate 8 west (toward beaches). We have now re-entered the La Jolla quadrangle.
81.0	2.9		Pass turnoff to Hotel Circle
82.8	1.8		San Diego Formation exposed in cliff to south of road (Presidio Park).
84.0	1.2		Crossing overpass, take lane for Rosecrans Street.
84.9	0.9		Turn right onto Sports Arena Boulevard.
85.4	0.5		Sports Arena, home of the San Diego State University basketball team.
85.8	0.4		Turn right on Midway Drive. To southwest note Upper Pleistocene terrace deposit unconformably overlying Lower Maestrichtian Cabrillo Formation.
86.3	0.5		San Diego River. Until the late 1850s it flowed into San Diego Bay. In 200 years it has had 10 major floods. The worst was in 1862 when the Corps of Engineers estimated 1,000,000 cubic feet per second. To the north we can see Mission Bay and Mount Soledad.
86.9	0.6		Cross bridge to Crown Point. This was a late Pleistocene bar, and is the type locality of the Bay Point Formation.
88.3	1.4		Turn left on Grand Avenue.
89.2	0.9		Turn right onto Mission Boulevard.
89.6	0.4		Turn left onto Loring Street.
89.7	0.1	STOP 8	Park at Beach and walk up the shore to the north. The flat lying reddish beds which cover the terrace are the Upper Pleistocene Bay Point Formation. The strata immediately overlying the abrasion surface are marine (Grant and Gale, 1931; Kern, 1977). This has been called the La Jolla terrace (Hanna, 1926). Kern (1977) believes that, of the several correlative terrace names, Nestor terrace (Ellis, 1919) has priority. Figure 28 (after Moore, 1971) shows the sequence of formations as we proceed northwest along the beach. Beneath the Upper Pleistocene strata is the Late Pliocene San Diego Formation dipping 5° E, the Eocene Mount Soledad Formation dipping 10° E, and the Maestrichtian Cabrillo Formation (conglomerate) dipping as much as 15° E. This is a good place to compare the clast types in the Pliocene, Eocene, and Cretaceous conglomerates. After walking up the beach to False Point return along the beach to Tourmaline Surfing Park.
90.0	0.3		From Tourmaline Surfing Park return to Mission Boulevard.
90.2	0.2		Turn left (north) onto Mission Boulevard. Cross Turquoise Street and continue up the hill (turns into La Jolla Mesa Boulevard).

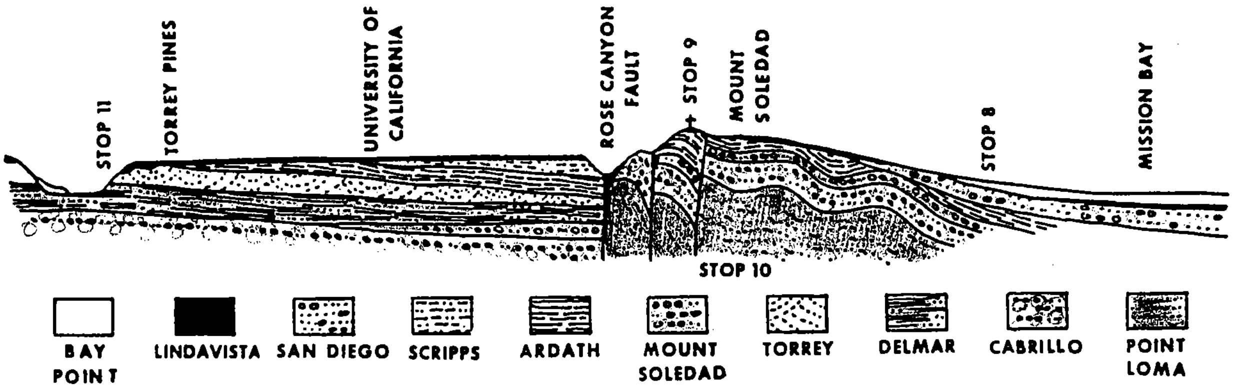


Figure 26. Cartoon geologic section west of Rose Canyon from Point Loma to Del Mar.

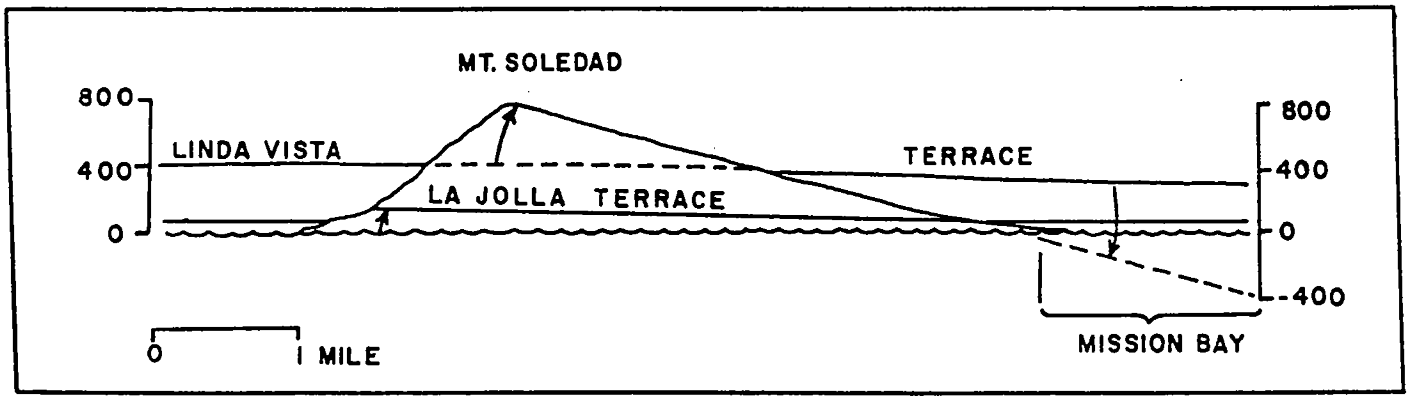


Figure 27 (from Peterson, 1970). Schematic structural-geomorphic interpretation for the Mount Soledad-Mission Bay area. View is from the west.

91.1	0.9		Road cuts expose Eocene Ardath shale overlain by ferruginous early Pleistocene Lindavista Formation.
91.4	0.3		Turn right onto La Jolla Scenic Drive (be careful not to turn onto Rutgers Road).
91.5	0.1		Soil pisolites in the Lindavista Formation.
92.1	0.6	STOP 9	Top of Mount Soledad. Eocene Mount Soledad conglomerate is exposed east of the viewpoint, Cretaceous Cabrillo Formation conglomerate west of the viewpoint, a thin capping of Lindavista Formation on the ridge top. Strands of the Rose Canyon fault trends southeast on both sides of the viewpoint. Linda Vista Mesa lies across Rose Canyon to the east. Note the north trending Beach Ridge facies of the Lindavista Formation capping the mesa across the fault zone to the north. Return down La Jolla Scenic Boulevard.
92.7	0.6		Turn right onto Nautilus Street. Road cuts expose Eocene Ardath Shale.

94.2	1.5	Turn right onto Fay Avenue.
95.2	1.0	Turn right onto Prospect Street.
95.6	0.4 STOP 10	Stop at Coast Boulevard, walk down to the cove, and out to the point to examine the sedimentary structures in the Campanian-Maestrichtian Point Loma Formation. Note in particular the flames, rip-ups, and "dish structures" produced by fluidized grain flow.
96.0	0.4	Return to the bus at the south end of Prospect Park.
96.4	0.4	Return to Prospect Street and go east on Torrey Pines Road.
97.0	0.6	Turn left on Torrey Pines Road. The tilted strata in the roadcuts is Point Loma Formation.

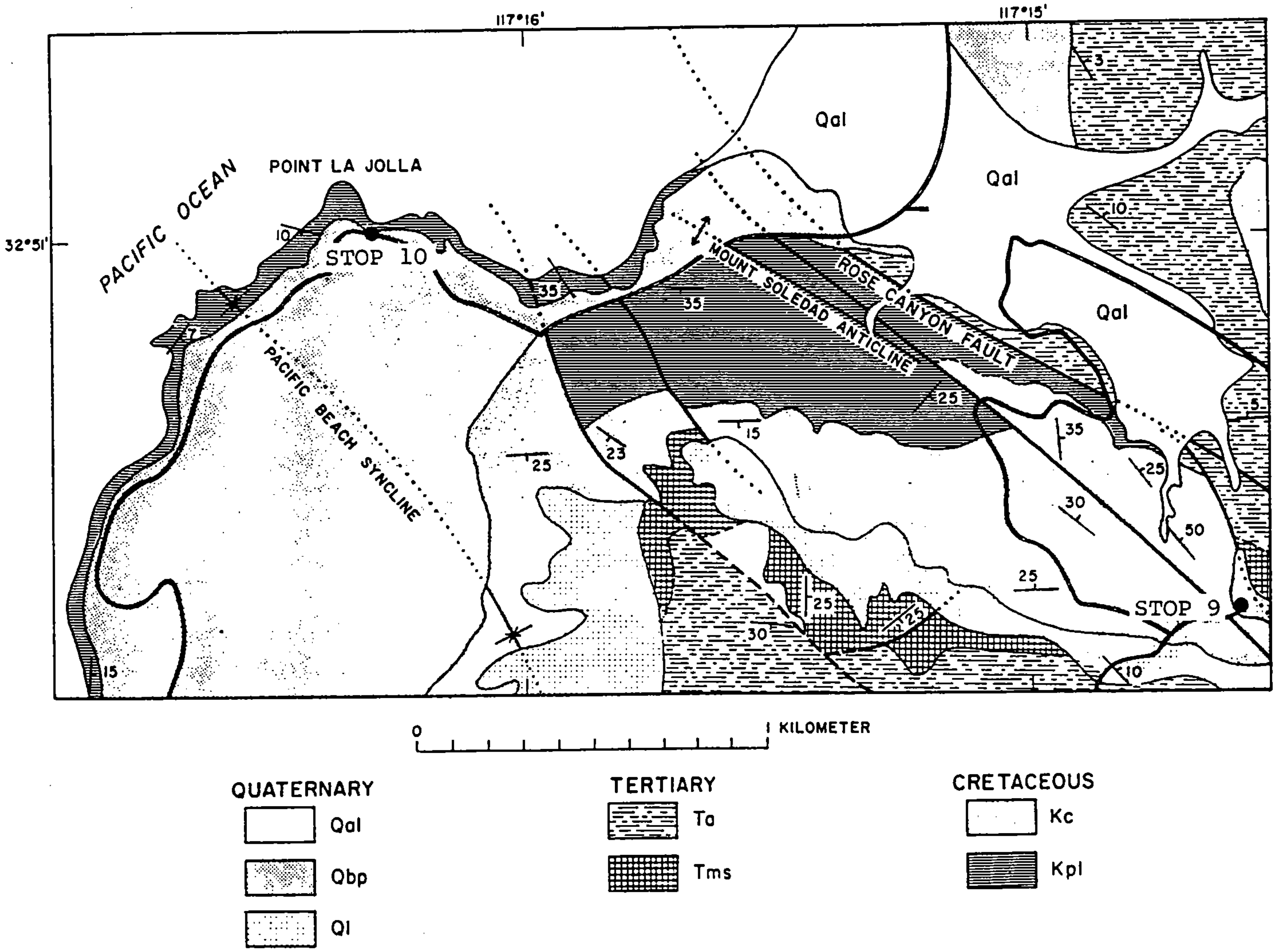


Figure 28 (after Kennedy and Moore, 1971). Geologic map for Stops 9 and10. Geologic units: Qal, Quaternary alluvium; Qbp, Bay Point Formation of Hertlein and Grant (1939); Ql, Lindavista Formation of Hanna (1926); Tsc, Scripps Formation; Ta, Ardath Shale; Tms, Mount Soledad Formation; Kc, Cabrillo Formation; Kpl, Point Loma Formation.

Cumulative mileage	Added		
97.9	0.9		Left turn--continue on Torrey Pines Road.
98.9	1.0		Exposures of Eocene Ardath Shale.
99.3	0.4		Lindavista Formation caps the mesa.
99.8	0.5		Turn left onto University Drive (University of California at San Diego campus).
100.3	0.4		Cross La Jolla Scenic Drive, continue north; name changes to North Torrey Pines Road.
102.9	2.6		View to the north across Soledad Valley shows the red Beach Ridge facies of the Lindavista Formation overlying the Eocene Torrey Sandstone. We are now in the Del Mar quadrangle.
103.4	0.5		Torrey Sandstone overlain by Lower Pleistocene Lindavista Formation; small fault; and a Pleistocene channel cut into the Torrey.
104.6	1.2	STOP 11	Parking Lot for Torrey Pines State Park beach. Greenish, oyster-bearing, Delmar Formation mudstone and sandstone at the base of the sea cliff (back-bar lagoonal facies, grading upward into the steep, cavernous-weathering, bar-facies of the Torrey Sandstone. Continue north on North Torrey Pines Road.
105.5	0.9		Turn right onto Carmel Valley Road.
106.6	1.1		Several residential streets lead up into cliffs which expose the large cross-laminated sets of Torrey Sandstone channel facies.
107.7	0.6		Pass under the freeway (Interstate 5).
107.9	0.2	STOP 11A	Stop at the concrete drainage ditch immediately east of the Shell Service Station. Fossiliferous exposure of the Bay Point Formation. Described by Kern (1971) as follows:

The marine invertebrate fauna of the Bay Point Formation in Carmel Valley, San Diego County, California, includes 10 species and subspecies of Foraminifera, 57 species of Mollusca, and 9 species of Ostracoda. This Late Pleistocene fauna lived in sediments probably deposited during marine regression late in an interglacial episode somewhat more than 100,000 years ago.

The fine to medium sand and the eelgrass in which these invertebrates lived was in about 30 feet of water in a narrow sheltered estuary. The water was slightly brackish, and the salinity may have decreased slightly during deposition of successive beds. Brackish conditions resulted in slight stunting of the molluscan fauna.

The thermal regime was similar to that at the same latitude today, except that summer temperatures in the sheltered water of the estuary may have been slightly higher than today.

108.2	0.3	Return under the freeway and turn onto Interstate 5 South.
110.2		(mileage approximate) Turn onto Interstate 805 South (re-enter La Jolla quadrangle).
117		(mileage approximate) Turn onto State 163 South.
120		Turn onto Interstate 8 East, watch for turnoff to Hotel Circle.
121		Turnoff to Hotel Circle.
122		Town and Country Hotel.

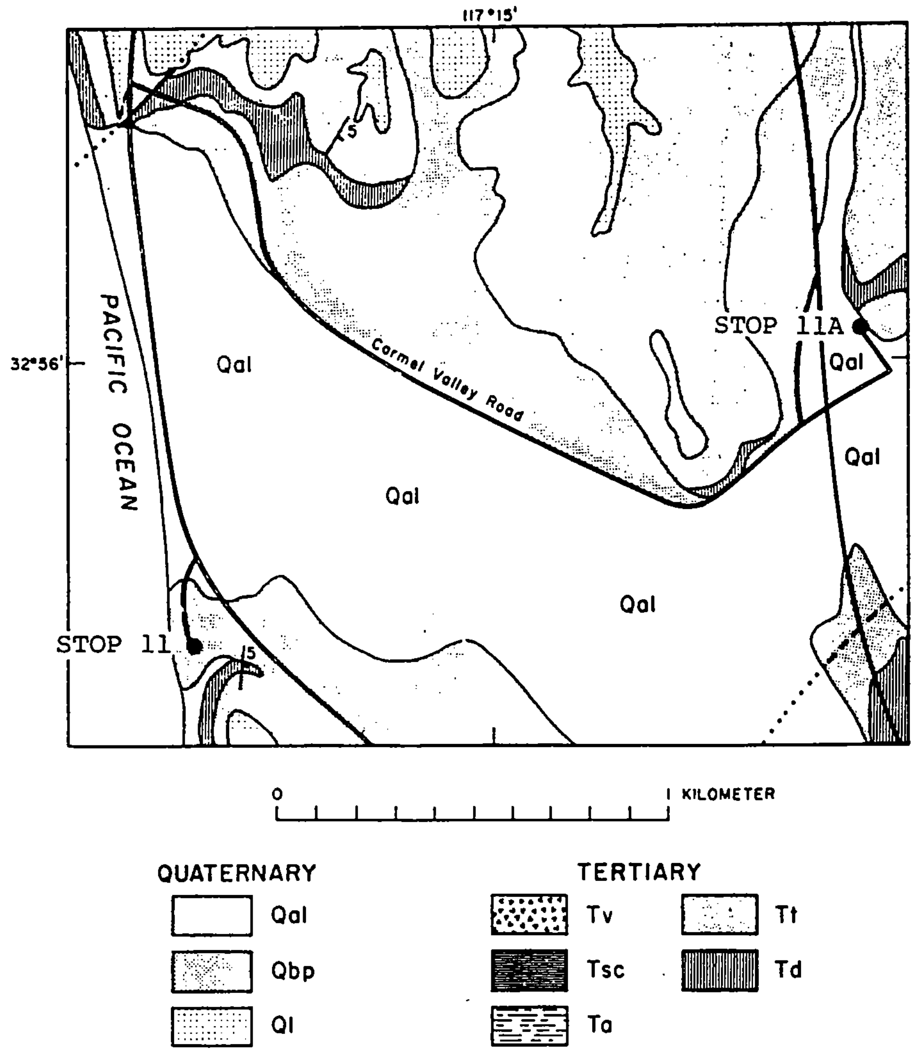


Figure 29 (after Kennedy and Moore, 1971). Geologic maps for Stops 11 and 11A. Geologic units: Qal, Quaternary alluvium; Qbp, Bay Point Formation of Hertlein and Grant (1939); Ql, Lindavista Formation of Hanna (1926); Tv, Tertiary volcanic rocks; Tsc, Scripps Formation; Ta, Ardath Shale; Tt, Torrey Sandstone; Td, Delmar Formation.

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