SEPM Trip 1

PHOTO BY DOUG INGLE

VIEW SOUTH AT MORO CANYON NEAR LAGUNA BEACH, CALIFORNIA. PROMINENT SEA CLIFFS AND HILL ARE FORMED OF LATE MIOCENE ANDESITIC INTRUSIVES.

MIOCENE SEDIMENTARY ENVIRONMENT and BIOFACIES, SOUTHEASTERN LOS ANGELES BAY

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PREFACE

The Field Trip Committee of the Pacific Sections of the American Association of Petroleum Geologists, Society of Economic Paleontologist and Mineralogists, and Society of Economic Geophysicists bids welcome to all field trip participants.

The new guidebooks cover a large segment of the southern one-third of the State and present both descriptive and interpretive information on some of the diverse and complex geology of the region. In addition to such subjects as the environmental aspects of metropolitan oil field development and future sources of geothermal power, a striking variety of geologic features and scenic routes are included. Moreover, at the suggestion of the Technical Program Committee, a number of papers in the technical sessions and symposia apply directly to specific facets of several field trips.

We wish to offer our heartfelt thanks to the more than 50 individuals who organized, contributed to, and implemented the field trips. To those who volunteered articles or services but were turned down for lack of space or time, our sincere apologies. We also wish to express our gratitude to those companies that provided manpower and facilities in support of publication. Furthermore, we extend our appreciation to the landowners and public officials who permitted access and visiting privileges.

The Field Trip Committee
J.G. VEDDER - Chairman
J.D. TRAXLER - Printing Chairman
PETE FISCHER - Editor
DEAN JOHNSON - Co-Editor

ROAD LOG
S.E.P.M. TRIP NO. 1

PLIOCENE-MIOCENE SEDIMENTARY ENVIRONMENTS AND BIOFACIES, SOUTHEASTERN LOS ANGELES BASIN-SAN JOAQUIN HILLS AREA, ORANGE COUNTY, CALIFORNIA

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The following road log highlights selected exposures of Neogene marine strata to be seen along a route traversing the northern flank of the San Joaquin Hills, upper Newport Bay, and sea cliff areas in Laguna Beach, Dana Point, and San Clemente, California (Fig. 1). Emphasis is placed on the remarkably varied paleoenvironments represented within the Oligocene[1]-Lower Pleistocene sequence of over 20,000 feet of marine sediments exposed in this area (Fig. 2). Scrutiny of sedimentary parameters, megafossils, and microfossils within this sequence reveals that it represents a complete cycle of basin formation and filling during the Neogene interval; Oligocene formations include non-marine and littoral marine deposition (Sespe and Vaqueros Formations), early Miocene deposits represent littoral through inner shelf environments (Vaqueros and lower Topanga Formations), middle Miocene deposits include shelf through lower bathyal environments (upper Topanga Formation and Monterey Shale), late Miocene deposits include lower bathyal through upper bathyal deposits (Monterey Shale and lower Capistrano Formation), whereas Pliocene and early Pleistocene deposition took place at bathyal through inner shelf depths (upper Capistrano and Fernando Formations). The controversial San Onofre Breccia of middle Miocene age was apparently deposited near the strandline as well as at bathyal depths. Ingle (this volume) provides paleobathymetric curves for the sequences encountered on this field trip.

This particular field trip represents combined elements of two recent and very popular Pacific Section S.E.P.M. field trips to the San Joaquin Hills-coastal Orange County area (Vernon and Warren, 1970; Bergen, 1971). The guidebooks and road logs for these two trips have been drawn upon freely in composing the following road log. Moreover, several papers from these same two publications are included in the present guidebook along with new contributions relating to the geology and paleontology of this area. Persons following this log independently would be wise to obtain copies of these two earlier guidebooks along with the U.S.G.S. report by Yerkes, McCulloch, Schoellhamer, and Vedder (1965) and the geological map by Vedder, Yerkes, and Schoellhamer (1957) for a more complete view of the geology of this area.

Some of the stops visited during this trip will be on private property—so PLEASE; (a) be careful with cigarettes and matches, (b) do not throw debris from the bus, (c) you will be held financially responsible for any property damage you may cause, and (d) landowners will not be responsible for personal accident or injury which may occur on their property. Use common sense and be particularly careful in climbing to outcrops.

The following road log begins at the intersection of Freeway 405 and University Drive on the northern flank of San Joaquin Hills (Fig. 1) rather than the point of departure at the Disneyland Hotel. The flat urban area traversed between the Disneyland Hotel and the above intersection represents Holocene floodplain deposits of Santa Ana River. If the weather (and smog!) is clear the Santa Ana Mountains can be seen on the north as one travels south along Freeways 5 and 405 and the rolling San Joaquin Hills will appear to the south.

Refer to Maps on Figures 1 and 3-11.

0.0 Intersection Freeway 405 and University Drive; exit Freeway.

0.2 Turn right onto University Drive; hill to the south is held up by Miocene diabase dikes and sills within the Vaqueros Formation.

1.7 **STOP NO. 1**—Intersection of side road to Sand Canyon Reservoir and University Drive. Looking south into Sand Canyon Wash hills immediately to the left are composed of coarse Vaqueros Formation sands representing littoral marine deposition. A gradational contact with the underlying non-marine Sespe Formation occurs just south of the South Coast Gun Club buildings seen on the left. Excavations within the non-marine Sespe Formation can be seen to the right and in front of the spillway area of Sand Canyon Reservoir. Boulder ridge in the far distance behind the reservoir area is composed of the Paleocene Silverado Formation representing an earlier pre-Oligocene marine cycle in this area.

Continue west along University Drive; low hills immediately to the south are composed of Vaqueros sandstone.

3.2 Intersection University Drive and Culver Drive; turn right onto Culver Drive and continue south past hills of Vaqueros sandstone. University of California at Irvine campus can be seen on the right.

3.7 Intersection Campus Drive and Culver Drive with community of Turtle Rock on the left. Canyon immediately to the left marks the approximate fault boundary between the Oligocene Vaqueros sandstones and a higher hill composed of the Los Trancos member of the middle Miocene Topanga sandstone representing shelf deposition. The hill is held up by a relatively thick sill of diabase with all beds dipping about 20° northwest.

4.8 Low road cuts in the Los Trancos member of the Topanga Formation; well bedded coarse to fine sands exhibit traction structures including ripples and represent inner shelf deposition. A few beds exhibit bioturbation and backfilled tubes.

Continue southwest along Culver Drive passing additional low roadcuts in the Los Trancos member of the Topanga Formation on the right; channeling is apparent in some of these exposures.

5.8 Intersection Culver Drive and Coyote Canyon Road (note that Culver Drive becomes Bonita Canyon Drive beyond this point). Turn left onto Coyote Canyon Road leading to land-fill project and proceed up hill.

6.2 Begin large road cut in Los Trancos member of the Topanga Formation.

6.4 **STOP NO. 2**—Turn right off paved road onto wide area on shoulder of road adjacent to overgrown dirt road leading up hill. Easily accessible and good exposures of interbedded sands and silts of the Los Trancos member of the Topanga Formation can be seen in road cuts at this point. Poorly preserved benthonic foraminifera of Relizian age are present in the finer grained beds at this location and indicate deposition at outer shelf depths (50-100 m). Scattered megafossils and commonly bioturbated beds attest to the former abundance of larger invertebrates.

Topanga Formation in the San Joaquin Hills (Comments by J. G. Vedder, U.S.G.S.)

Widespread exposures of a thick sequence of beds composed dominantly of sandstone that form a northwest-trending broad belt of outcrops in the central San Joaquin Hills are assigned to the Topanga Formation.

Three members have been differentiated in the area of outcrop that extends in a broad strip through the central San Joaquin Hills from Laguna Beach nearly to Upper Newport Bay. Undifferentiated strata that probably are equivalent to the lower and middle members constitute most of the outcrops in a coastal belt about a mile and a half wide north and east of Laguna Beach. A similar undifferentiated sequence lies northeast of the Laguna Canyon fault and extends southeast beyond the mouth of Aliso Creek. A relatively thin section of the Topanga Formation is exposed north of Trabuco Creek and in isolated patches in the foothills east of El-Toro Air Station. A thick section of strata assigned to the formation is present in the subsurface southwest of the Pelican Hills fault zone.

The lower contact of the Topanga Formation is gradational in the San Joaquin Hills but is unconformable in the

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[1] Placement of the Oligocene-Miocene boundary is in dispute; this report places the Zemorrian stage of Kleinpell (1938) and the Vaqueros Formation within the Oligocene on the basis of planktonic criteria (see Ingle, this volume).

foothills of the Santa Ana Mountains. A mile northwest of the juncture of Niguel Road and Laguna Canyon Road, lenticular very thick bedded sandstone beds at the base of the Topanga Formation lie without apparent discordance on thinner bedded more persistent and uniform beds of limy sandstone at the top of the Vaqueros Formation. A similar change in the character of the bedding marks the contact about two miles north of Laguna Beach near Moro Canyon.

In the foothills of the Santa Ana Mountains the base of the Topanga Formation is marked by an erosional disconformity; the contact is well exposed in the cliff-forming outcrops on the west side of Trabuco Creek where conglomeratic sandstone beds at the base of the Topanga Formation are slightly channeled into the underlying finer grained strata of the Vaqueros Formation.

Los Trancos Member of the Topanga Formation (Comments by J. G. Vedder, U.S.G.S.)

A thick sequence of interbedded sandstone and siltstone beds that form an accurate belt of exposures in the central and northwestern parts of the San Joaquin Hills is assigned to the Los Trancos Member of the Topanga Formation. Outcrops of the member extend northwestward from the vicinity of Los Trancos Canyon across Coyote Canyon and Bonita Creek and thence eastward to Bommer Canyon. Faulted exposures of the member are present along the Pelican Hills zone southeast of Los Trancos Canyon. The member extends westward and northwestward in the subsurface at least to Upper Newport Bay and probably well beyond. Strata assigned to the member also were penetrated by wells southwest of the Pelican Hills fault zone near Corona del Mar.

The lower contact of the Los Trancos Member is relatively well defined, and the beds at the base apparently rest conformably on the thick-bedded sandstone sequence at the top of the underlying Bommer Member. Weakly resistant strata at the base of the Los Trancos Member contrast sharply with the bold outcrops of the Bommer Member.

The dominant lithology of the Los Trancos Member is indistinctly to massively bedded micaceous clayey siltstone that breaks with a hackly or conchoidal fracture. The siltstone beds are moderately indurated and locally contain thin laminae of very fine-grained sandstone and shale. Interbedded poorly sorted micaceous fine- to medium-grained sandstone beds are distributed throughout the section but are increasingly abundant in the middle and upper parts of the member near the Pelican Hills fault zone. Locally, lenticular very coarse-grained pebbly sandstone beds are intertongued with the finer grained clastics; these sandstones are very poorly sorted, lack definite bedding, and contain a high percentage of angular blue schist clasts and clayey matrix. Nonpersistent beds of water-laid tuff and highly tuffaceous sandstone as much as six feet thick are interbedded with the sandstone and siltstone beds at a few places. Numerous sill-like intrusives of diabase, two inches to five feet thick, are common in the Los Trancos Member, particularly in the downfaulted block west of Bommer Canyon.

A maximum thickness of 3,100 feet is estimated for the Los Trancos Member in the Coyote Canyon-Bonita Creek area. The section penetrated in Morton and Sons well Irvine No. 56-1 just east of Upper Newport Bay suggests that the member thins to about 2,300 feet in a westerly direction from the outcrop section.

Megafossils are uncommon in the Los Trancos Member, and the bulk of those collected are unidentifiable molds of small fragmentary pelecypods. The only identifiable species that may be considered diagnostic is *Aequipecten andersoni*. Foraminifera from several localities in the member are indicative of the Relizian Stage.

The bulk of the underlying Bommer Member in the type area is composed of lenticular thick-bedded pebbly sandstone beds that weather to prominent cavernous cliff-forming outcrops. The member consists of a resistant, very thick bedded lower sandstone unit, a less resistant thinner and finer grained middle sandstone-siltstone unit, and a resistant, thick-bedded upper sandstone unit that is similar to the lower unit.

The maximum estimated thickness of the Bommer Member in the type area is about 2,400 feet. A thick sequence of beds in Laguna Canyon that presumably is equivalent to the Bommer Member is approximately 1,800 feet thick.

The most abundant fossil mollusks in the Bommer Member are *Turritella temblorensis* and *Turritella ocoyana*. Even though these species range down into strata of early Miocene age elsewhere, their frequency plus the lack of diagnostic early Miocene forms suggest a middle Miocene age. Core samples from the member in Shell Oil Company Contraflush No. 12 yielded foraminifera that represent the Relizian Stage.

Diabasic Intrusives—Diabase dikes, which form a radiating pattern north and northwest from Laguna Beach, intrude sedimentary rocks that range in age from Paleocene to middle Miocene; many of these were emplaced along pre-existing faults. Within the Los Trancos Member pyroxene diabase has intruded the sediments to form small sills and large silllike bodies that are nearly concordant with the bedding. Similar diabase has been penetrated in a number of wells and coreholes to the west and northwest of the San Joaquin Hills and along the Pelican Hills fault zone. A single exposure of intrusive rock that projects through terrace deposits between Bonita Reservoir and upper Big Canyon may be the remnant of a plug; the rock is an amygdular coarse-grained diabase.

Intrusion of the diabase dikes and sills took place during part of the Relizian Stage, but probably was not everywhere simultaneous as suggested by relations along the pre-Luisian Shady Canyon fault. After fault fracturing, some diabase apparently moved up along the fault near Laguna Canyon, but older diabase bodies were cut by the fault west of Sand Canyon Reservoir although it is possible that intrusion was simultaneous and later movement occurred along the north segment of the fault.

6.6 Turn around at dirt road leading to county land fill project and travel north on Coyote Canyon Road to intersection at base of hill.

7.4 Intersection Coyote Canyon Road and Bonita Canyon Drive (Culver Drive to the right). Road cuts at intersection contain poorly bedded outer shelf deposits in the Los Trancos member of the Topanga Formation.

7.6 Approximate boundary between Los Trancos and Paularino members of the Topanga Formation; faulted exposures of both members occur in roadcuts adjacent to Bonita Canyon Reservoir.

7.9 **STOP NO. 3**—Exposures of submarine andesitic flows and autobreccias near the base of the Paularino member of the Topanga Formation. Turner (1970) recently obtained a KA date of 15.4= 1.3 m.y. for this unit. These exposures represent a transition from shelf to bathyal deposition and volcanism may have been associated with this structural hinge-line.

Lower Paularino Member of the Topanga Formation and associated breccias (Comments by J. G. Vedder, U.S.G.C.)

At the northwest margin of the San Joaquin Hills, an incompletely exposed sequence of interbedded sandstone and siltstone beds containing lenses of sedimentary breccia and volcanic flow breccia is assigned to the Paularino Member of the Topanga Formation. Rock types similar to characteristic outcrop lithologies were penetrated by exploratory wells to the west and northwest, but the member is not known to be present in the subsurface southwest of the exposed part of the Pelican Hills fault zone.

The lower contact of the Paularino Member is a disconformity that is marked by discontinuous outcrops of andesite flows and flow breccias. These flow remnants separate Catalina Schist-bearing siltstone and sandstone beds at the top of the Los Trancos Member from the basal, volcanic-bearing sandstone and breccias of the Paularino Member.

The lower part of the Paularino Member primarily is composed of fine- to medium-grained tuffaceous sandstone beds that are interbedded with lesser amounts of fine- to very coarse grained sandstone. Thin beds of sandy siltstone and mudstone are distributed through the sequence. The distinctive bluish-gray sandstone beds contain a high percentage of dark mineral grains and volcanic rock fragments. Thin streaks composed chiefly of pumiceous fragments and rock granules of variable composition locally are distributed through the bluish sandstone beds. Large pods and lenses of breccia that contain a large amount of glassy andesite are intertongued with and possibly are injected into the sandstone beds in the lower part of the member. The andesite blocks commonly attain a diameter of four feet and occasionally are far larger. The larger bodies of breccia attain thicknesses of 150 feet or more and extend for nearly a half mile along the strike. Locally these breccia bodies apparently lack a sandy matrix and bedding in the containing sandstone is highly deformed near some of the breccia masses suggesting that the breccia may have formed along the distal edges of nearby submarine lava flows which were partially injected nto the unconsolidated sediments.

Higher in the Paularino Member, the sedimentary breccias are finer grained and more restricted in size and distribuion, and the dominant lithology is ine- to very-coarse-grained micaceous andstone. Thinly laminated fine-grained micaceous sandstone and andy siltstone beds are increasingly bundant near the top of the section nd resemble Monterey Shale. The andy siltstone beds range from masive to fissile and at some places contain foraminifera that suggest assignment to the Relizian and early Luisian tages.

The Paularino Member may be as much as 1,500 feet thick between Bonita Reservoir and San Joaquin Dam, but the sparsity of outcrop precludes accurate estimates of thickness. About 1,360 feet of strata assigned to the member were penetrated in Morton and Sons well Irvine No. 56-1 and apprxoimately 1,455 feet of similar rocks were drilled in Standard Oil Company well Irvine No. 1 (north). The member presumably thins southwest from Bonita Creek and the upper part may intertongue with the Monterey Shale in the same direction.

Flows and Flow Breccias—Poorly exposed outcrops of volcanic rocks in the vicinity of Bonita Creek Reservoir are interpreted as submarine flows and autobreccias along the contact between the Los Trancos and Paularino Members. Slightly above the base of the Paularino Member, breccia tongues that are believed to be intermixed pyroclastic volcanic rocks and marine sediments are exposed in a belt about 2 miles long that extends from the mouth of Sand Canyon Wash to MacArthur Boulevard. An erosional disconformity at the top of the flows and flow breccias is suggested by detrital andesite debris in the sedimentary section that immediately overlies the flows and that underlies the zone of pyroclastic and sedimentary breccia lenses. The largest exposed flow remnant is approximately 80 feet thick.

The lenticular and podlike masses of breccia that occur within the Paularino Member presumably include some pyroclastic breccia and injected flow debris. Large angular blocks of glassy andesite in the breccia commonly are vesicular or amygdular and the matrix locally consists of poorly sorted and mixed glass and palagonite. The rock has the characteristic appearance of a pyroclastic breccia and may have formed near submarine vents or along the margins of submarine sediments of the Paularino Member.

Zones of breccia and volcanic rock similar to those in outcrop were penetrated in several wells and coreholes to the west and northwest of the exposures near Bonita Creek.

8.1 Low road cut on right (north) contains coarse volcanic sands in Paularino member of the Topanga Formation. Large gravity structures and swirled tuffaceous shales indicate rapid downslope transport.

8.5 Low road cut on right (north) of tuffaceous and diatomaceous shales in the upper portion of the Paularino Member of the Topanga Formation representing middle bathyal deposition. Benthonic foraminifera within shales are representative of the lower Luisian Stage.

8.55 Unconformity between middle Miocene Topanga Formation and overlying Plio-Pleistocene shallow water sediments.

9.0 Intersection Bonita Canyon Drive and MacArthur Boulevard; turn right.

9.4 Intersection MacArthur Boulevard and University Drive.

9.7 Intersection MacArthur Boulevard and Bristol Street; turn left onto Bristol.

9.9 Intersection Bristol and Jamboree Road; turn left onto Jamboree Road.

10.2 Cross bridge over Upper Newport Bay; old salt ponds on the right. Travel uphill onto surface of Pleistocene marine terrace.

12.0 Intersection San Joaquin Hills Rd. and Jamboree Rd.; view to the right (west) across the surface of Pleistocene marine terrace interrupted by Newport Bay.

12.9 Intersection Jamboree Rd. and Back Bay Drive; turn right onto Back Bay Drive past hotel and marina.

13.6 Old road cut in contorted siliceous shales of middle Miocene Monterey Shale (behind barbed wire fence!)

13.9 **STOP NO. 4.** Intersection Back Bay Drive and San Joaquin Hills Road. Well bedded and laminated diatomites, diatomaceous shales, and siltstones of the Monterey Shale occur in steep road cuts on both sides of this intersection. Prolific benthonic and planktonic foraminiferal faunas of Luisian age occur in diatomites on the south side of the intersection along with abundant siliceous microfossils (see articles by Casey, Ingle, Warren and Wornardt in this volume). Lower Mohnian faunas occur in diatomaceous shales on the north side of the intersection. Analysis of these beds and associated faunas indicates that deposition occurred within a silled basin at middle to lower bathyal depths where dissolved oxygen values were less than 0.2 ml/1 0^2 excluding a benthic infauna and inturn allowing preservation of laminated diatomites (see Ingle, this volume). Green and gray siltstones probably represent displaced turbidite material from shallower depths on the basin slope and sill.

14.3 **STOP NO. 5**—Exposures of bathyal upper Miocene laminated diatomites within the Monterey Shale occur on the point immediately south of Big Canyon. These beds represent the stratigraphically highest portion of the Monterey Shale. The conformable and gradational contact with the radiolarian-rich mudstones of the over-

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lying Capistrano Formation occurs beneath Big Canyon but is well exposed on the west side of Upper Newport Bay and can be seen from this stop.

14.8 Bluff on north side of Big Canyon. Red brown mudstones exposed along the base of the bluff represent late Miocene radiolarian-rich beds of the lower Capistrano Formation. Abundance of radiolarians, petrology, and lack of calcareous material suggests these sediments represent deposition at depths exceeding 3000 m similar to deep basinal sediments extent in the Gulf of California today.

15.1 Poor exposures of early Pliocene silts and turbidite sands of the upper Capistrano Formation and lower Fernando Formation. Benthonic foraminiferal faunas of Repettian age representing lower bathyal and middle bathyal depths have been collected in equivalent beds on the west side of upper Newport Bay.

15.3 Good exposures of middle Pliocene sandy siltstones of the Fernando Formation representing predominantly turbidite and gravitite deposition (see article by Natland, this volume) at middle bathyal depths.

Road deteriorates at this point although it may be paved in the near future. Exposures farther north along Back Bay Drive represent progressively shallower deposition during the later Pliocene. Early Pleistocene inner shelf deposits of the uppermost Fernando Formation (see Ingle, this volume) have been destroyed by excavation for tract housing.

Turn around and return to intersection of Back Bay Drive and Jamboree Road.

17.6 Intersection Jamboree Rd. and Back Bay Dr.; turn right onto Jamboree Rd.

17.8 Intersection Jamboree Rd. and Pacific Coast Highway; turn left onto Pacific Coast Highway and travel south through Corona del Mar.

Traverse between Corona de Mar and Laguna Beach crosses surface of Pleistocene terrace cut on Middle Miocene Monterey Shale. Higher terraces can be seen on the left of the highway.

23.6 Moro Beach; hill and prominent cliff at south end of beach composed of late Miocene (?) intrusive andesite. Continue past residential community of Emerald Bay and enter Laguna Beach city limits.

25.3 Intersection Cliff Drive and Pacific Coast Highway; turn right onto Cliff Drive which turns into Barranca Street.

25.32 **STOP NO. 6**—Park on Cliff Dr. (Barranca St.) and walk toward beach. Cemented walkway with sign leads to Crescent Bay Beach and marine reserve. Exposures of sandy fossiliferous San Onofre Breccia and portions of the "graded sandstone facies" of this same unit are exposed on the south side of Crescent Bay and continue south to Boat Canyon. Refer to the paper by C. Stuart (this volume) and Vedder (1971) for a detailed explanation of these exposures. An exposure of Monterey Shale in fault contact with the San Onofre Breccia is exposed at the north end of the Bay.

25.33 Turn left onto Cliff Drive and continue south.

25.8 Parking area at Divers Cove. Walk down stairs to examine prominent andesite intrusive within lower Topanga Formation. Immediately north of parking area another walkway leads between apartments to Fishermans Cove with additional good exposures of San Onofre Breccia at north end of this beach.

26.3 Intersection Cliff Dr. and Pacific Coast Highway; turn right onto Pacific Coast Highway and travel south through central Laguna Beach.

27.4 Intersection of Pacific Coast Highway and Crest Street. Excellent exposures of San Onofre Breccia occur in the sea cliffs at the end of Crest Street and south to Aliso Beach. Good exposures of this unit also occur along Pacific Coast Highway in South Laguna; tell-tale red color and blue schist fragments mark this unit in spotty roadcuts along Pacific Coast Highway from Laguna south to Salt Creek.

33.4 Salt Creek.

34.3 Intersection Green Lantern Street and Pacific Coast Highway; turn right onto Green Lantern in town of Dana Point.

35.0 Intersection Green Lantern St. and Cove Road; overview of Dana Point marina and cliffs of Miocene Capistrano formation including exposures of submarine fan and channel facies. Turn left onto Cove Road and proceed to base of cliffs and parking area at Dana Point.

35.3 **STOP NO. 7**—Spectacular exposures of San Onofre Breccia are present in the cliffs at the seaward end of Dana Point to the right (west) of the intersection of Cove Road and Del Obispo St. at base of cliffs. Fault contact between San Onofre breccia and exposures of Capistrano Formation occurs at bend in cliff section immediately behind the above intersection at base of Cove Rd. Park and walk west to exposures of San Onofre Breccia. This portion of the San Onofre Breccia is assigned to the "mud-matrix breccia facies" of Stuart (this volume) and contains car-sized angular blocks along with typical channelized deposits of breccia dominantly composed of Catalina Schist.

35.8 **STOP NO. 8**—Exposures of submarine fan and channel deposits within the lower Capistrano Formation are displayed in the cliff section and road cuts from the base of Dana Cove Rd. east along Del Obispo Road almost to the intersection with Pacific Coast Highway. These deposits, termed the Doheny Miocene Fan and channel system by Bartow (1966, and this volume) have been discussed in detail by Normark and Piper (1969) and Piper and Norwalk (1971). Microfossil evidence within silts and shales enclosing these coarse deposits indicates they were deposited at bathyal depths (Ingle, this volume). Piper and Normark (1971) recognize five principal facies within these deposits representing a prograding turbidite sequence; (a) lower sands and conglomerates, (b) slide blocks, (c) western upper sands, (d) channel margin silts, and (e) the Doheny channel facies proper. The lower conglomerates, breccias and sands are exposed at the western end of the cliffs with the slide blocks, channel margin silts, and Doheny channel facies exposed in newer road cuts in the eastern portion of the exposures. Please refer to papers in this volume by Bartow, Ingle, and Natland for more detailed discussions of these deposits.

36.5 Intersection Del Obispo Road and Pacific Coast Highway; turn left onto Pacific Coast Highway.

36.9 Intersection Copper Lantern St. and Pacific Coast Highway; turn right onto Copper Lantern Street.

37.2 **STOP NO. 9**—Exposures of diatomaceous late Miocene Capistrano Formation at intersection of La Paz St. and Copper Lantern St. Low roadcuts on Copper Lantern St. contain thin bedded and laminated diatomites within a sequence of radiolarian-rich mudstones. Diatomites contain a Mohnian or Delmontian benthonic foraminiferal fauna described by White (1956) and Ingle (this volume). Early Pliocene sandy siltstones of the upper Capistrano Formation are exposed one block north of this locality at the intersection of Copper Lantern St. and Selva St.

37.4 Intersection Selva St. and Copper Lantern St.; turn right onto Selva, continue to Stonehill.

37.7 Intersection of Selva and Stonehill streets; turn right.

38.1 Intersection of Stonehill and Del Obispo Streets; turn right.

38.9 Intersection of Del Obispo St. and Pacific Coast Highway; turn right and travel south on Pacific Coast Highway past Doheny Beach State Park. Alternate routes allow travel south to San Clemente via the San Diego Freeway (5) to the Calafia St. exit or travel south to San Clemente via Coast Highway (highway 1) past additional outcrops of the lower Capistrano Formation joining Freeway 5 in San Clemente with exit at Calafia St. The freeway entrance is directly south of the Santa Fe railroad underpass adjacent to Doheny Beach State Park; the coast route continues to the right of the underpass.

46.4 **STOP NO. 10**—Intersection San Diego Freeway (#5) and Calafia Ave. exit; exit freeway onto Calafia Ave. and continue west to end of road and parking area for San Clemente State Beach. Exposures of lower (?) Capistrano formation occur in low cliffs north and south of parking area adjacent to the Santa Fe railroad tracks (WATCH OUT FOR TRAINS!). The better exposures of this sequence lie south of the parking area and contain a full spectrum of sedimentary structures associated with deposition under traction and gravity (Natland, this volume). This sequence has been described as a submarine fan-channel system by Weser (1971) but microfossil evidence confirming depth of deposition is absent leading to controversy about the origin of these deposits.

END OF FIELD TRIP!

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[1] Placement of the Oligocene-Miocene boundary is in dispute; this report places the Zemorrian stage of Kleinpell (1938) and the Vaqueros Formation within the Oligocene on the basis of planktonic criteria (see Ingle, this volume).

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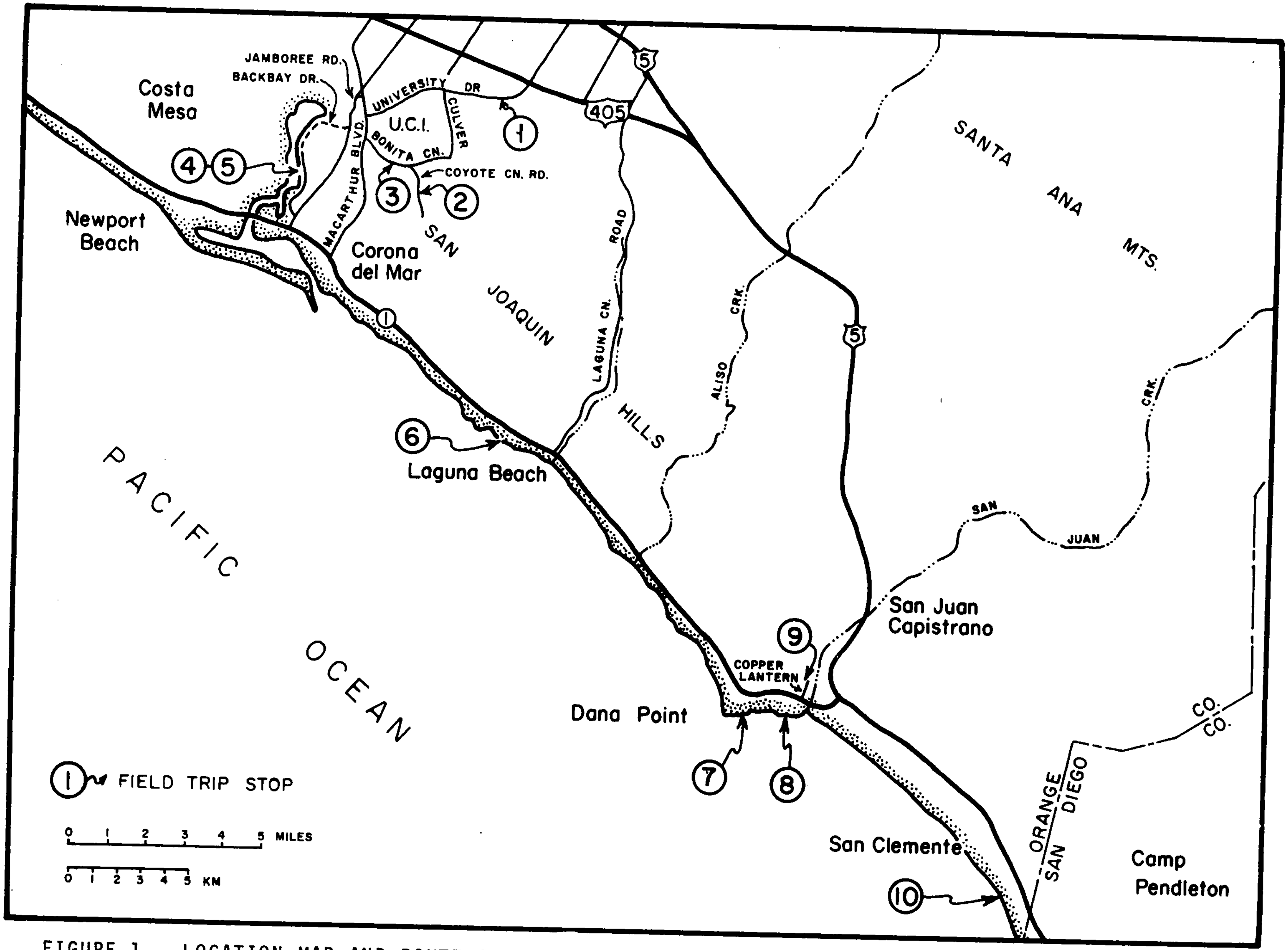
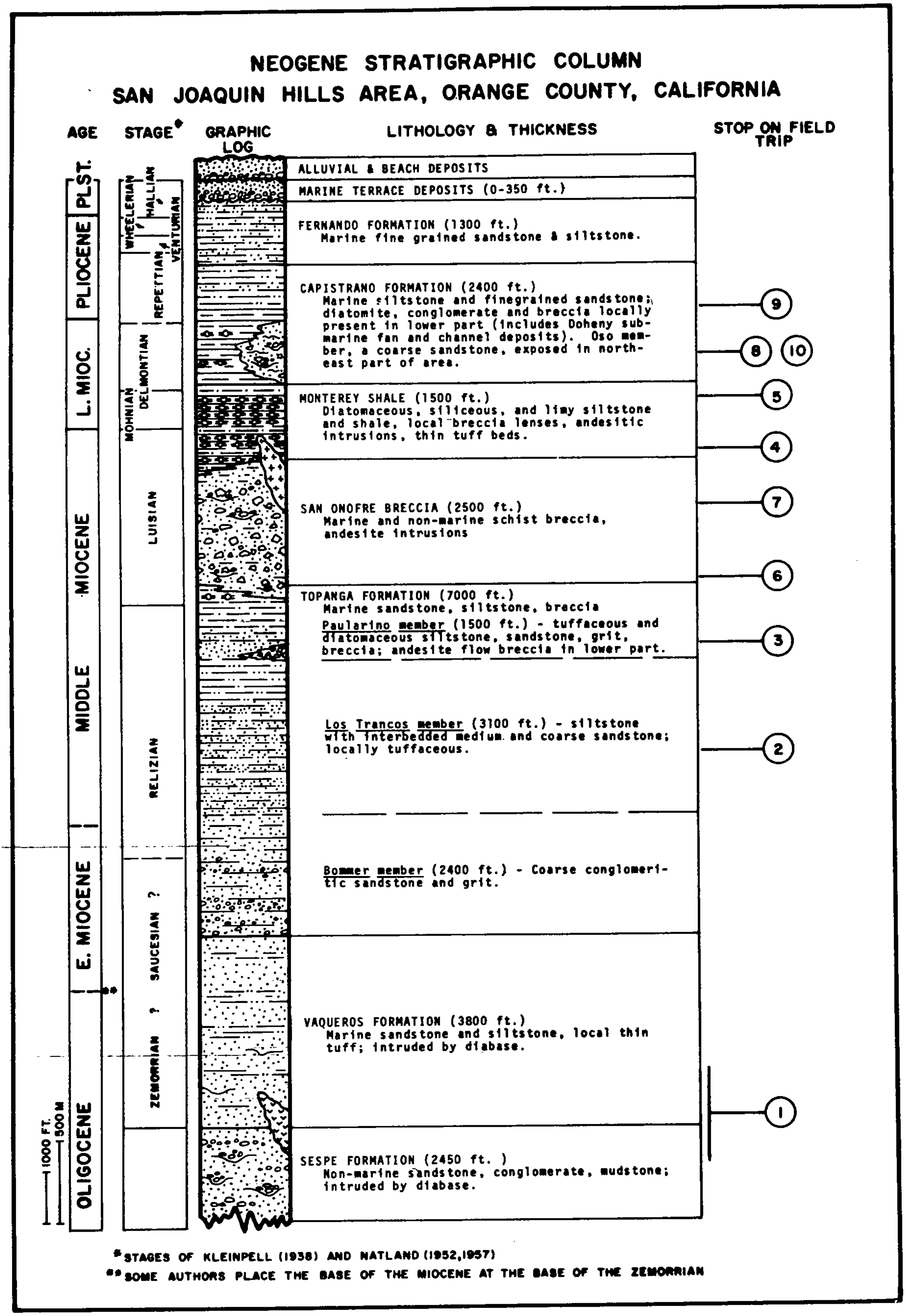


FIGURE 1 - LOCATION MAP AND ROUTE OF S.E.P.M. TRIP NO. 1, PLIOCENE - MIOCENE ENVIRONMENTS AND BIOFACIES, SOUTHEASTERN LOS ANGELES BASIN - SAN JOAQUIN HILLS AREA, ORANGE COUNTY, CALIF.



NEOGENE STRATIGRAPHIC COLUMN
SAN JOAQUIN HILLS AREA, ORANGE COUNTY, CALIFORNIA

ALLUVIAL & BEACH DEPOSITS

MARINE TERRACE DEPOSITS (0-350 ft.)

FERNANDO FORMATION (1300 ft.)
Marine fine grained sandstone & siltstone.

CAPISTRANO FORMATION (2400 ft.)
Marine siltstone and finegrained sandstone; diatomite, conglomerate and breccia locally present in lower part (includes Doheny submarine fan and channel deposits). Oso member, a coarse sandstone, exposed in northeast part of area.

MONTEREY SHALE (1500 ft.)
Diatomaceous, siliceous, and limy siltstone and shale, local breccia lenses, andesitic intrusions, thin tuff beds.

SAN ONOFRE BRECCIA (2500 ft.)
Marine and non-marine schist breccia, andesite intrusions

TOPANGA FORMATION (7000 ft.)
Marine sandstone, siltstone, breccia

Paularino member (1500 ft.) - tuffaceous and diatomaceous siltstone, sandstone, grit, breccia; andesite flow breccia in lower part.

Los Trancos member (3100 ft.) - siltstone with interbedded medium and coarse sandstone; locally tuffaceous.

Bommer member (2400 ft.) - Coarse conglomeritic sandstone and grit.

VAQUEROS FORMATION (3800 ft.)
Marine sandstone and siltstone, local thin tuff; intruded by diabase.

SESPE FORMATION (2450 ft.)
Non-marine sandstone, conglomerate, mudstone; intruded by diabase.

*STAGES OF KLEINPELL (1938) AND NATLAND (1952,1957)

**SOME AUTHORS PLACE THE BASE OF THE MIOCENE AT THE BASE OF THE ZEMORRIAN

FIGURE 2 - NEOGENE STRATIGRAPHIC COLUMN FOR THE SAN JOAQUIN HILLS AREA, ORANGE COUNTY, CALIFORNIA. COMPILED AND MODIFIED FROM DATA IN YERKES, McCULLOCH, SCHOELLHAMER, AND VEDDER (1965).

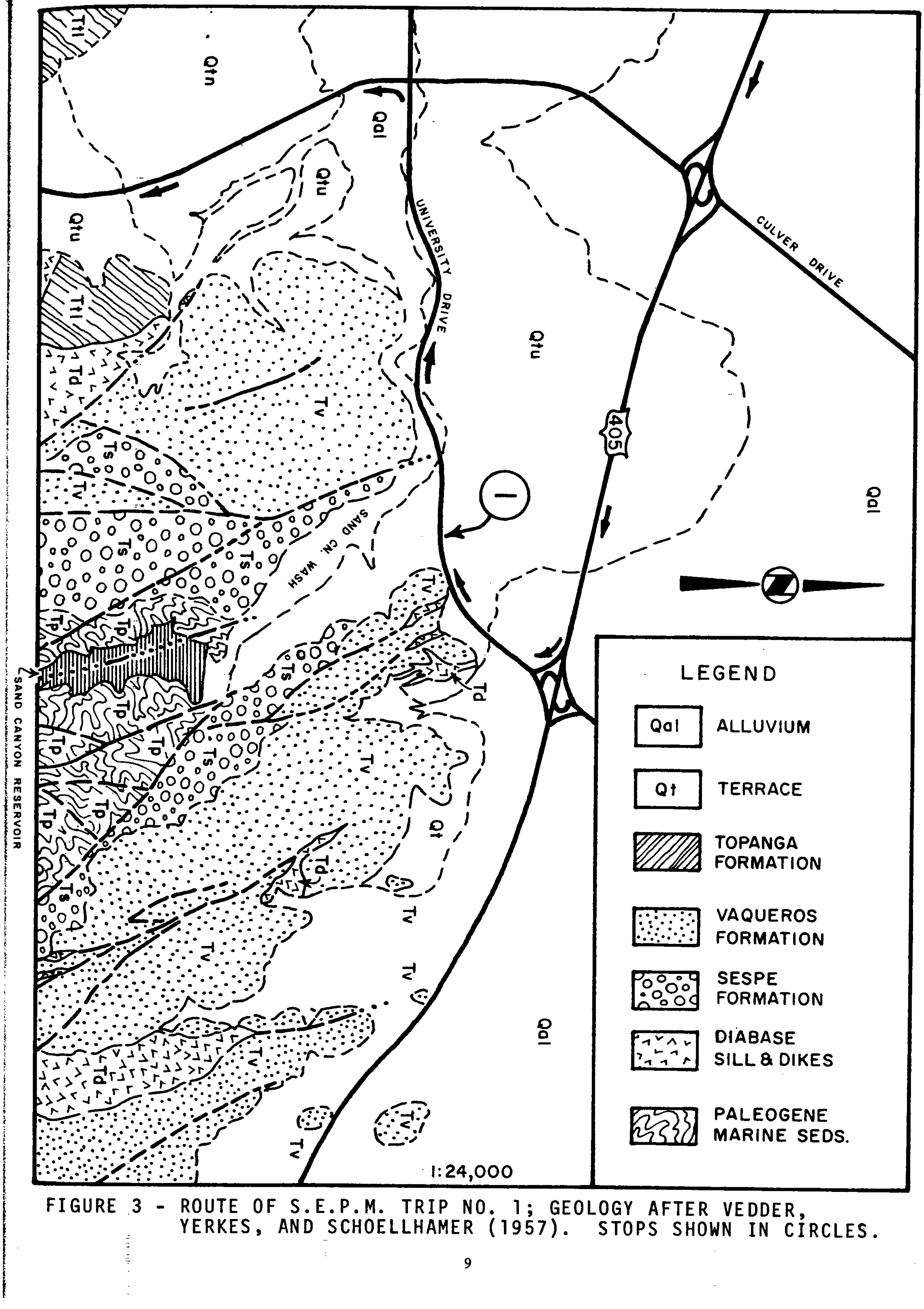


FIGURE 3 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957). STOPS SHOWN IN CIRCLES.

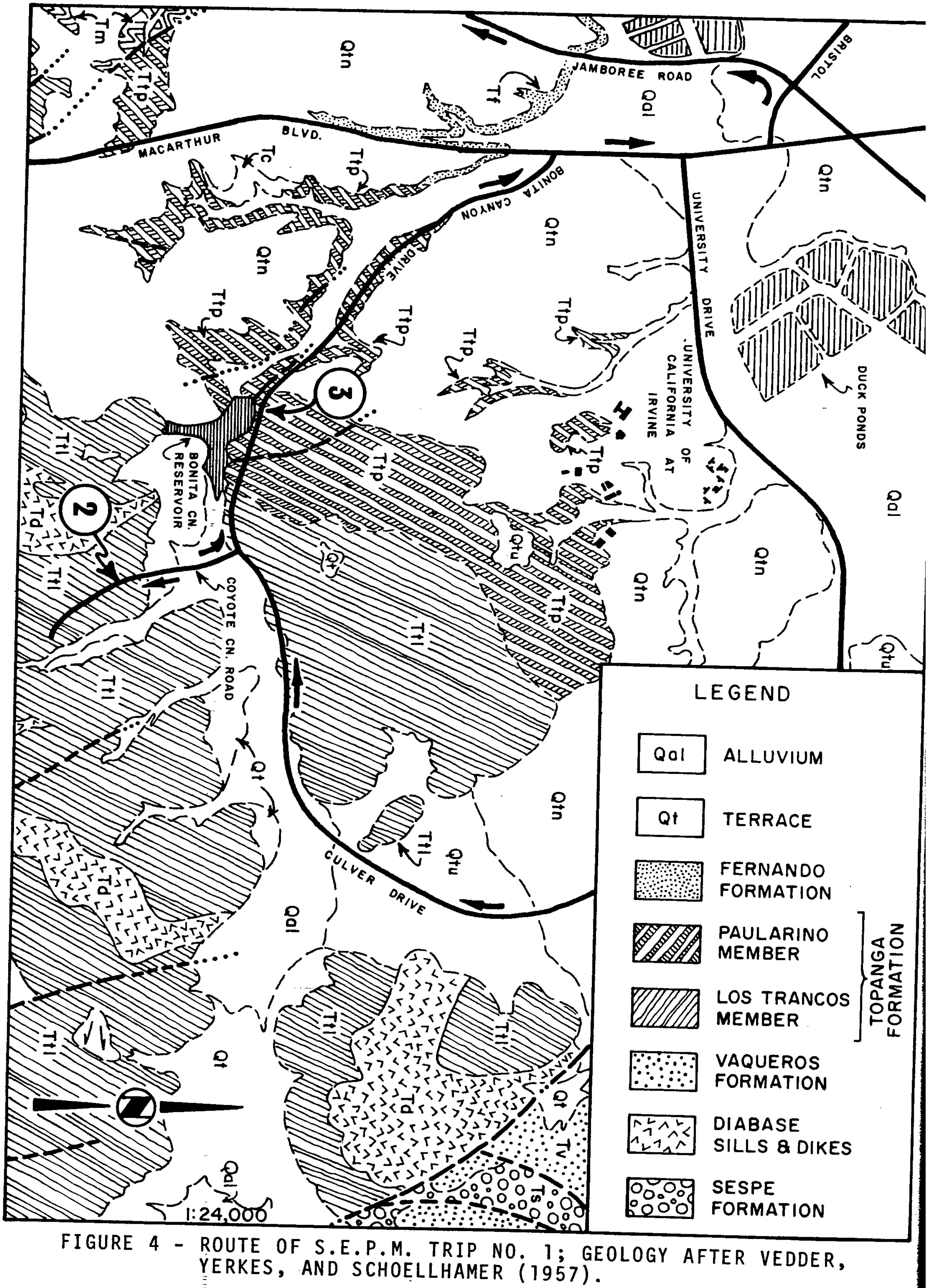


FIGURE 4 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957).

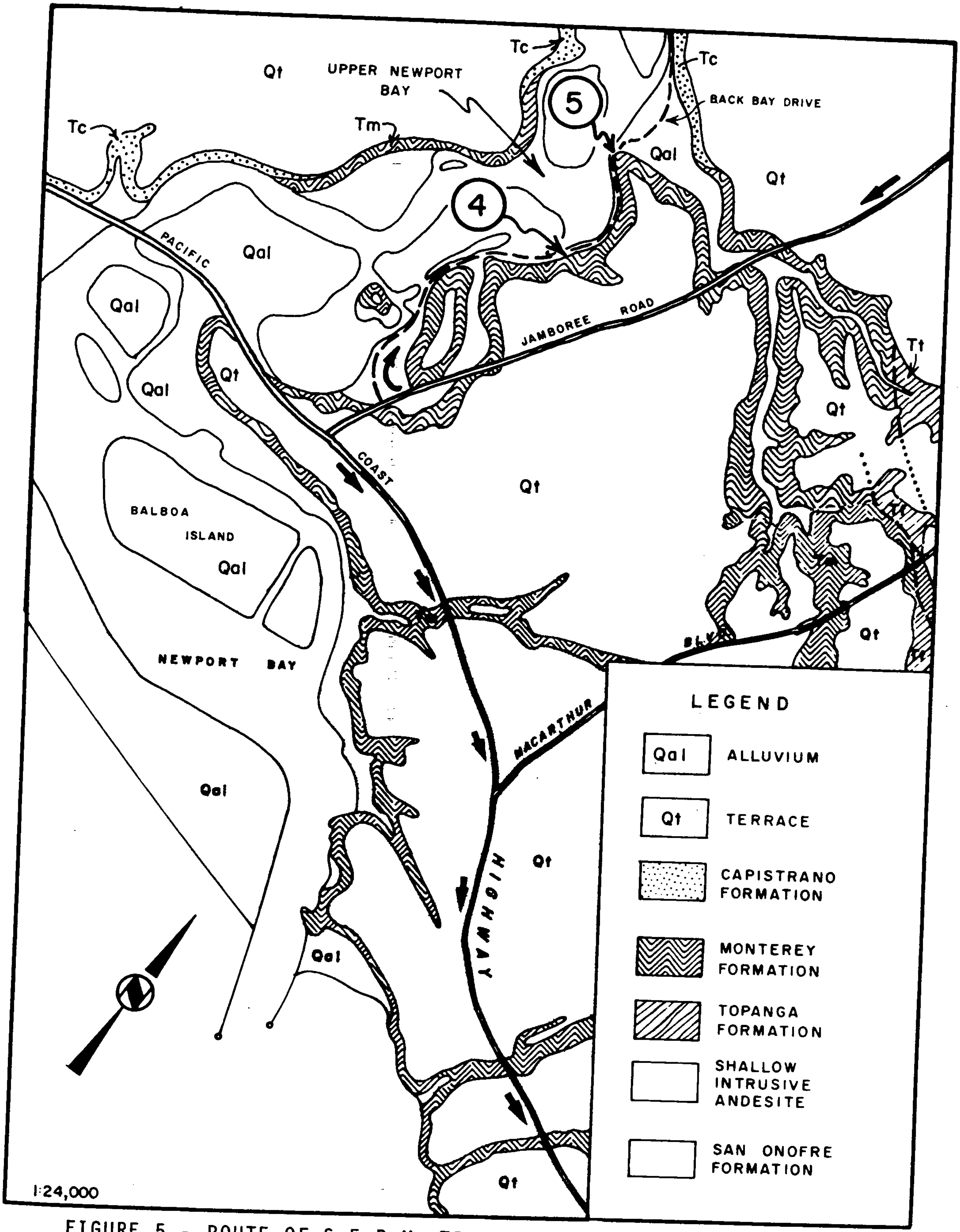


FIGURE 5 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957).

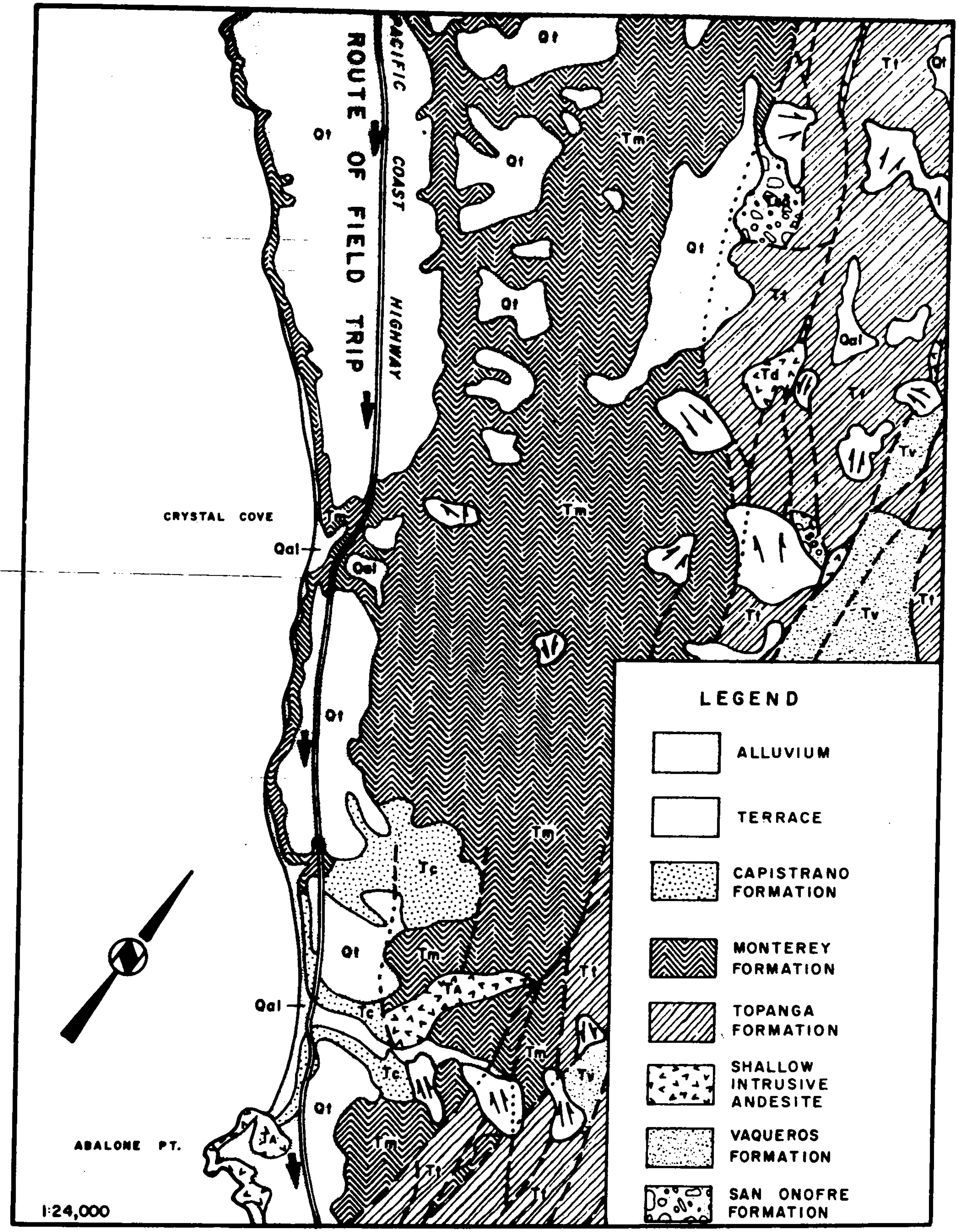


FIGURE 6 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957).

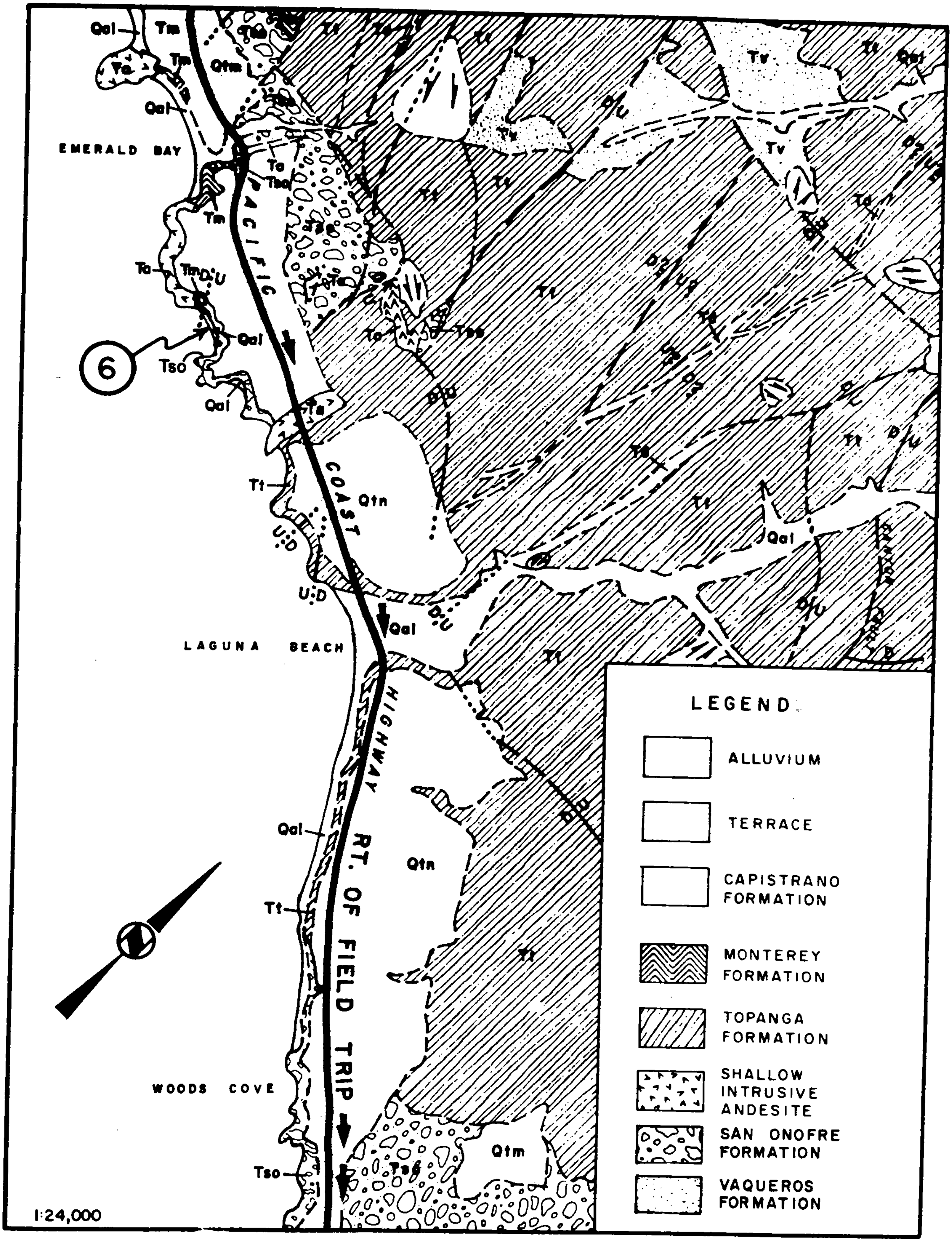


FIGURE 7 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957).

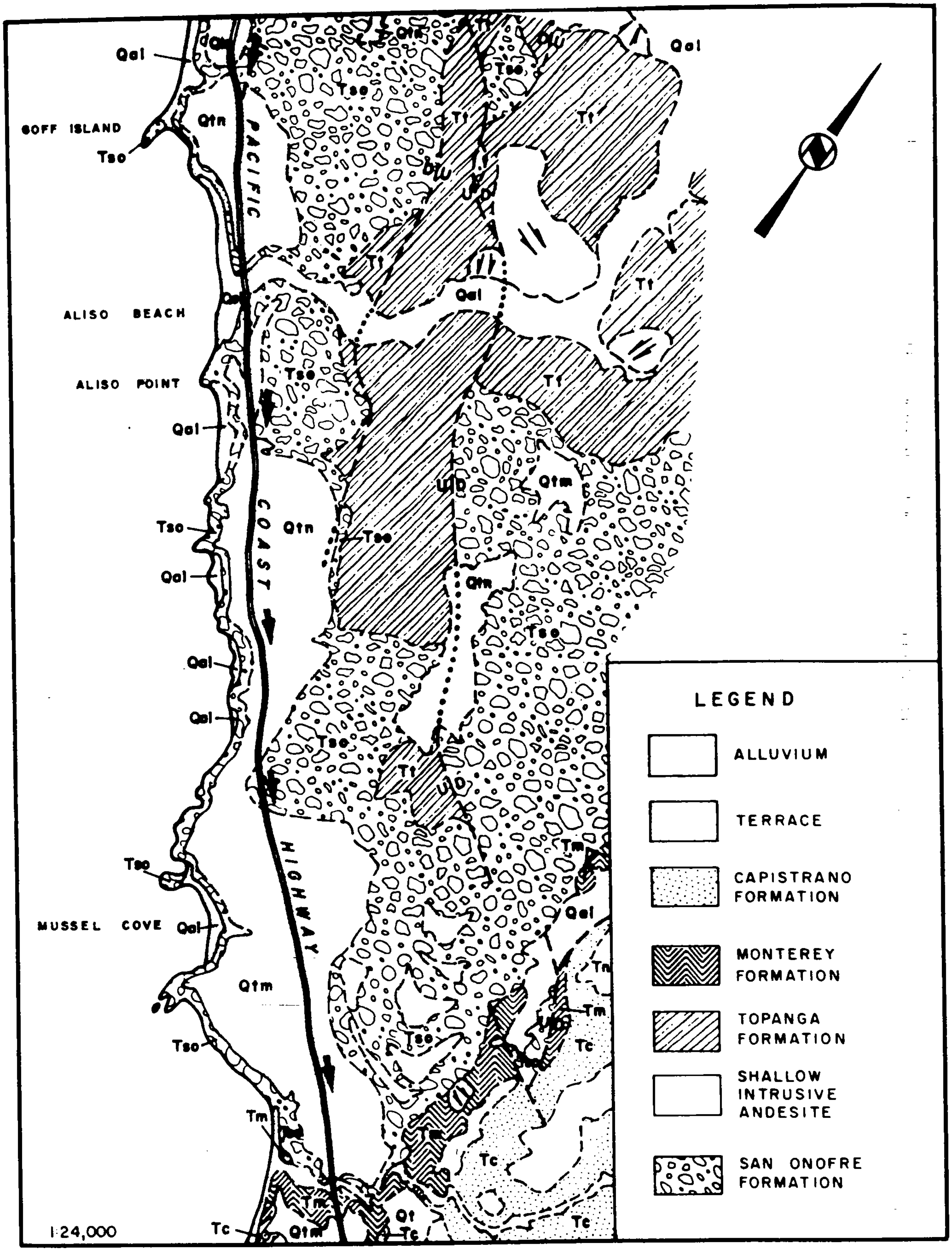


FIGURE 8 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957).

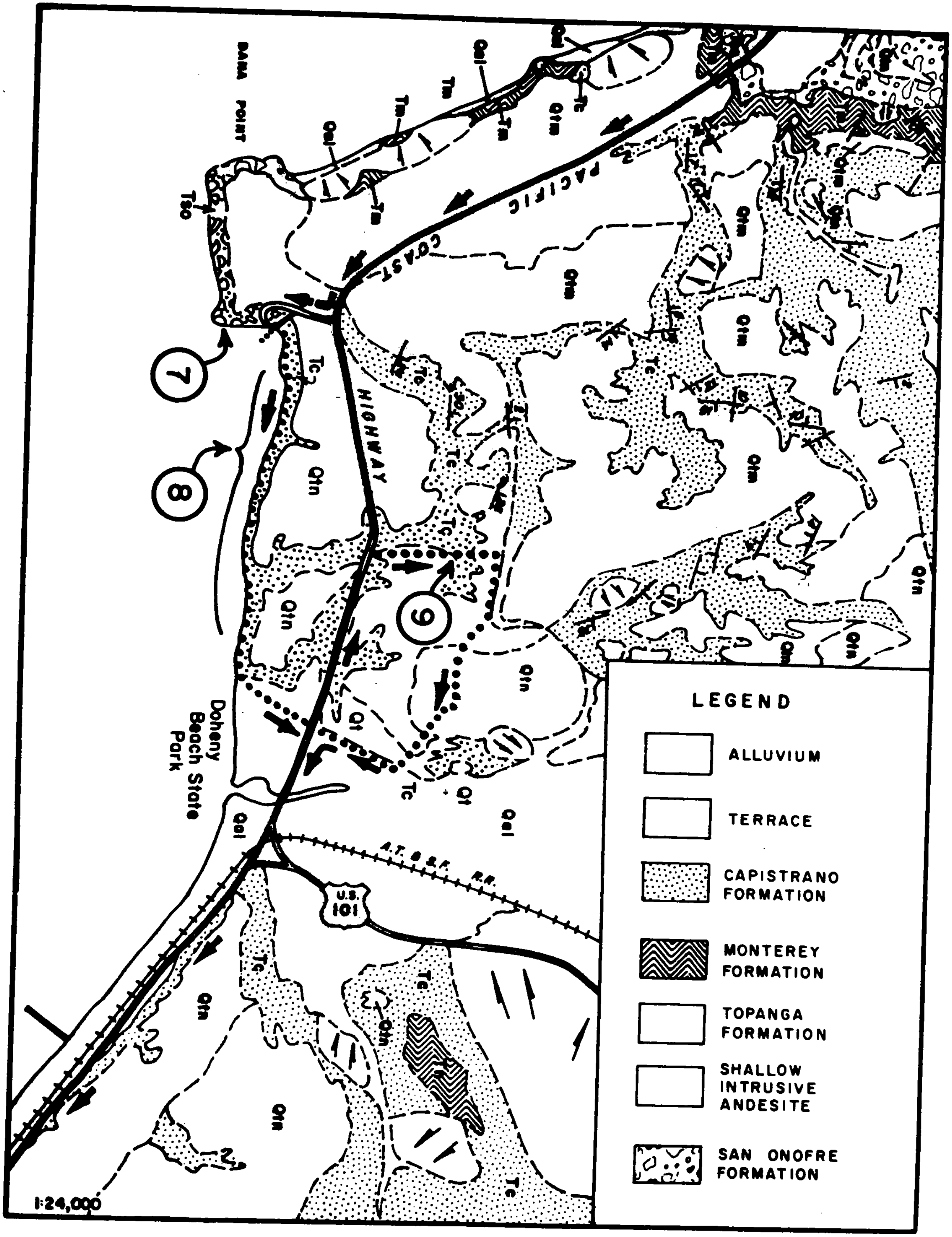


FIGURE 9 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957).

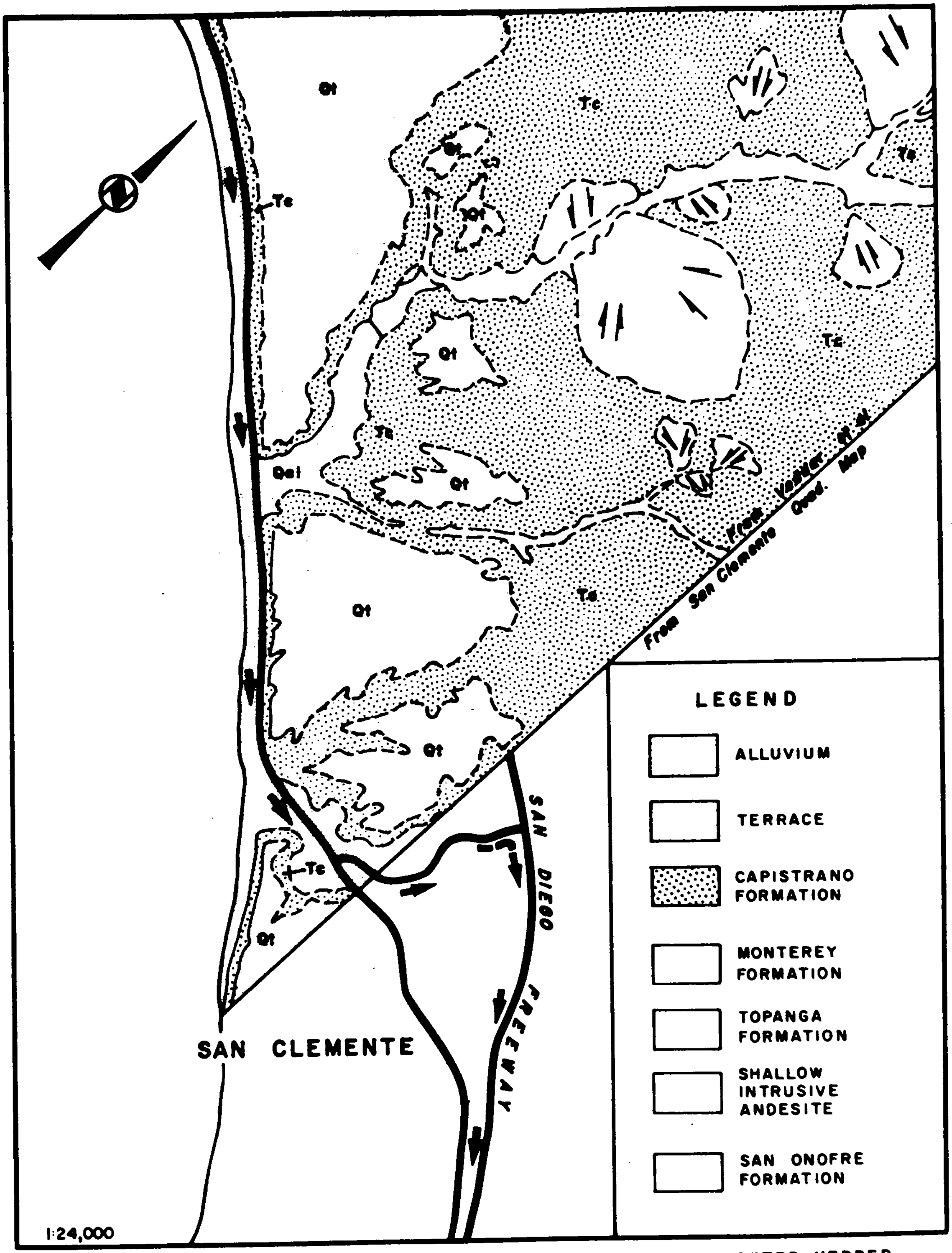


FIGURE 10 - ROUTE OF S.E.P.M. TRIP NO. 1; GEOLOGY AFTER VEDDER, YERKES, AND SCHOELLHAMER (1957).

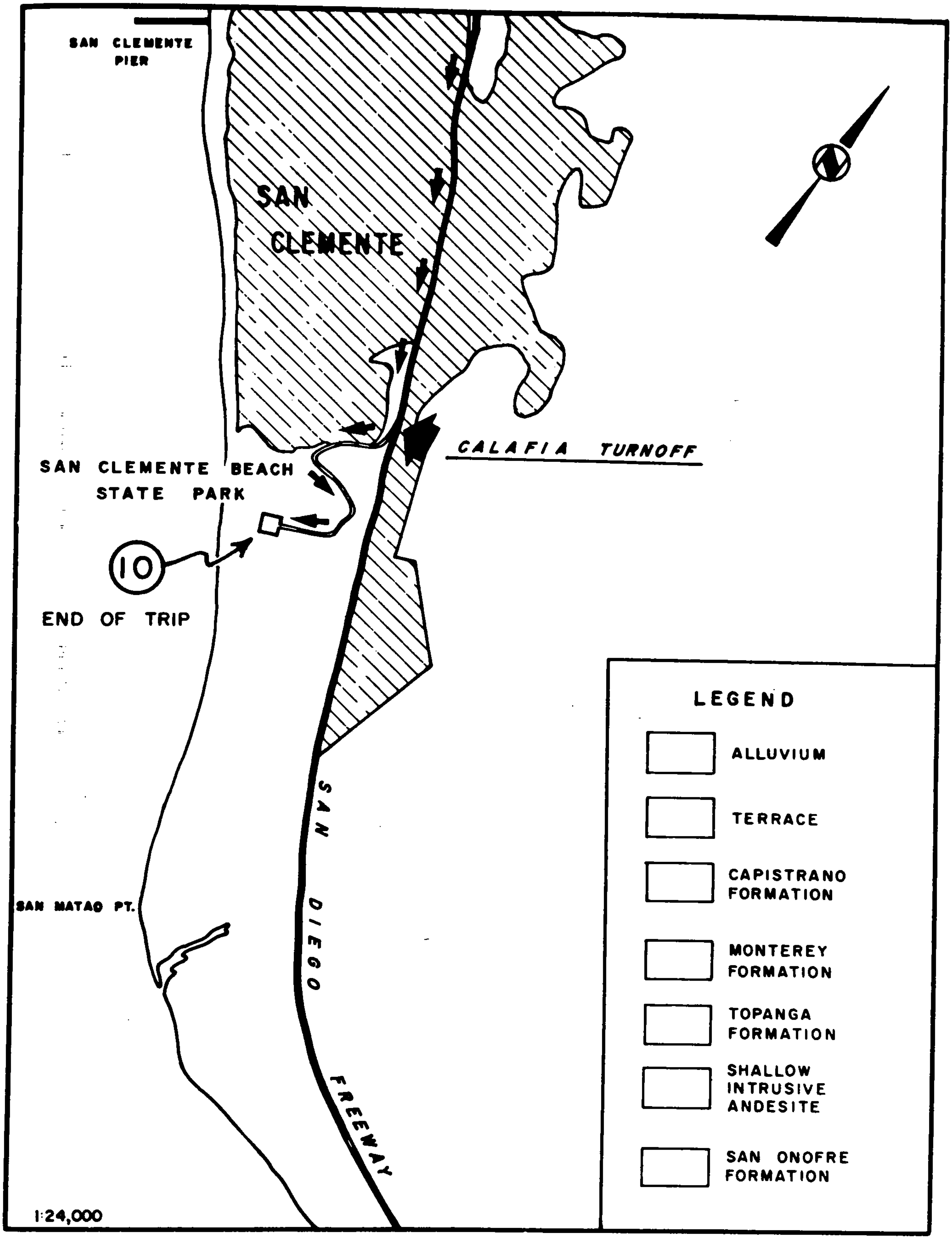


FIGURE 11 - ROUTE OF S.E.P.M. TRIP NO. 1; DISTRIBUTION OF CAPISTRANO FORMATION IS NOT SHOWN; EXPOSURES ESSENTIALLY CONFINED TO CLIFF AND ARROYO AREA ALONG BEACH.

BIOSTRATIGRAPHY AND PALEOECOLOGY OF EARLY MIOCENE THROUGH EARLY PLEISTOCENE BENTHONIC AND PLANKTONIC FORAMINIFERA, SAN JOAQUIN HILLS-NEWPORT BAY-DANA POINT AREA, ORANGE COUNTY, CALIFORNIA

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INTRODUCTION

The Middle and Late Tertiary marine sediments exposed in the western Santa Ana Mountains and coastal area extending south from the Newport Bay-San Joaquin Hills area to San Clemente, California constitute a unique marine geologic resource readily available for study without ship or sea. Analysis of these sediments in light of modern marine lithofacies and biofacies patterns illustrates that they constitute an evolving shelf-to-basin-to-shelf sequence representing deposition at the margin of a major marine basin over a 15-20 million year interval. Moreover, Pleistocene structural and erosional events have enhanced dissection of these deposits so that the diverse marine paleoenvironments represented within this sequence can be easily sampled, scrutinized, and ultimately compared with analogous and well known Recent marine environments off southern California and in the Gulf of California.

The purpose of this particular report is to summarize the paleoecologic and paleobathymetric history of Lower Miocene through Lower Plsistocene marine deposits exposed on the flank of the San Joaquin Hills in Bonita Canyon and in the sea cliffs bordering upper Newport Bay as well as Upper Miocene-Lower Pliocene deposits exposed in the Dana Point-Capistrano area of Orange County, California (Fig. 1). Paleontologic and geologic evidence indicates the Bonita Canyon-Newport Bay sections and Dana Point-Capistrano section represent in part a record of synchronous sedimentary events in two different areas of a single marine basin. This study represents an extension and refinement of an earlier investigation (Ingle, 1962, 1963, 1967)[1] and forms a portion of a larger investigation in progress (Ingle, 1971a) reported on in two earlier Pacific Section S.E.P.M. guidebooks (Ingle, 1971b, 1972).

PREVIOUS WORK

Bonita Canyon - Newport Bay Area

A uniquely complete and essentially continuous sequence of Early Miocene through Early Pleistocene marine sediments is exposed in the cliffs bordering Newport Bay and in the adjacent Bonita Canyon area on the northwestern flank of the San Joaquin Hills, Orange County, California (Figs. 1-3). This sequence encompasses more than 5000 meters of sand, mudstone, diatomaceous shale, siliceous, shale, breccia, volcanic extrusives and tuffs, and records the shelf-to-basin-to-shelf evolution of this portion of the continental margin during the Late Cenozoic interval (Fig. 4). The sediments exposed in these two areas have been assigned to the following formations, from oldest to youngest; Vaqueros Sandstone, Topanga Formation, Monterey Shale, Capistrano Formation, and Fernando Formation.

The sediments and microfossils within the Newport Bay section (Figs. 1 and 3) have been studied for over 40 years (Rankin, 1930). It is well known among local biostratigraphers that prolific foraminiferal assemblages representative of Kleinpell's (1938) Luisian and Mohnian stages and Natland's (1957) Repettian, Wheelerian, and Hallian stages can be collected from various horizons within this sequence (Natland and Rothwell, 1954). In addition, Campbell and Clark (1944) described Miocene radiolarian faunas from several intervals in the Middle and Upper Miocene sediments exposed at Newport Bay in what has become a basic reference work on Miocene radiolarians of the temperate North Pacific area. More recently Ingle (1962, 1963) presented a comprehensive paleoecologic history of the Newport Bay section based on analysis of both benthonic and planktonic foraminifera, Lipps (1964) studied the Miocene planktonic foraminifera in detail, Asano, Ingle, and Takayanagi (1968) studied the development of *Globigerina quinqueloba* Natland throughout the section, and Wilcoxin (1969) reported on the distribution of calcareous nannoplankton within Miocene portions of the section. It is also of interest to note that Parker (1964) utilized selected Miocene foraminiferal faunas from Newport Bay in her study of the Mohole cores. Finally, Vedder (1972) has detailed Pliocene molluscan faunas within the Newport Bay section and Warren (1972, and this volume) has reported on detailed biostratigraphic study of Luisian and Mohnian benthonic foraminifera from these sediments. Indeed, the Newport Bay section constitutes one of the classic Tertiary microfaunal localities of California; unfortunately it may not be available for study in the near future due to urban development of the area.

In contrast to the well known Middle Miocene (Luisian) through Pleistocene sequence exposed at Newport Bay the Early to Middle Miocene marine sequence exposed on the northwestern flank of the adjacent San Joaquin Hills (Figs. 1 and 2) has received little study. This is the case despite the fact that good exposures of a portion of this sequence are available in the Bonita Canyon area (Fig. 2) and contain microfaunas and macrofaunas representing sedimentary and biologic events during the initial phases of Miocene marine deposition in southern California. Vedder, Yerkes, and Schoellhamer (1957) were the first to map and describe these deposits in detail and to present cursory paleontologic information assigning the Topanga Formation to the Lower Luisian and Relizian on the basis of sparse benthonic foraminiferal assemblages.

DANA POINT - CAPISTRANO AREA

The Miocene and Pliocene marine deposits exposed in the coastal area surrounding the Dana Point and San Juan Capistrano areas of California (Fig. 4) have only recently become the subject of detailed geologic investigation despite their accessibility and direct relationship to the throughly studied sediments of the same age in the central Los Angeles Basin to the north. Interestingly, the fossiliferous nature of some of these sediments was reported over 80 years ago by Goodyear (1890). However, it was not until 1925 that Woodford mapped portions of this area during his classic investigation of the San Onofre Breccia and in the process defined the Capistrano Formation of Miocene and Pliocene age. Later workers, including Reed and Hollister (1936), Kleinpell (1938) and Driver (1948) all make reference to this unit. The first comprehensive description of Late Tertiary sediments in this area was presented by Woodford, Schoellhamer, Vedder, and Yerkes (1954) with a detailed geologic map completed by Vedder, Yerkes, and Schoellhamer (1957) and subsequent mapping of local areas by students from several universities (Rogers, 1966). The first detailed paleontologic investigation of the

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[1] Early phases of this study (Ingle, 1962, 1963, 1967) were supported by an American Association of Petroleum Geologists Grant-in-Aid of Research and NSF grant GF-257 and were conducted in the Department of Geology, University of Southern California.

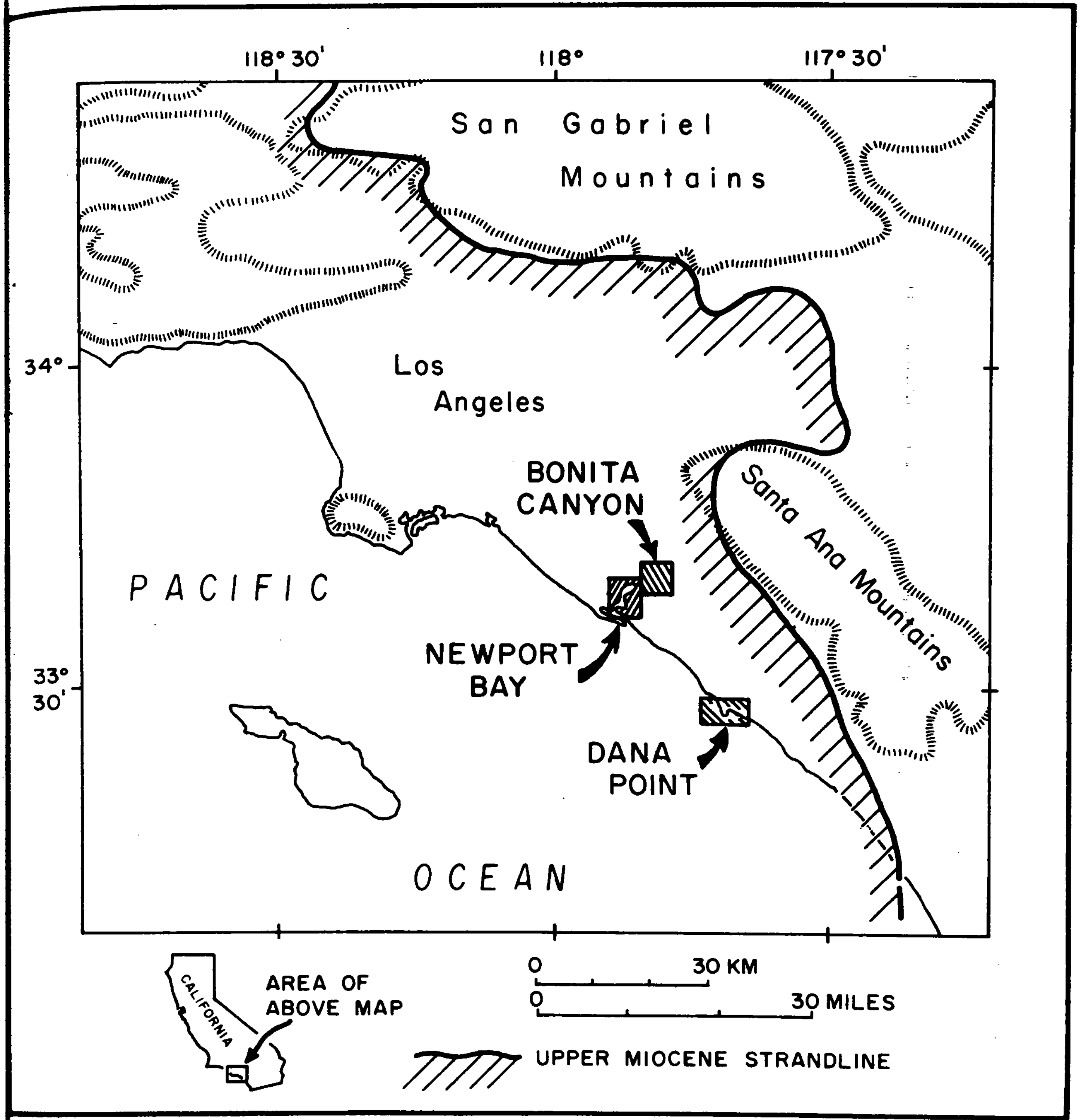

FIGURE 1 - Location map of the Los Angeles Basin region showing the positions of the Bonita Canyon, Newport Bay, and Dana Point-Capistrano areas. The configuration of the Upper Miocene strandline is modified after Corey (1954) and based on the geographic limits of both surface and subsurface occurrences of Upper Miocene marine sediments.

Capistrano Formation was completed by White (1956) who described Upper Miocene and Pliocene benthonic foraminifera from this unit and concluded that portions of the formation had been deposited at depths exceeding 1200 meters.

The pace of investigation increased in the 1960's and Smith (1960) reported on Miocene benthonic foraminifera from the Miocene Monterey Shale and Puente Formation of the Santa Ana Mountains and Capistrano area. Ingle (1962, 1963) presented a comprehensive paleoecologic and sedimentary history of Late Tertiary marine sediments in the Capistrano, Dana Point, and Newport Bay areas in an unpublished thesis recognizing the massive sands in the lower Capistrano Formation as turbidites and utilizing quantitative analyses of lower bathyal[2] through shelf-depth foraminiferal and radiolarian biofacies. Bartow (1964, 1966) made a concentrated study of the spectacular exposures of turbidite sands and breccias at the base of the Capistrano Formation in the sea cliffs at Dana Point and concluded these sediments represent a portion of a Miocene deepsea fan and channel. Subsequently, a number of academic and industrial research teams have studied these same exposures as a superb example of an ancient fan sequence. Recent reports by Normark and Piper (1969, 1970) present the most detailed analyses to date and interpret the Dana Point exposures in light of the large amount of information.

FIELD AND LABORATORY PROCEDURES

Samples were collected from Pleistocene through Miocene portions of the Newport Bay section during 1959-1965 whereas samples were collected from the Bonita Canyon section in 1964-1965. Samples were collected from the Dama point - Capistrano area during 1959-1962. It is important to note urbanization in these two areas has resulted in the destruction of some of the sample localities depicted on Figures and.

All sample localities were plotted on U.S.G.S. topographic maps in conjunction with pace and compass, tape and compass, or odometer traverses. Lithologies illustrated on stratigraphic columns are from outcrop descriptions. Formation boundaries are based on mappable lithologic breaks and are identical to those of Vedder, Yerkes, and Schoellhamer (1957).

A 100 to 250 gram portion of each sample was washed through a 250 mesh Tyler screen (0.061 mm openings). Washed samples were dried and floated in CC$_4$; as not all foraminifera floated a separate count was made of specimens contained in residues. A modified Otto microsplitter was used to divide faunas into practical but statistically significant alequots of 200 to 400 specimens. Tabulations of speciments counted and species percentage abundance tables for the Bonita Canyon - Newport Bay sections are not presented in this report due to space limitations; these data will be provided in a future report (Ingle, in prep.). Species abundance data for Dana Point-Capistrano samples are given in Ingle (1971b).

GEOLOGIC SETTING

Utilizing the Upper Miocene strandline as a reference it is apparent that the Dana Point and Newport Bay areas are located in a southern lobe of the LateTertiary Los Angeles Basin (Fig. 1). Reed and Hollister (1936, p. 24) termed this structural trough and the adjacent Los Angeles Basin proper the Capistrano Embayment. Intensive geologic investigation of the Los Angeles Basin region in connection with petroleum exploration has revealed that it has been the site of marine deposition from the Late Cretaceous through a major portion of the Pleistocene with an interval of nonmarine deposition essentially confined to the Oligocene (Woodford, Schoellhamer, Vedder, and Yerkes, 1954). The tempo of sedimentation increased abruptly during the Late Oligocene and Early Miocene in the Newport Bay-San Joaquin Hills-Capistrano area as evidenced by more than 1000 meters of coarse clastics deposited at littoral and shelf depths and assigned to the Vaqueros Formation.[3] Rapid subsidence followed in the Middle Miocene interval producing a series of deep marine basins in southern California during the Middle and Late Miocene with a subsequent period of basin filling continuing to the present. Only those basins nearest the Miocene-Pliocene strandline have been filled to date; other basins are sill submerged and in various stages of filling (Gorsline and Emery, 1959; Emery, 1960). Fortunately, Pleistocene tectonic events have exposed these basin-fill units in the Bonita Canyon, Newport Bay and Dana Point areas of the San Joaquin Hills.

Yerkes, McCulloch, Schoellhamer, and Vedder (1965) have demonstrated that the Los Angeles Basin region can be divided into four major structural blocks each displaying a somewhat different sedimentary and tectonic history. The San Joaquin Hills area including sections described in this report are situated on the sourhwest margin of the central block.

Comparison of equivalent Neogene marine sequences deposited in the central area of the Los Angeles Basin and the Newport Bay-San Joaquin Hills area to the south (Fig. 5) illustrates that depositional rates and subsidence varied significantly even between these subareas of the central block. This display of rapid change in lithologic facies, accompanying variation in biofacies, thicknesses, and tectonic history over such a short distance and within such a short interval is best understood when analogies are made with modern basin filling sequences observed immediately off the coast of southern California (Emery, 1960) or in the Gulf of California today.

Events during Neogene basin formation within the Capistrano Embayment are typical of similar tectonic-basin filling cycles which occurred in many areas along the eastern and western rim of the Pacific Basin during the Miocene and Pliocene. This pattern is exemplified by Miocene-Pliocene events in Japan (Asano, Ingle, and Takayanagi, 1969) and southern California. It now appears that these essentially simultaneous periods of basin formation are directly related to an episodic adjustment of major crustal plates in the Pacific area associated with sea floor evolution (Le Pichon, 1968; Yeats, 1968; Dott, 1969; Atwater, 1970) including the Gulf of California.

GENERAL STRATIGRAPHY

Bonita Canyon Section

Although Miocene marine events are initially recorded in the Early Miocene Vaqueros Sandstone in the San Joaquin Hills this unit was not studied in detail due to sparse and poorly preserved littoral and neritic microfaunas. The oldest units studied in detail are the Los Trancos and Paularino members of the Middle Miocene Topanga Formation. Westward dipping exposures of these two units along Bonita Canyon Drive, Coyote Canyon Road, and Culver Dr. (Fig. 2) on the northwestern flank of the San Joaquin Hills form the Bonita Canyon section of this report (Fig. 6). Dips within this section range from 35° w to 18° w with strike

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[2] Depth classification of benthic marine environments follows Ingle (1967).

[3] The Oligocene-Miocene boundary is currently placed between the Zemorrian and Saucesian stages based on planktonic criteria (Lipps, 1965, 1967; Bandy and Ingle, 1970); future study may reveal that Vaqueros sediments in the San Joaquin Hills contain both Saucesian and Zemorrian age microfaunas although meager data available suggests only a Saucesian age for this unit in this area.

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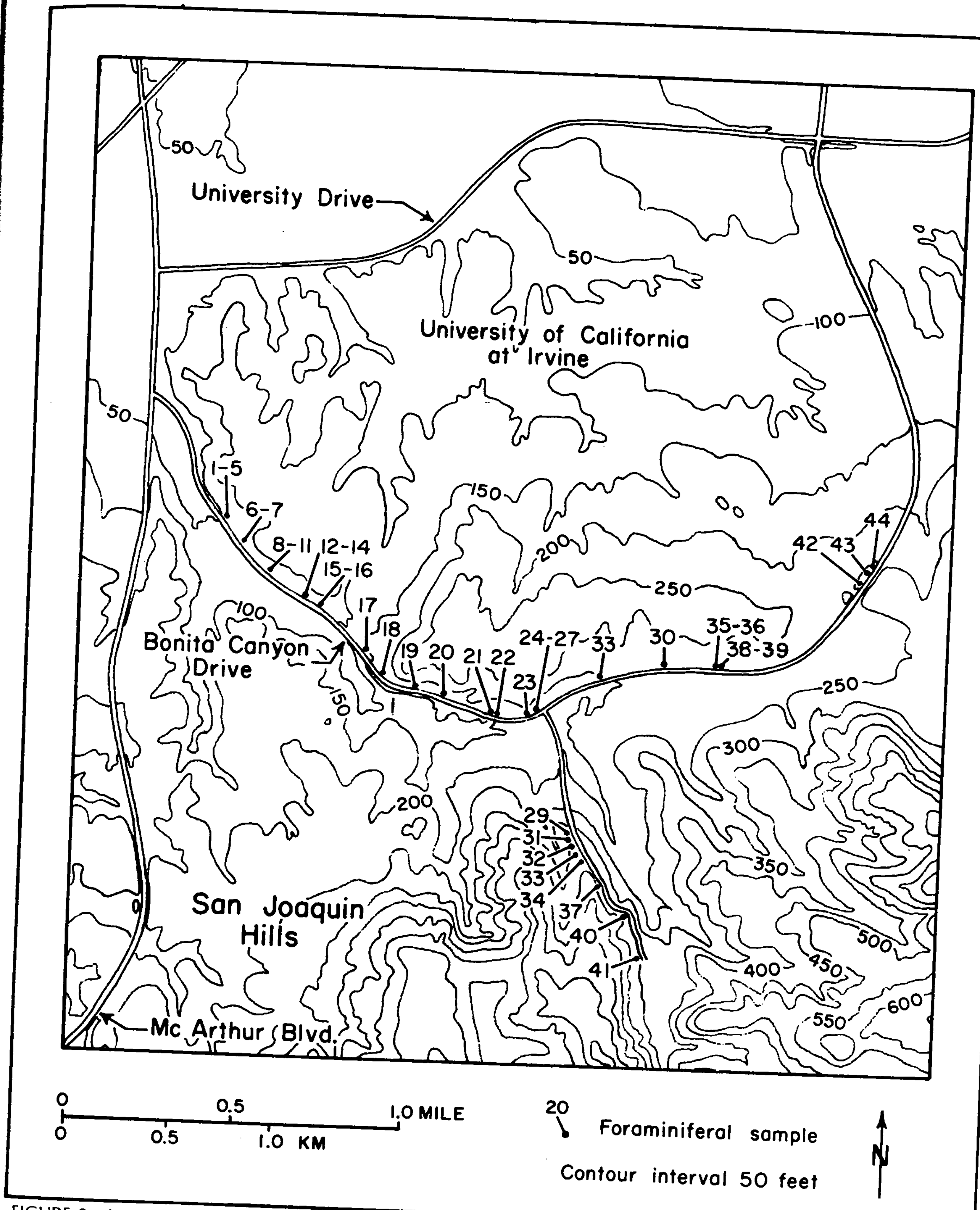

FIGURE 2 - Location map of microfossil samples collected from the Paularino and Los Trancos members of the Middle Miocene Topanga Formation exposed in the Bonita Canyon area on the northwestern flank of the San Joaquin Hills, Orange County, California. The base map is modified from 1965 editions of the U.S.G.S. Laguna Beach and Tustin, California quadrangles (1:24,000).

varying between N10°E to N55°E. A number of small faults interrupt this section (Fig. 6) and are accompanied in some instances by small drag folds.

The Los Trancos member of the Topanga Formation sampled within the Bonita Canyon section consists of about 650 meters of interbedded fine to medium sandstone and siltstones with siltstones becoming predominant in the upper half of the member. A number of sedimentary structures were observed in the sandstone interbeds which appear to be indicative of traction flow. In addition scattered megafossils appear in the lower portion of the member along with a number of body fossils; numerous intervals are also intensely bioturbated. Sedimentary structures, megafossils, bedding, grain size, and bioturbation within the lower portion of this member are characteristic of an outer shelf-upper bathyal[4] paleoenvironment. This conclusion is corroborated by paleoecologic analysis of associated benthonic foraminifera encountered at scattered horizons in the lower half of this member. Unfortunately, foraminifera are either recrystallized or leached from many horizons within this member, however, analysis of scattered well preserved faunas indicate a Relizian age for this portion of the Topanga Formation.

The overlying Paularino member of the Topanga Formation consists of a lower unit of about 150 meters of sandy siltstone, a middle unit of 80 meters of interbedded andesite flow breccia and medium to coarse sandstones overlain by 150 meters of well bedded medium to coarse turbidite sands with common tuffs and sand size andesite fragments, with an upper unit consisting of about 150 meters of thin bedded diatomaceous shale, diatomite, and interbedded white tuffs. The Topanga Formation is unconformably overlain by silty sands of the Plio-Pleistocene Niguel Formation in the Bonita Canyon area. The andesite flow breccia characteristic of the Paularino member occurs near the base of this unit in nearby exposures and in some cases marks the boundary with the underlying Los Trancos member (Vedder, Yerkes, and Schoellhamer, 1957). Abundant Lower Luisian foraminifera occur at scattered horizons in the diatomaceous shales in the upper portion of this unit with only sparce Relizian faunas encountered in the lower sands and silts.

Newport Bay Section

Sedimentary units sampled in the cliffs on the east and west sides of Newport Bay (Fig. 3) form the northeast dipping flank of a northwest trending anticline. Dips range from 50°N adjacent to the crest of the anticline near the base of the section to 10°N within the stratigraphically highest portions of the section.

The Newport Bay section includes three principal units. The Middle to Upper Miocene Monterey Shale is composed of several tens of meters of contorted siliceous shale at the base of the section grading upward into more than 300 meters of soft punky laminated diatomaceous shales and diatomites with scattered interbeds of grey mudstone (Fig. 8). Prolific foraminiferal assemblages indicative of Kleinpell's (1938) Upper Luisian through Upper Mohnian stages characterize this unit. The stratigraphically highest portion of this formation is composed of massive laminated diatomites containing an Upper Mohnian fauna and is equivalent to the Valmonte Diatomite Member of the Monterey Shale as defined within the nearby Palos Verdes Hills (Woodring, Bramlette, and Kew, 1946). It should be noted that the stratigraphically lowest portion of the Monterey Shale exposed at Upper Newport Bay was not sampled during this study, however, Lipps (1964) included samples from several lower horizons in his study of the planktonic foraminifera.

Conformably overlying the Monterey Shale are approximately 400 meters of massive red-brown radiolarian-rich mudstones and grey sandy siltstones mapped as the Capistrano Formation by Vedder, Yerkes, and Schoellhamer (1957). The mudstone portion of this formation is lithologically and faunally equivalent to the Upper Miocene Malaga Mudstone Member of the Monterey Shale exposed in the Palos Verdes Hills whereas the siltstone portion of the unit is equivalent to beds traditionally mapped as the Repetto Formation in the Palos Verdes Hills and central Los Angeles Basin. Radiolarian tests are abundant to common throughout the mudstone portion of the formation whereas foraminifera are lacking with the exception of Mohnian foraminifera found in diatomites at the boundary with the underlying Monterey Shale (Fig. 8). Lower Pliocene Repettian Stage foraminiferal faunas are found in scattered localities in the siltstone portion of the Capistrano Formation as first reported by Crouch (1951).

The boundary between the Capistrano Formation and the overlying 300 meters of sandy silts and siltstone assigned to the Fernando Formation is placed at a prominent bed of sandy conglomerate well exposed on Palisades Road. In light of the faunal and paleobathymetric continuity across this boundary (Figs. 8 and 9) the conglomeratic horizon is interpreted as a "turbidite" deposit and is not considered indicative of an unconformity. Numerous other thin sand horizons within this formation are also interpreted as "turbidite" deposits. The Fernando Formation contains benthonic foraminiferal assemblages characteristic of Natland's (1957) Pliocene Repettian, Venturian and Wheelerian stages and his Pleistocene Hallian Stage. The stratigraphically highest portion of the section grades from a sandy siltstone to a silty sand containing common to abundant small molluscan shells.

The Middle Miocene to Early Pleistocene sediments of the Newport Bay section are unconformably overlain by flat lying Pleistocene marine terrace deposits.

DANA POINT — CAPISTRANO SECTION

The detailed geologic map of the San Joaquin Hills - San Juan Capistrano area by Vedder, Yerkes, and Schoellhamer (1957) illustrates that four principal units crop out in the coastal area surrounding Dana Pount. The Middle Miocene San Onofre Breccia comprizes the oldest unit exposed in this area and it is inpart interbedded with and overlain by laminated diatomites and diatomaceous siltstones assigned to the Monterey Shale (Woodford, Schoellhamer, Vedder, and Yerkes, (1954). A detailed analysis and discussion of these two units will not be undertaken in this report and the reader is referred to Ingle (1962, in prep.) for a comprehensive paleoecologic interpretation of this portion of the section. However, it is important to note that these sediments represent the initial closed-basin phase of basin development in this area. Benthonic foraminiferal assemblages in the Monterey Shale are indicative of Kleinpell's (1938) Luisian and Lower Mohnian stages and con-

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[4] Depth classification of marine environments follows Ingle (1967).

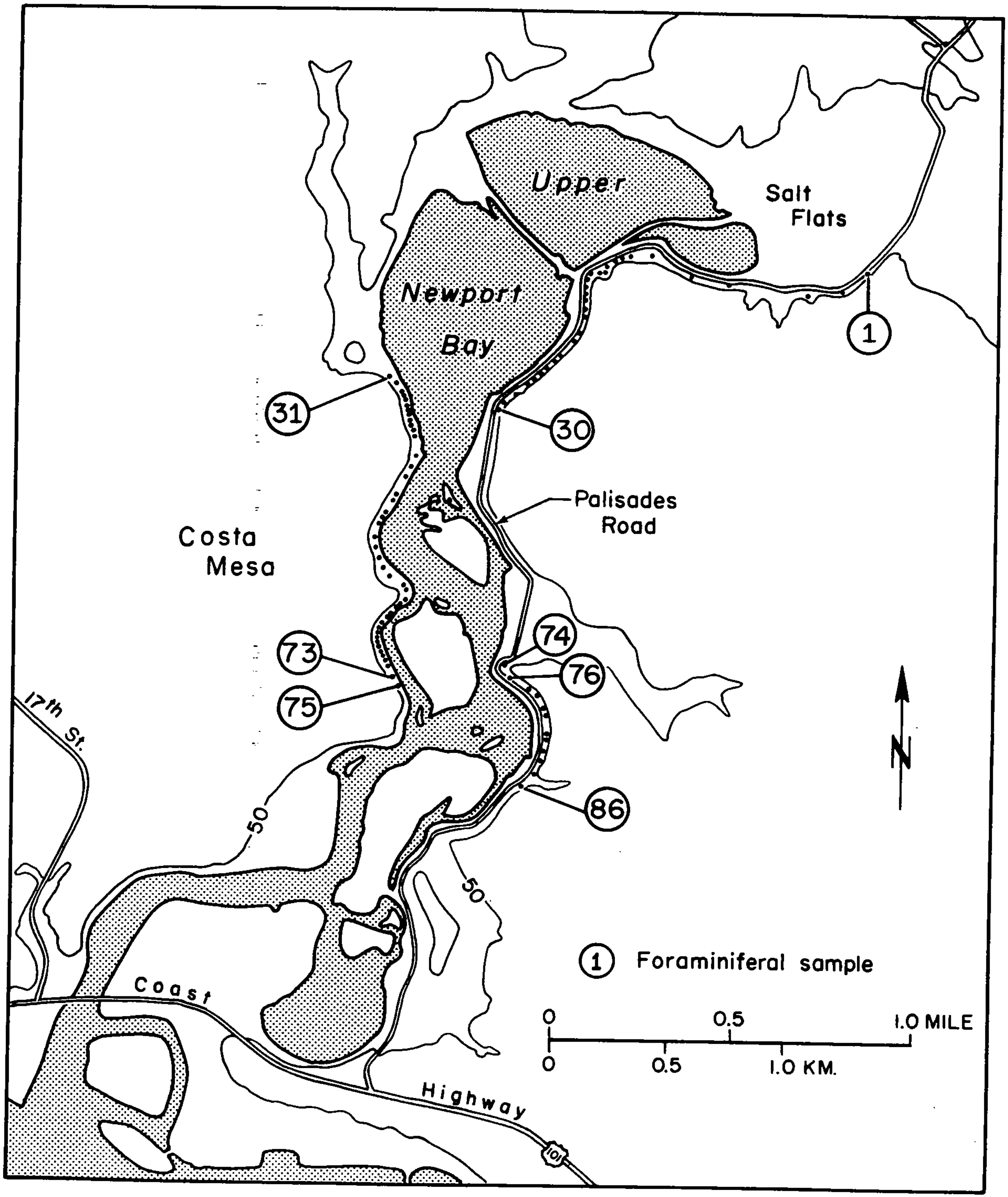

FIGURE 3 - Location map of microfossil samples collected from the Monterey Shale, Capistrano, and Fernando formations exposed in the east and west bluffs facing Newport Bay, Orange County, California. Base map modified from the 1965 edition of the U.S.G.S. Newport Beach quadrangle (1:24,000).

tain robust species of *Valvulineria*, *Pullenia*, *Uvigerina*, and *"Siphogenerina"* (Woodford, Schoellhamer, Vedder, and Yerkes, 1954; Smith 1960; Ingle, 1962) all indicative of upper bathyal to middle bathyal water depths. Moreover, the presence of laminated diatomites indicates deposition of these sediments took place in an oxygen deficient environment; in all likelyhood a response to a sill-depth within the oxygen minimum zone similar to closed basins containing oxygen-deficient water extant in the Gulf of California and off southern California today.

The Upper Miocene and Lower Pliocene Capistrano Formation conformably overlies the Monterey Shale with the boundary marked by a rather abrupt change from the predominantly laminated diatomites and siliceous rocks of the Monterey Shale to the massive, dark to red brown, fractured siltstone and radiolarian-rich mudstones of the lower Capistrano Formation. In the area immediately east of Dana Point the basal Capistrano Formation is composed of breccia, coarse sand, and interbedded silts first noted by Woodford (1925) and included in the Doheny channel and fan deposits described by Bartow (1966) and Normark and Piper (1969; 1971).

Outcrops of the Capistrano Formation in the area immediately north and east of Dana Point exhibit a northwest-southeast strike with dips ranging from 30° to 10° north. A crude stratigraphic column of the Capistrano Formation in the Dana Point area was erected during the present study by extention of strike and dip to a section line drawn parallel with San Juan Creek (Fig. 4). Thus microfossil samples collected during this investigation (Fig. 4) and those reported by White (1956) were placed in stratigraphic context and lithologic changes more clearly delineated. This section reveals that the Capistrano Formation in the Dana Point area is composed of a 227 meter thick basal turbidite unit containing lenses of breccia, coarse sand, and interbedded silts which is in turn overlain by an intermediate unit composed of 240 meters of brown radiolarian-rich siltstone and mudstone with scattered thin horizons of diatomite, and an upper unit composed of 180 meters of grey to light brown micaceous silt and siltstone (Fig. 11).

Unconformably overlying the Capistrano Formation is a patchy marine unit of well rounded conglomerate, silty sands, and silts of Late Pliocene and Early Pleistocene age commonly referred to the Niguel Formation (Vedder, Yerkes, and Schoellhamer, 1957; Fig. 11).

PALEOECOLOGY AND PALEOBATHYMETRY

INTRODUCTION

In recent years paleontologists have put increasingly heavy emphasis on studies of modern marine environments in order to interpret fossil assemblages. The southern California area has perhaps received more attention in this respect than any other in the world due to; (1) the throughly studied relationship between existing offshore basins to analogous filled Tertiary basins onshore (Emery, 1960) and (2) the relatively large number of investigations dealing with the quantitative distribution of modern benthonic foraminiferans in the marginal eastern Pacific[5]. In addition, recent studies of the Gulf of California have delimited a number of Recent marine environments which appear to be modern analogues of many fossil biofacies and lithofacies common to Cretaceous through Pleistocene marine sediments in California (Byrne and Emery, 1960; Bandy, 1961; Van Andel and Shor, 1964).

Studies by Bandy (1953, 1961), Bandy and Arnal (1957, 1960, 1969), Bandy and Kolpack (1963), and Ingle (1967) have demonstrated the increase in precision of paleoecologic interpretation afforded by use of quantitative microfaunal data. These same reports have presented standardized procedures for establishing and interpreting depth-diagnostic benthonic foraminiferal biofacies based on the shallowest limits of living benthonic species or their fossil isomorphs. Identical techniques were used to group the benthonic foraminifera encountered in the Newport Bay and Bonita Canyon sections into six biofacies indicative of inner shelf through lower bathyal depths as well as a seventh biofacies composed of species associated with low-oxygen environments (Table 1).

Table 1

SPECIES COMPOSITION OF BENTHONIC FORAMINERAL BIOFACIES NEWPORT BAY AND BONITA CANYON SECTIONS, ORANGE COUNTY, CALIFORNIA[1]

Inner Shelf[2] Biofacies

0 - 50 M

Astrononion stelligerum (d'Orbigny)
Astrononion stellatum (Cushman and Edwards)
Buccella sp.
Buliminella elegantissima (d'Orbigny)
Cancris auricula (Fichtel and Moll)
Cibicides delicatus
Cibicides fletcheri Galloway and Wissler
Cibicides lobatus (Montagu)
Cibicides reflugens Denys de Montfort
Elphidium fichtelianum (d'Orbigny)
Elphidium minutum (Reuss)
Nonionella incisum (Cushman
Nonionella miocenica Cushman
Nonionella miocenica stella Cushman and Moyer
Nonionella montereyana (Cushman and Galliher)
Quinqueloculina akneriana d'Orbigny
Quinqueloculina sp.
Siphotextularia flintii (Cushman)

Outer Shelf Biofacies

50 - 150 M

Bolivina brevior Cushman
Bolivina californica Cushman
Bolivina plicatella Cushman
Bolivina tongi Cushman
Bolivina tongi filicostata Cushman and McCulloch
Bulimina marginata d'Orbigny
Bulimina pagoda Cushman
Buliminella brevior Cushman
Buliminella californica Cushman
Buliminella curta Cushman
Buliminella ecuadorana Cushman and Stevenson
Cancris auricula (Fichtel and Moll)
Gaudryina arenaria Galloway and Wissler
Hanzawaia basiloba (Cushman)
Hanzawaia illingi (Nuttal)
Sigmoilina tenuis (Czjzek)
Valvulineria depressa Cushman
Valvulineria miocenica Cushman

Upper Bathyal Biofacies[3]

150 - 500 M

Baggina californica Cushman
Baggina cancriformis Kleinpell
Baggina robusta globosa Kleinpell
Bolivina advena Cushman
Bolivina acuminata Natland
Bolivina bramletti Kleinpell
Bolivina californica Cushman
Bolivina cuneiformis Kleinpell
Bolivina parva Cushman and Galliher
Bolivina pacifica Cushman and McCulloch
Bolivina plicata d'Orbigny
Buliminella curta basispinata Cushman
Buliminella subfusiformis Cushman

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[5] An extensive bibliography of these papers is provided by Ingle (1967).

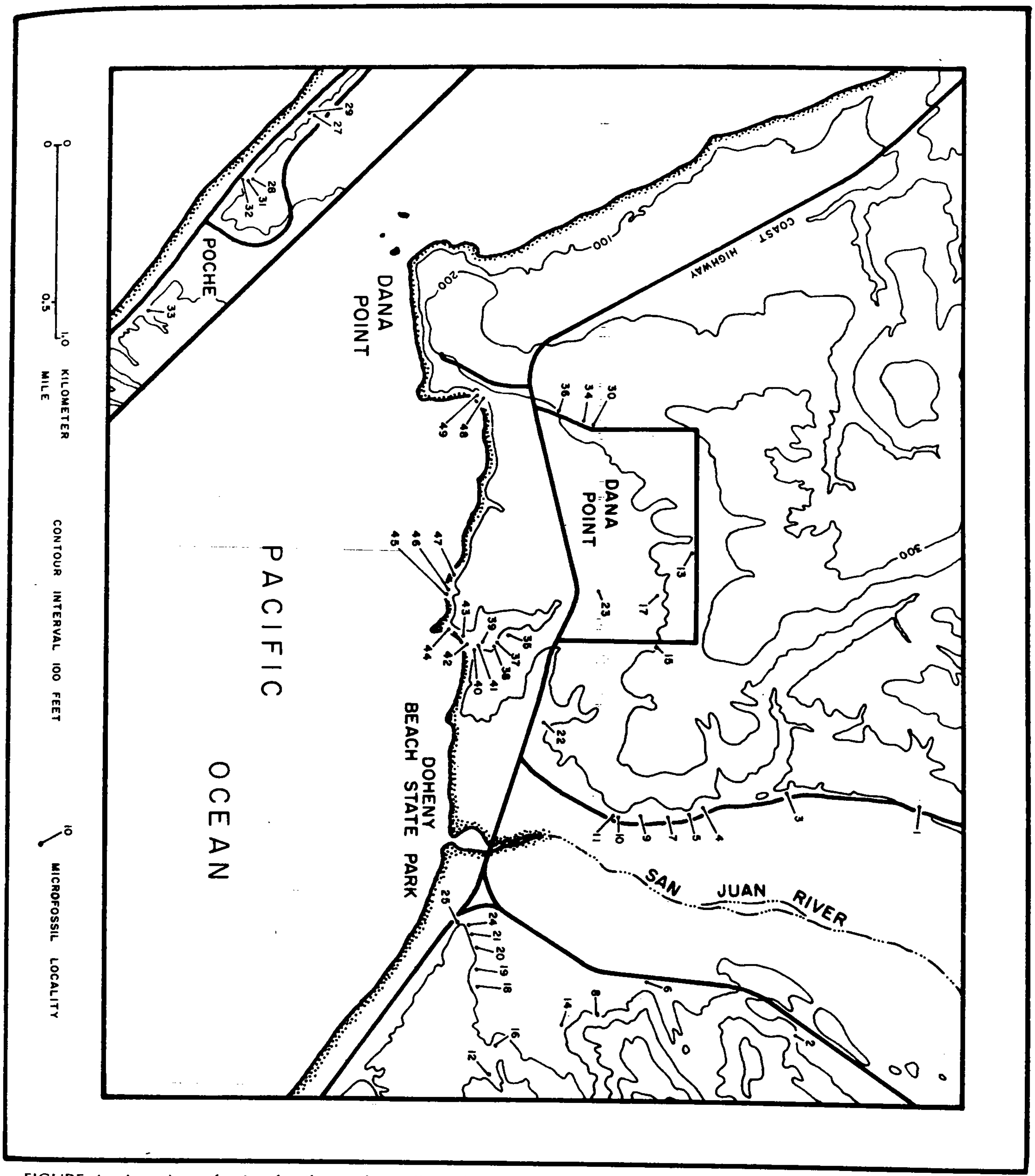

FIGURE 4 - Location of microfossil samples collected from exposures of the Capistrano Formation in the Dana Point and Capistrano areas, Orange County, California. The base map is modified from the 1948 edition of the U.S.G.S. Dana Point quadrangle (scale 1:24,000). It is important to note that the natural configuration of the coastline immediately east of Dana Point (as depicted on this map) has recently been altered in conjunction with harbor construction and that some microfossil localities shown on this mpa have been destroyed.

Table 1
(cont.)

Cassidulina californica Cushman and Hughes
Cassidulina limbata Cushman and Hughes
Cassidulina monicana Cushman and Kleinpell
Cassidulina subglobosa Brady
Cassidulina subglobosa quadrata Cushman and Hughes
Cassidulina tortuosa Cushman and Hughes
Cassidulina translucens Cushman and Hughes
Cassidulinoides californiensis Bramlette
Cassidulinoides cornuta (Cushman)
Cibicides mckannai Galloway and Wissler
Chilostomella czizeki Reuss
Chilostomella ovoidea Reuss
Epistominella relizensis (Cushman)
Epistominella subperuviana (Cushman)
Fursenkoina ("Virgulina") californiensis (Cushman)
Fursenkoina ("Virgulina") californiensis grandis (Cushman and Kleinpell)
Globobulimina ovula pedroana (Kleinpell)
Globobulimina pacifica Cushman
Globobulimina pyrula (d'Orbigny)
Gyroidina altiformia R.E. and K.E. Stewart
Pullenia salisburyi R.E. and K.E. Stewart
Trifarina angulosa (Williamson)
Trifarina hughesi (Galloway and Wissler)
Uvigerina kernensis subcalva White
Uvigerina peregrina Cushman
Uvigerina sequndoensis Cushman and Galliher
"Uvigerinella" californica Cushman
"Uvigerinella" obesa Cushman
Valvulineria californica Cushman
Valvulineria californica obesa Cushman

Upper Middle Bathyal Biofacies
500 - 1500 M

Bolivina argentea Cushman
Bolivina floridana Cushman
Bolivina imbricata Cushman
Bolivina interjuncta Galloway and Wissler
Bolivina sinuata Galloway and Wissler
Bolivina semiperforata Martin
Bolivina spissa Cushman
Bulimina spinifera Cushman
Bulimina subacuminata Cushman and R.E. Stewart
Bulimina subcalva Cushman and K.C. Stewart
Cassidulina cushmani R.E. and K.C. Stewart
Cassidulina delicata Cushman
Concavella (Epistominella) gyroidinaformis (Cushman and Goudkoff)
Epistominella pacifica (Cushman)
Epistominella smithi R.E. and K.C. Stewart)
Megastomella (Epistominella) capitanensis Cushman and Kleinpell)
Stainforthia ("Virgulina") complanata (Egger)
Stainforthia ("Virgulina") nodosa (R.E. and K.C. Stewart)
Stainforthia ("Virgulina") pontoni (Cushman)
Uvigerina hispidocostata Cushman and Todd
Valvulineria araucana (d'Orbigny)

Lower Middle Bathyal Biofacies
1500 - 2000 M

Gyroidina healdi (R.E. and K.C. Stewart
Gyroidina multicamerata (Kleinpell)
Plectofrondicularia californica Cushman and R.E. Stewart
Oridorsalis umbonatus (Reuss)
Planulina ariminensis d'Orbigny
Pullenia bulloides (d'Orbigny)
Pullenia miocenica Kleinpell)
Pullenia miocenica globula Kleinpell
Rectouvigerina ("Siphogenerina") collomi (Cushman)
Rectouvigerina ("Siphogenerina") hughesi (Cushman)
Stilostomella advena (Cushman and Laiming)
Stilostomella adolphina (d'Orbigny)
Uvigerina hispida Schwager

Lower Bathyal Biofacies
2000 + M

Bulimina rostrata Brady
Gyroidina soldani d'Orbigny
Karreriella milleri Natland
Melonis pompilioides (Fichtel and Moll)
Melonis barleeanus (Williamson)
Uvigerina senticosa Cushman

Low - oxygen Biofacies[4]
300 - 2000 M

Bolivina benedictensis Pierce
Bolivina decurtata Cushman
Bolivina seminuda Cushman
Bolivina pocheensis White
Bolivina tumida Cushman
Hopkinsina magnifica Bramlette
Suggrunda Kleinpelli Bramlette
Uvigerina hootsi Rankin (?)

1. Arrangement and interpretaion of biofacies follows procedures and principles described by Bandy (1961), Bandy and Arnal (1960, 1969) and Ingle (1967). Not all species included within each biofacies were encountered in any given sample nor were all of the species encountered in either of the sections included in one of the seven biofacies.

2. The term "shelf" is equivalent to the neritic or sublittoral zones of many authors.

3. A number of the species assigned to this biofacies exhibit a transitional distribution from the outer shelf to upper bathyal zone; these species are marked with an asterisk (*).

4. Species thought to be indicative of anaerobic bottom conditions induced by low-oxygen content (less than 0.2 m1/1 02) of ambient basin water due to intersection of the basin sill with the oxygen minimum zone.

PALEOECOLOGIC AND PALEOBATHYMETRIC TRENDS

BONITA CANYON SECTION

The bulk of the coarse sandstones assigned to the Vaqueros Sandstone in the San Joaquin Hills and associated megafaunas (Loel and Corey, 1932) represent deposition in a subtropical to warm temperate littoral environment and represent the initiation of rapid subsidence during the Lower Miocene (Saucesian) in this area of the so-called Capistrano Embayment (Reed and Hollister, 1936). A maximum of 600 meters of coarse sandstones of the Bommer member of the overlying Topanga Formation represent continued littoral deposition and subsidence during the Early Middle Miocene (Relizian). Thin beds of finer sands in the upper portion of the Bommer member together with common Middle Miocene megafossils throughout this unit (Vedder, Yerkes, and Schoellhamer, 1957) suggest a transition from littoral to inner shelf deposition.

Outer shelf to upper bathyal Relizian benthonic foraminiferal biofacies dominated by *Valvulineria depressa* along with common specimens of several species of *Buliminella, Bolivina* and *Epistominella reliziensis* together with increasing percentages of planktonic specimens (Figs. 6 and 7) suggest a transition from outer shelf to upper bathyal depths in the overlying Los Trancos member of the Topanga Formation. Comparison with modern biofacies trends in the Gulf of California illustrates a modern analogue of this sequence emphasizing the characteristically high percentages of displaced elements of inner and outer shelf biofacies in the upper bathyal slope environment. Mixed upper bathyal and shelf biofacies occur throughout the Los Trancos member with a significant occurrence of species characteristic of

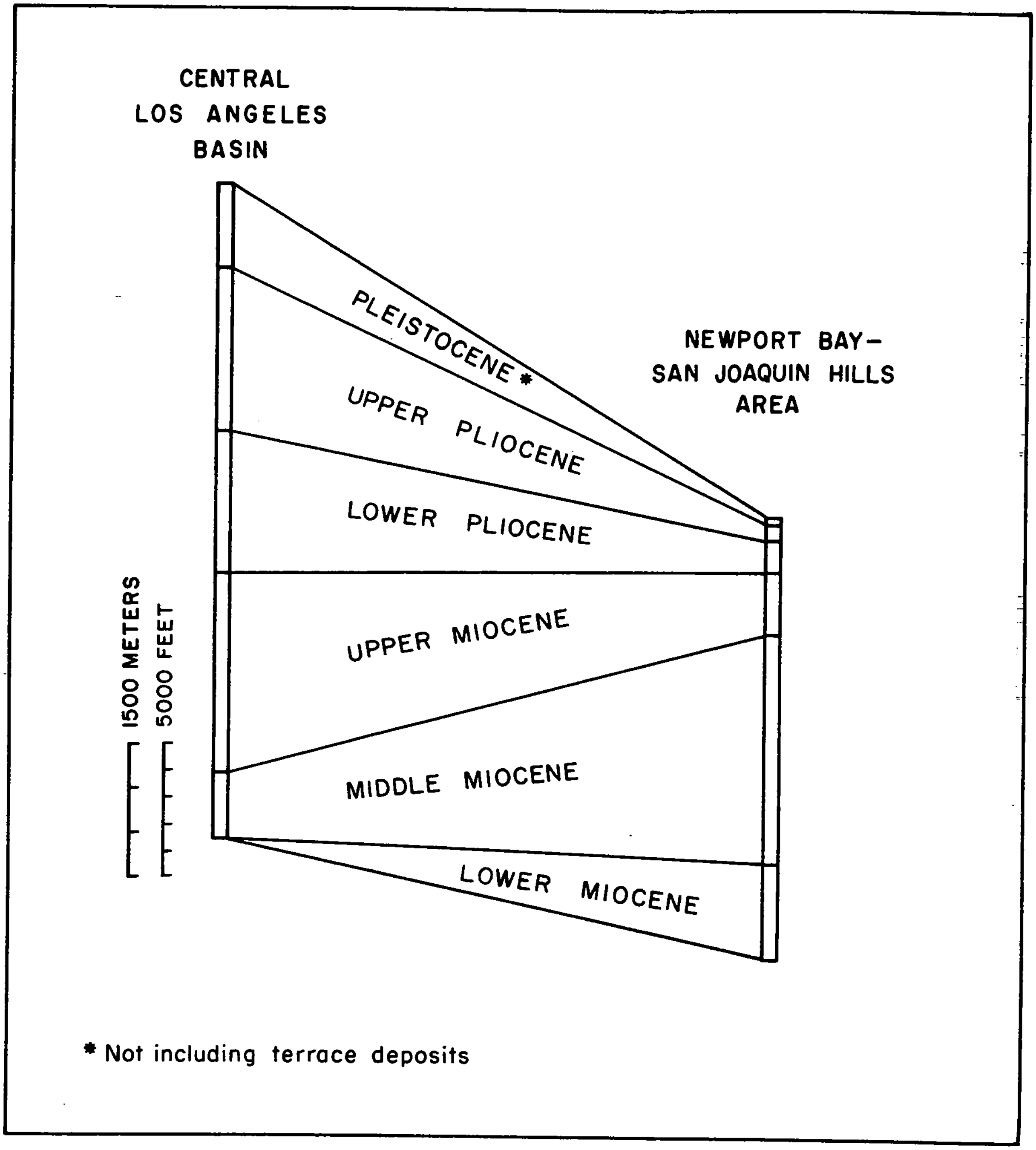

FIGURE 5 - Variation in thickness of Early Miocene through Pleistocene clastic marine deposits in the central Los Angeles Basin and the Newport Bay - San Joaquin Hills area, California. Plotted from data of Woodford, Schoellhamer, Vedder, and Yerkes (1954) and Yerkes, McCulloch, Schoellhamer, and Vedder (1965).

anerobic bottom conditions in the upper portion of this member (Fig. 7). This latter event may represent the intersection of the upper surface of the oxygen-minimum zone with the upper bathyal slope suggesting a water depth of about 500 meters. As noted earlier bioturbated and interbedded sandy siltstones, siltstones, and thin sandstones of this unit also suggest transition from traction deposits of the shelf to gravity driven "turbidite" deposition on the upper bathyal slope.

The initial appearance of common radiolarian tests in the Paularino member of the Topanga Formation (Fig. 6) and the appearance of middle bathyal foraminifera including *Rectouvigerina hughesi, Pullenia miocenica* and *Uvigerinella obesa* in associated laminated diatomaceous deposits suggest water depth reached 1500 meters by Lower Luisian time (Figs. 6 and 7). Indeed, the abundance of the low oxygen biofacies (Table 1) together with laminated diatomaceous deposits in the stratigraphically highest portion of the Paularino member indicate that subsidence and basin formation had reached a critical stage during Lower Luisian time. These deposits and associated diatomites indicate closed basin conditions prevailed with sill depth of the basin located within the oxygen minimum zone allowing formation of laminated diatomites on the basin slopes and floor similar to deposition of analogous deposits in the Santa Barbara Basin and in the Gulf of California today. Displaced members of inner shelf to middle bathyal biofacies within these deposits suggest a sill depth of about 1000 to 1500 meters.

Planktonic foraminiferal biofacies in the Bonita Canyon section are dominated by simple five-chambered forms including *Globigerina concinna, G. angustiumbilicata,* and *G. bulloides* all suggesting cool to warm temperate surface temperatures in the paleo-California current system during the Relizian-Lower Luisian interval.

NEWPORT BAY SECTION

The exotic San Onofre Breccia representing in part chaotic deposition of coarse debris into the deep Middle Miocene (Luisian) basin occurs within sediments assigned to both the Topanga Formation and the overlying Monterey Shale and forms a wedge between these two units in areas adjacent to the Bonita Canyon and Newport Bay sections (Woodford, Schoellhamer, and Yerkes, 1954; Ingle, 1962). The San Onofre Breccia was not studied during this investigation, however, it is clear that a continuing record of basin evolution is represented in the Newport Bay section and that only a portion of Luisian time is missing between the base of this section and the highest portions of the older Bonita Canyon section.

Continuing deposition of laminated diatomites accompanied by high percentages of the low oxygen biofacies in Upper Luisian, Lower Mohnian, and Upper Mohnian portions of the Monterey Shale of the Newport Bay section (Figs. 8, 9 and 10) indicate continued deposition in a closed basin system. Prolific abundance of radiolarians together with displaced members of the lower middle bathyal biofacies suggest basin depth may have reached 2000 meters by Upper Luisian time (Figs. 8 and 9).

A general increase in radiolarian number to over 10,000/gm within the massive mudstone sequence of the Capistrano Formation (Fig. 8) along with an absence of any calcareous microfauna (even molds of benthonic foraminifera are absent from most of this unit) suggest a climax in basin subsidence to depths of 3000 meters or deeper. Indeed, the massive radiolarian-rich mudstones of this sequence exhibit many characteristics in common with sediments deposited at depths of 3000 to 3600 meters in the Gulf of California today (Van Andel, 1964, p. 293; Ingle, 1967, p. 255). The Miocene-Pliocene boundary is placed within this unit at the point of last appearance of the radiolarian *Prunopyle titan* (Ingle, 1963, 1967; Bandy and Ingle, 1970).

A transition from the lower bathyal massive mudstones of the Capistrano Formation to siltstones and sandy siltstones of the upper portion of this unit and the overlying Fernando Formation (Figs. 8 and 9) marks the initial appearance of a prograding wedge of slope deposits during the Early Pliocene. The progressive appearance of lower bathyal, middle bathyal, upper bathyal, and shelf biofacies in the Fernando Formation (Fig. 9) presents a clear picture of filling of this portion of the basin during the Early Pliocene through Early Pleistocene interval.

Paleo-oceanographic implications of planktonic foraminiferal biofacies variation in the Neogene of southern California, including the Newport Bay section, has been reviewed in earlier reports (Ingle, 1963, 1967; Bandy and Ingle, 1970) and will not be detailed here. Biofacies variations and appearance of temperature sensitive index species such as *Globigerina pachyderma* and tropical keeled globoratalids within the Late Middle Miocene (Luisian) through Early Pleistocene sediments at Newport Bay (Fig. 10) illustrate an oscillation of surface temperature from cool to warm temperate in the Middle Miocene, subarctic to warm temperate in the Upper Miocene, subtropical in the Early Pliocene, with oscillations of subarctic to warm temperature conditions in the Middle Pliocene to Early Pleistocene interval.

DANA POINT—CAPISTRANO SECTION

The relatively thick turbidite and fan unit composed of breccia and arkosic sand at the base of the Capistrano Formation at Dana Point is bracketed by fine grained sediments containing rare to common middle bathyal foraminifera including *Uvigerina hispidocostata* and *Bulimina subacuminata* along with common radiolarians suggesting water depths of 1500 meters or deeper. This interpretation is further strengthened by the relatively high abundance of radiolarian tests and sponge spicules within silts and siltstones interbedded with the turbidites. Although coarse clastics are absent on the basin floor in the Newport Bay area during this same interval there is a sympathetic increase in the percentage of displaced upper bathyal and shelf species suggesting a simultaneous increase in the downslope transport of fine grained material in this area. As the Doheny channel and fan system aggressively prograded onto the basin slope and floor in the Dana Point area in the Late Miocene quiet deposition of largely biogenous laminated diatomaceous sediments prevailed on the basin floor to the north (Figs. 8, 9, 11) preserved due to oxygen-deficient ambient water below sill depth.

The increase in radiolarian number with time during the uppermost Miocene interval in both the Dana Point and Newport Bay sections indicates a general subsidence in both areas. Water depths may have reached 2000 meters in the Dana Point area and exceeded 3000 meters in the Newport Bay area where radiolarian number is greater than 10,000 analogous to modern radiolarian-rich sedimentary facies in the deeper portions of the Gulf of California today (Bandy, 1961; Ingle, 1967). The increased subsidence in this portion of the basin apparently occurred in concert with a renewed and major period of subsidence in the central Los Angeles Basin to the north.

The infrequent occurrence of thin laminated diatomites in the Dana Point and Newport areas suggests dissolved oxygen levels in the basin were marginals and circulation sluggish during the Late Miocene interval. However, the abrupt appearance of sandy and micaceous silts in the upper portion of the Capistrano section in the Dana Point area (Fig. 11) marks the initial appearance of a prograding wedge of slope deposits during the Early Pliocene

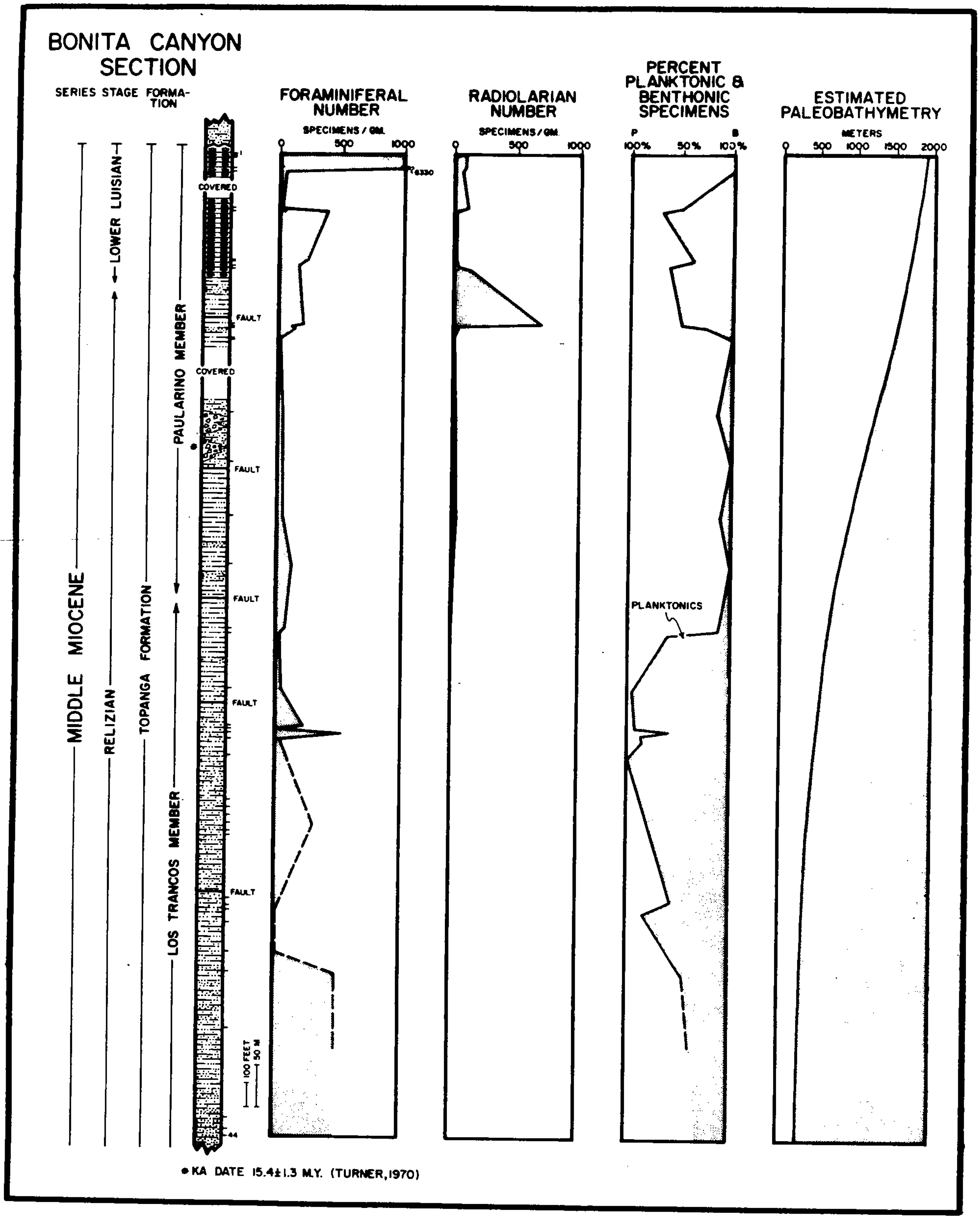

FIGURE 6 - Gross foraminiferal and radiolarian trends and estimated paleobathymetry within the Topanga Formation exposed in Bonita Canyon, Orange County, California. Solution and/or recrystallization of foraminiferal tests is extensive in major portions of this section, consequently trends illustrated should be viewed as best estimates.

in this area. As noted earlier planktonic correlations demonstrate that this major sedimentary event occurred much earlier in the southern end of the basin immediately adjacent to the shelf and strandline than in a more isolated portion of the basin represented in the Newport Bay section. The rare occurrence of *Melonis pompilioides* and *Bulimina rostrata* in Lower Pliocene deposits of the Capistrano-Dana Point section dictate that water depth was a minimum of 1800-1900 meters during this period.

Unfortunately, evidence of middle Pliocene and younger events is missing in the Capistrano-Dana Point area due to erosion of an unknown thickness of Capistrano Formation in the Late Pliocene or Early Pleistocene prior to deposition of the littoral and inner shelf deposits of the Niguel Formation.

BIOSTRATIGRAPHY AND AGE

BONITA CANYON SECTION

Benthoic foraminifera encountered in the Los Trancos and Paularino members of the Topanga Formation include species characteristic of the Relizian and Lower Luisian stages of Kleinpell (1938) corraborating earlier determinations reported by Vedder, Yerkes, and Schoellhamer (1957). Common to abundant specimens of *Valvulineria depressa* together with *Epistominella reliziana* indicate a Relizian age for the entire Los Trancos member and the lower portions of the Paularino member. The appearance of *Rectouvigerina (Siphogenerina) hughesi, Valvulineria californica obesa, Valvulineria californica,* and *V. depressa* suggest a Lower Luisian age for the stratigraphically highest portion of the Paularino member of the Topanga Formation.

Planktonic faunas in the Los Trancos member and lower Paularino member of the Topanga Formation are characterized by abundances of *Globigerina concinna* and *G. angustiumbilicata* typical of other Early Middle Miocene (Relizian) sequences in California (Bandy and Ingle, 1970). Rare occurrences of *Globorotaloides suteri relizensis* emphasize a Relizian age for the Los Trancos member. The initial appearance of *Globigerina bulloides* ss in the lower Paularino member and the appearance of abundant specimens of this species in the upper portion of this member is indicative of a Luisian age for these sediments (Bandy and Ingle, 1970).

An important potassium-argon date of 15.4† 1.3 m.y. performed on samples from the andesite flow breccia near the base of the Paularino member of the Topanga Formation (Fig. 7) has been reported by Turner (1970) and used as evidence that the Saucesian-Relizian boundary is about 15.3 m.y.

NEWPORT BAY SECTION

Typical Upper Luisian benthonic foraminifera including *Rectouvigerina (Siphogenerina) collomi* and abundant specimens of *Valvulineria californica* characterize the lowest horizons of the Monterey Shale in the Newport Bay section (Fig. 9). Overlying portions of this formation contain typical Lower Mohnian benthonic assemblages characterized by *Concavella (Epistominella) gyroidinaformis* and Upper Mohnian assemblages containing common specimens of *Bolivina benedictensis, B. seminuda, B. sinuta,* and *Cassidulina modeloensis.*

Planktonic foraminiferal faunas in the lower portions of the Monterey Shale at Newport Bay exhibit a transition from the *Globigerina concinna — G. angustrumbilicata* biofacies to assemblages entirely dominated by *Globigerina bulloides.* The first abundant occurrence of *Globigerina pachyderma* occurs in the Upper Mohnian portion of this section (Fig. 10) and exhibits a temperature induced sinistral coiling habit providing an ideal planktonic index to this portion of the Upper Miocene interval over wide areas of the Pacific and elsewhere (Bandy, 1960; Ingle, 1967; Kennett, 1968; Bandy, Casey and Wright, 1971). Rare but significant occurrences of the important Late Miocene index species *Globorotalia (T.) mayeri, Globorotalia menardi, "Sphaeroidinella subdehiscens"* and *Orbulina universa* also occur in the Mohnian sediments of this section allowing correlation with the Mohole cores to the south (Ingle, 1967; Bandy and Ingle, 1970) and the recognition of Neogene planktonic zones (Blow, 1969) 11 through 18. The reader is referred to Ingle (1962; 1967, 1971, in prep.), Lipps (1964, 1967), and Bandy and Ingle (1970) for a more complete discussion of these planktonic events.

The radiolarian-rich mudstones of the Capistrano Formation do not contain any age diagnostic benthonic or planktonic foraminifera and were assigned a "Delmontian" age simply on the basis of superposition and the occurrence of the radiolarian *Prunopyle titan* which appears to represent a good index to the Miocene-Pliocene boundary in bathyal and abyssal deposits over a wide area of the Pacific (Ingle, 1963, 1967; Bandy, Casey and Wright, 1971).

The uppermost portions of the Capistrano Formation and the overlying Fernando Formation contain benthonic foraminifera indicative of Natland's (1952, 1957) Repettian, Venturian, Wheelerian, and Hallian stages as marked by the progressive appearance upsection of faunas characterized by *Melonis pompilioides, Bulimina subacuminata, Uvigerina peregrina,* and *Cassidulina*-rich intervals along with accompanying diagnostic species.

Early Pliocene planktonic faunas in the Capistrano and Fernando formations are characterized by warm temperate to subtropical incursions of faunas dominated by *Globoquadrina dutertrei* along with rarer occurrences of Pliocene index species including *Globorotalia (T.) inflata*[6] and *G. crassaformis.* Middle Pliocene to Early Pleistocene faunas in this section are dominated by sinistral and dextral coiling populations of *Globigerina pachyderma* (Fig. 10) with the Pliocene-Pleistocene boundary marked by the initial appearance of *Globorotalia truncatulinoides* s.s. in the highest portion of the Fernando Formation. Correlation of these planktonic events with the paleomagnetic scale of Cox (1969) suggests that the Fernando Formation encompasses the upper part of the Gauss through at least lower portion of the Matayama magnetic epochs representing an interval spanning 2.8 through 1.79 m.y. before the present (Bandy, Casey, and Wright, 1971).

DANA POINT— CAPISTRANO SECTION

White (1956) has presented a detailed discussion of the age assignment of benthonic foraminifera found in the Capistrano Formation. He concluded that the relatively meager assemblages found in the lower portion of the formation likely belong within Kleinpell's (1938) Upper Mohnian Stage of the Upper Miocene whereas benthonic species present in the upper portion of the unit are typical of Natland's (1957) Repettian Stage of the California Pliocene. The writer is in aggrement with White's (1956) conclusions regarding stage assignments based on benthonic species. However, the widespread recognition that benthonic foraminiferal biofacies are often time transgressive casts doubt upon age assignments based solely on analysis of benthonic species.

The distribution of sparse planktonic foraminifera and the stratigraphic limits of the radiolarian *Prunopyle titan* within the Capistrano Formation offer additional and in some respects more definitive evidence of the age of

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[6] Includes *G. puncticulata.*

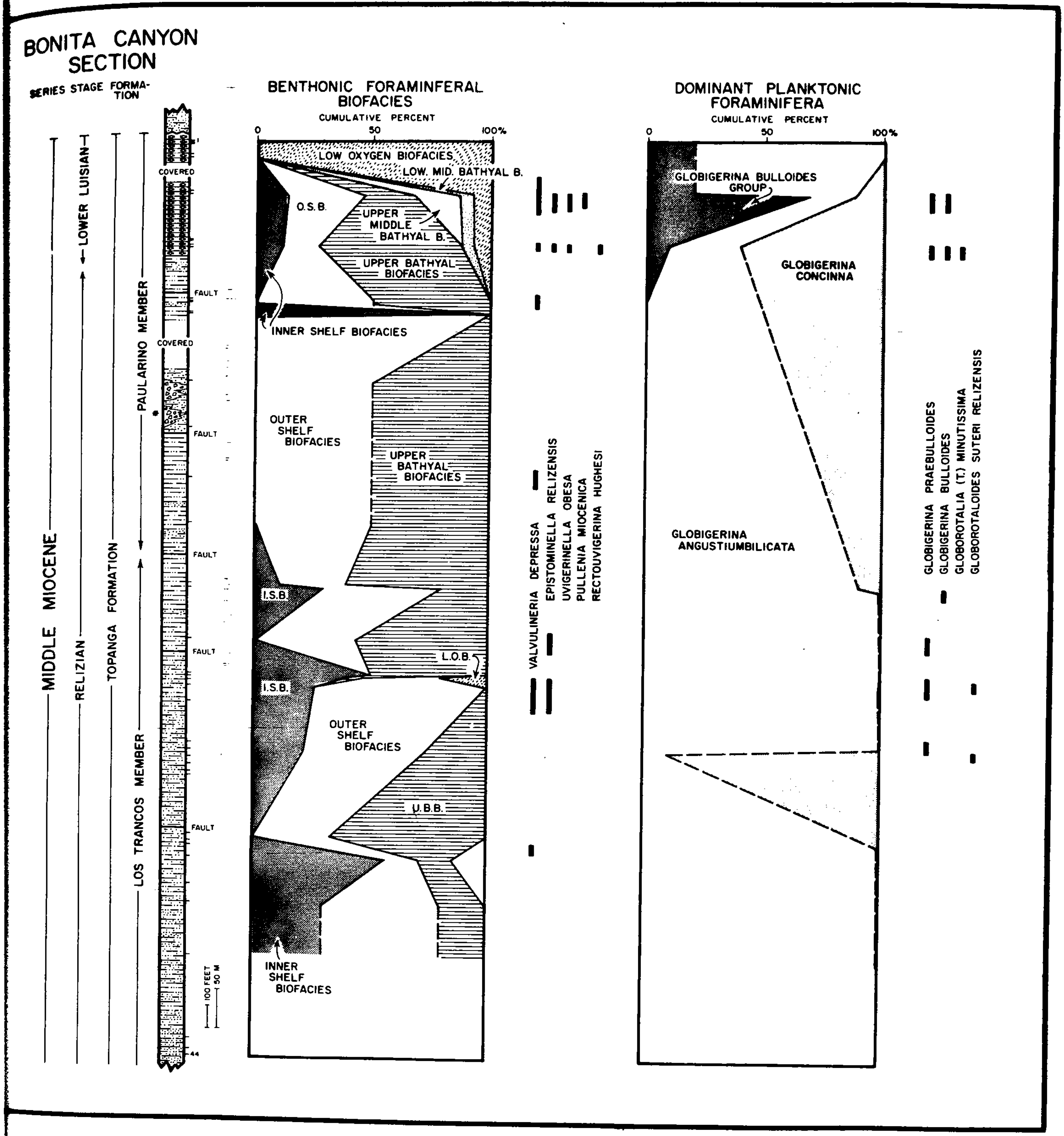

FIGURE 7 - Stratigraphic variation of benthonic foraminiferal biofacies, dominant planktonic species, and absolute ranges of selected species of benthonic and planktonic foraminifera within the Bonita Canyon section, Orange County, California. Solution and/or recrystallization of foraminiferal tests is extensive in major portions of this section, consequently trends illustrated should be viewed as best estimates.

this unit. Studies of temperate and high latitude Neogene planktonic foraminifera have disclosed that *Globigerina pachyderma* exhibits a persistent sinistral coiling habit in the Late Miocene, Middle Pliocene, and Pleistocene in response to periods of intense polar refrigeration (Bandy, 1960; Ingle, 1962, 1963, 1967; Bandy, Casey, and Wright, 1970) after its initial appearance in the uppermost Middle Miocene. Moreover, Late Miocene sinistral coiling populations of this species recognized in California commonly coincide with the top of the Mohnian Stage. Significantly, a dominantly sinistral population of this species is present in sample 29 near the base of the middle radiolarian-rich mudstone unit of the Capistrano Formation (Fig. 11) suggesting that the top of the Mohnian Stage may occur near this horizon and that sediments below this level are Upper Miocene in age.

In addition, the extinction of the radiolarian *Prunopyle titan* is known to occur immediately prior to the Miocene-Pliocene boundary in both polar and temperate areas (Ingle, 1962, 1963, 1967; Bandy and Ingle, 1970; Bandy, Casey, and Wright, 1970) and also mark the top of the "Delmontian Stage" in California. This species makes its final appearance in sample 16 of the Capistrano-Dana Point section (Fig. 11) suggesting the Miocene-Pliocene boundary occurs at or near this horizon. Bandy, Casey, and Wright (1970) correlate this paleontologic event with an interval in the upper portion of the Gauss Normal paleomagnetic epoch (Cox, 1969) in turn suggesting an absolute date of about 2.8 million years for this horizon. Unfortunately, there is a major inconsistancy between the radiometric scale utilized in conjunction with the paleomagnetic reversal scale and potassium argon dates of correlative horizons performed on volcanic ash deposits in the California Miocene and Pliocene. (Bandy and Ingle, 1970; Bandy, Casey, and Wright, 1970). In any case, the planktonic datums are consistent and provide concrete evidence that the Miocene-Pliocene boundary does indeed occur midway through the Capistrano Formation.

Finally, planktonic foraminifera from the upper portion of the Capistrano Formation contain dextral coiling populations of *Globigerina pachyderma* and significant percentages of *Globorotalia (T.) inflata* s. 1 and *G. puncticulata* indicating a major increase in surface water temperature and an Early Pliocene age for this portion of the formation.

CORRELATION OF THE CAPISTRANO DANA POINT AND NEWPORT BAY SECTIONS

Fortunately, two critical planktonic datums allow direct and relatively precise correlation of the Capistrano - Dana Point and Newport Bay sections (Fig. 12). Alignment of these two sections is made on the basis of the stratigraphically highest occurrence of the radiolarian *Prunopyle titan* and the stratigraphically lowest occurrence of exclusively sinistral coiling populations of *Globigerina pachyderma*. Correlation of these two stratigraphic columns on the basis of synchronous planktonic events allows the coincident but differing sedimentary histories of these two areas of the southeastern Los Angeles Basin to be analyzed during the Late Miocene - Pliocene interval (Fig. 12). For example, it is immediately apparent that the rate of sedimentation in the southern portion of the basin represented at Dana Point was much higher during this interval than in the Newport Bay area presumably due to the proximity of the Miocene - Pliocene strandline, shelf, and submarine canyon-fan complex (Figs. 1 and 12). Moreover, "Lower Pliocene" Repettian benthonic foraminiferal faunas appear earlier in the Capistrano - Dana Point area than in the Newport Bay section illustrating the time-transgressive nature of the depth dependent benthonic biofacies.

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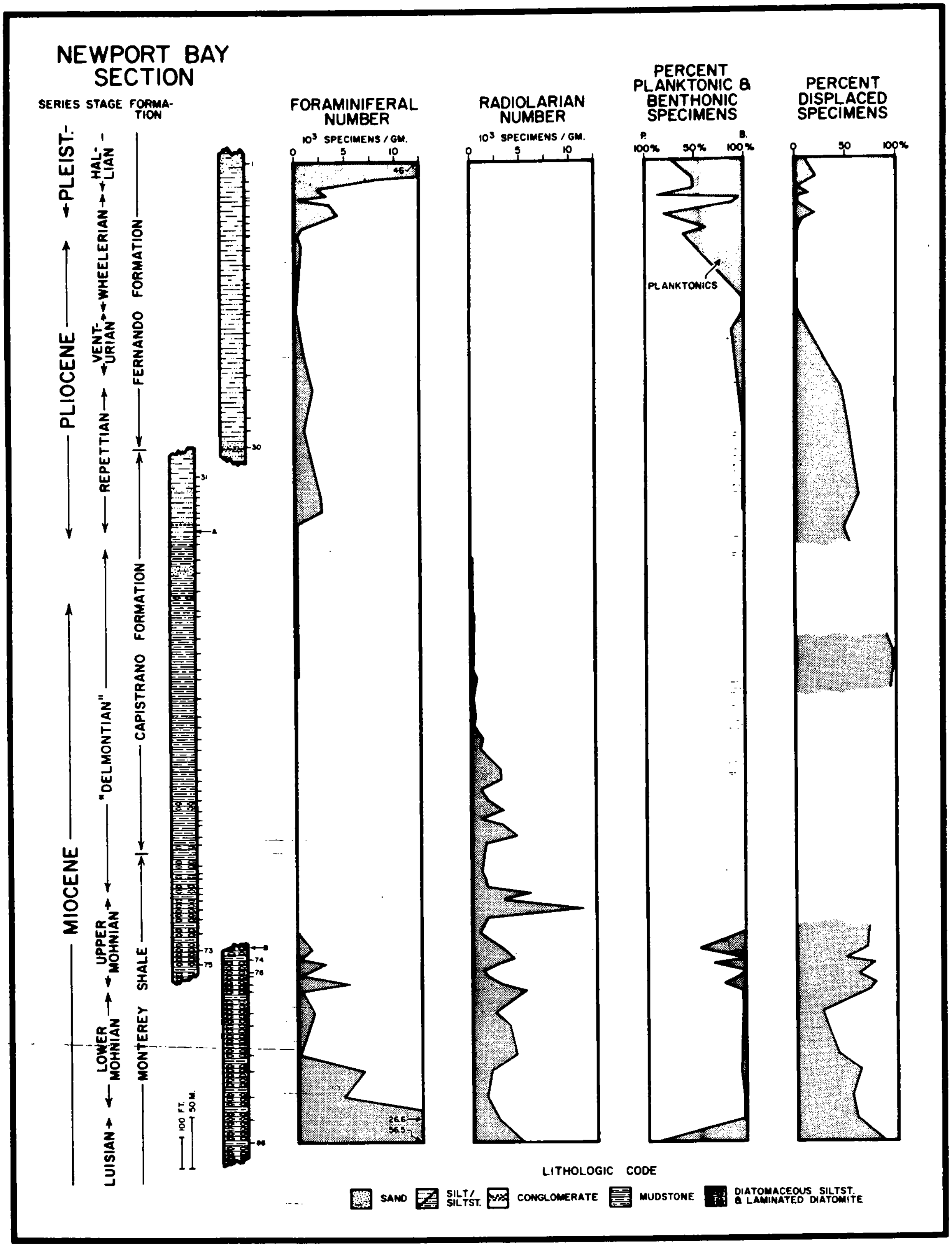

Figure 8 — Gross foraminiferal and rediolarian trends delineated within the Monterey Shale, Capistrano, and Fernando formations exposed at Newport Bay, Orange County, California. Adapted and modified from Ingle (1962, 1963).

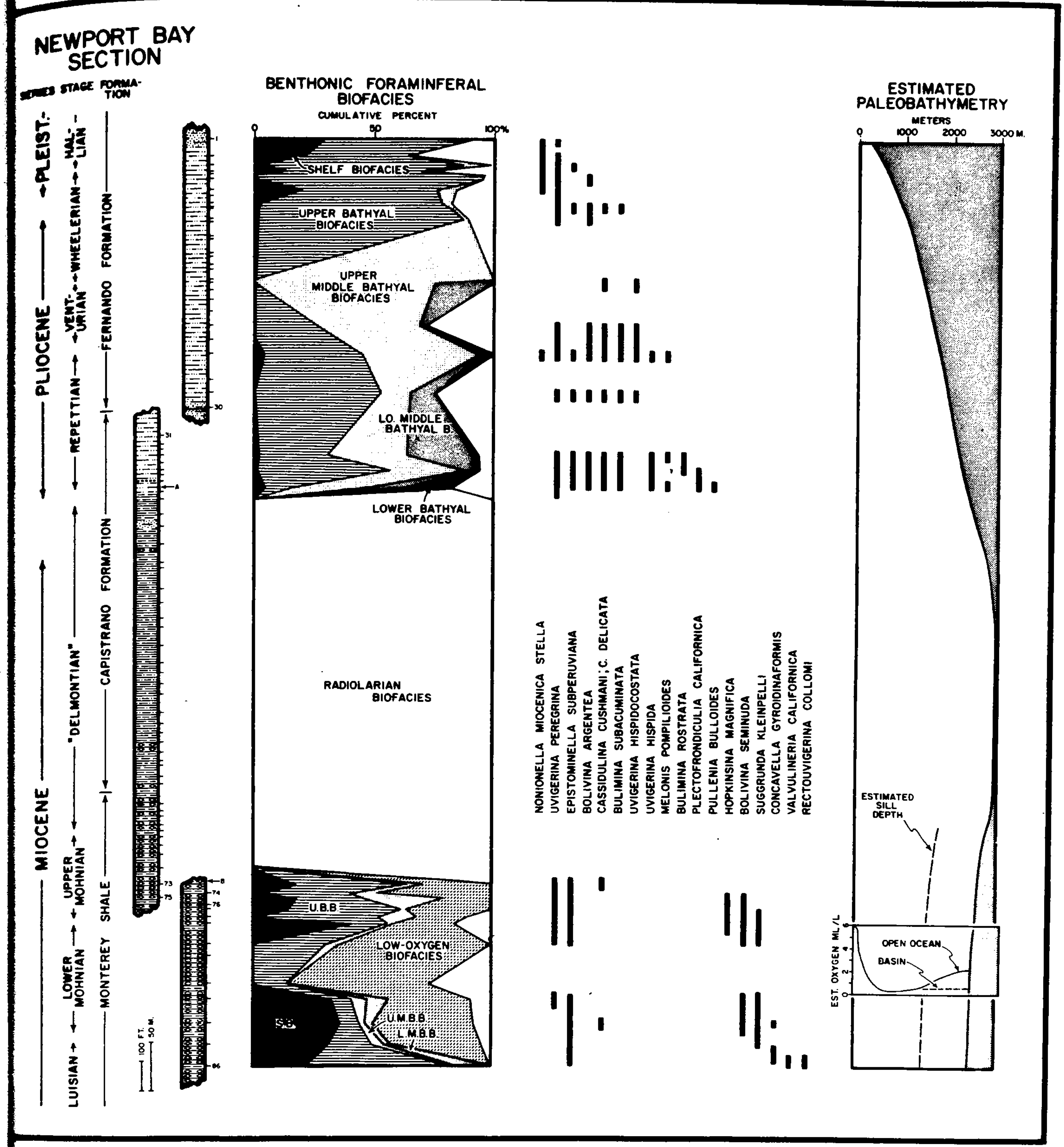

figure 9 — Stratigraphic variation of benthonic foraminiferal biofacies, absolute ranges of selected species of benthonic foraminifera, and estimated paleobathymetry within the Newport Bay section, Orange County, California.

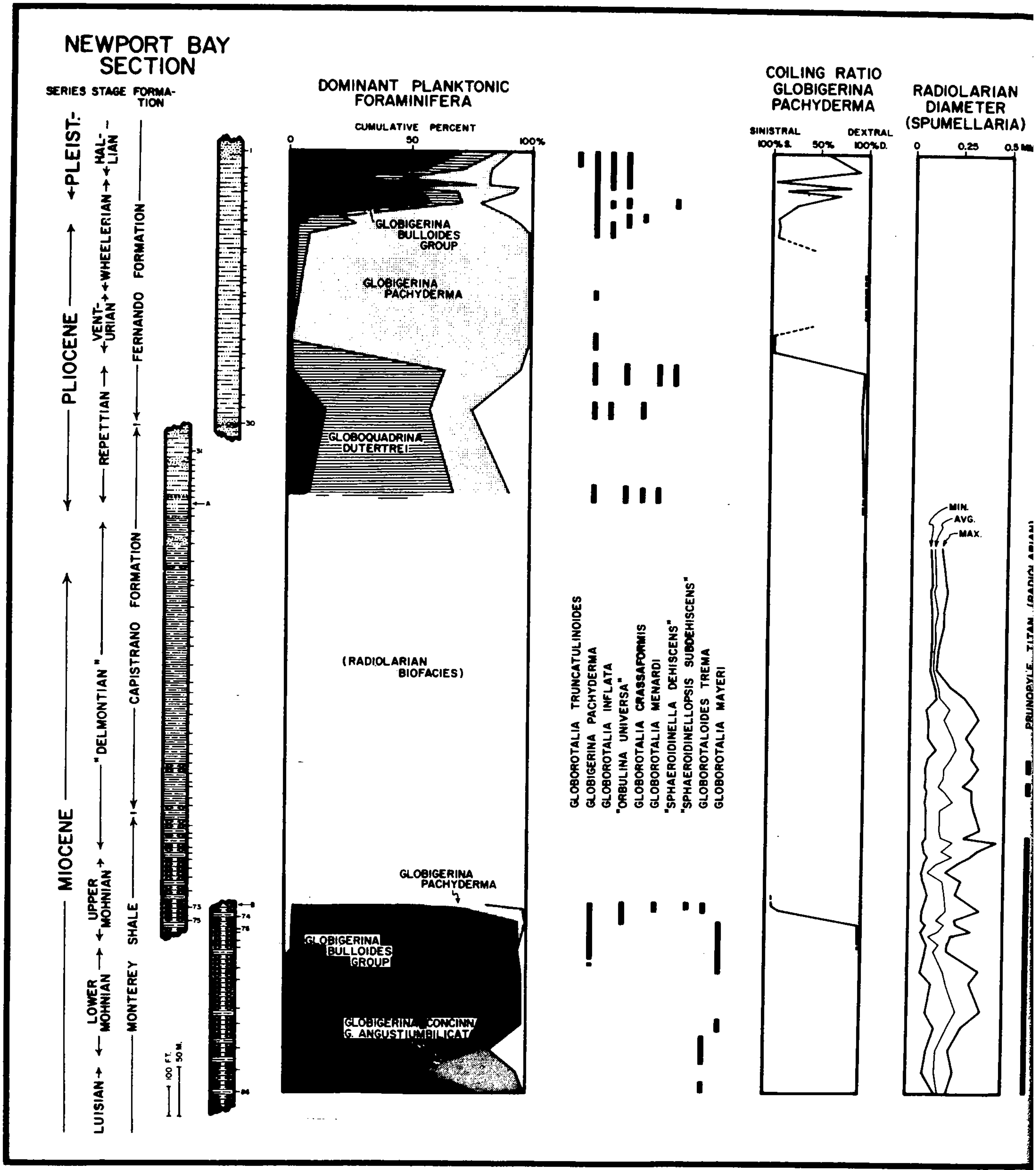

Figure 10 — Stratigraphic variation of dominant planktonic foraminifera, absolute ranges of significant species of planktonic foraminifera and the radiolarian *Prunopyle titan*, variation in coiling direction *Globigerina pachyderma*, and variation in diameter of radiolarian tests (Spumellaria) within the Newport Bay section, Orange County, California.

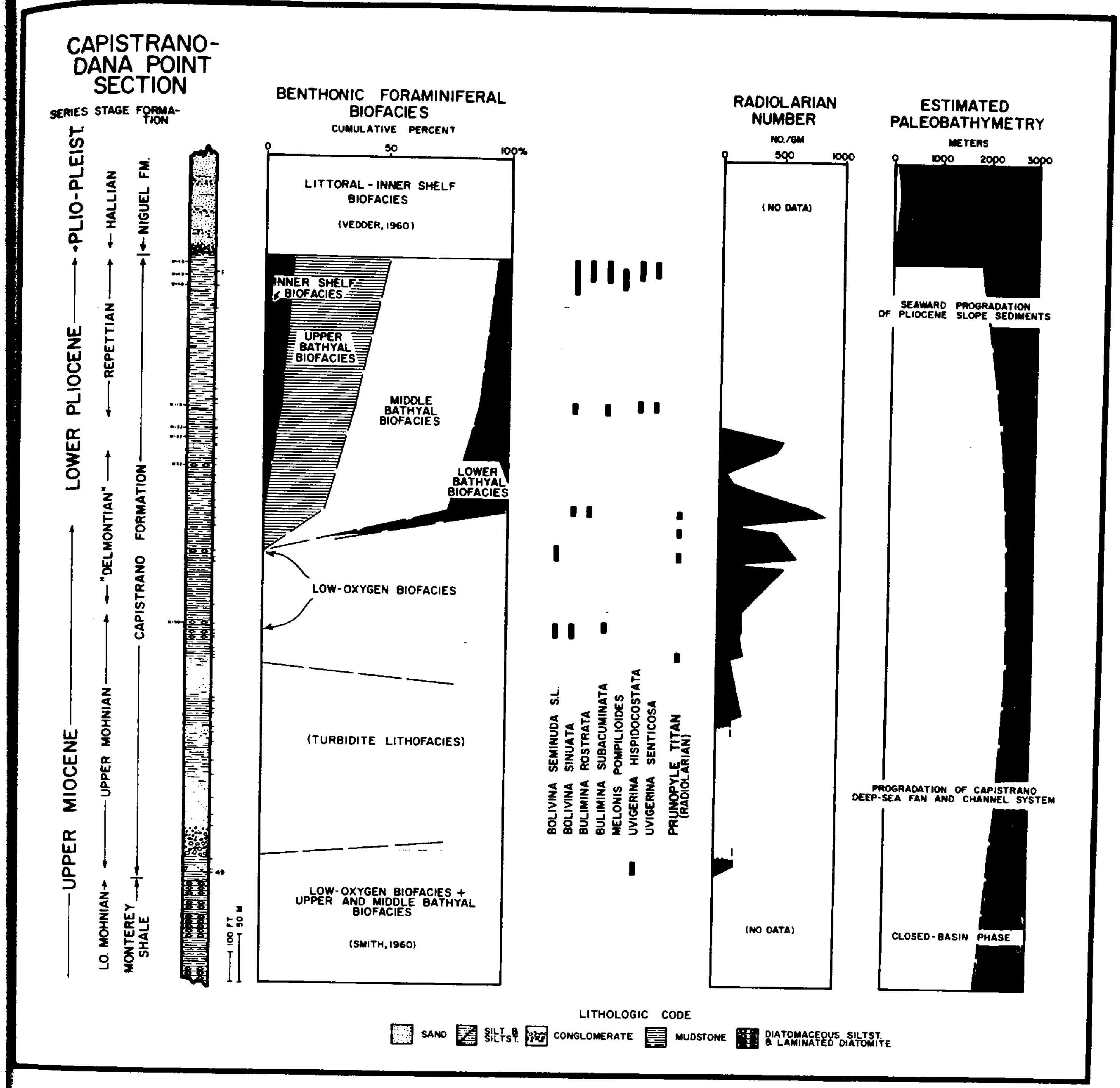

Figure 11 — Stratigraphic variation of benthonic foraminiferal biofacies, ranges of selected species of benthonic foraminifera and the radiolarian *Prunopyle titan*, variation of radiolarian number, and estimated paleobathymetry within the Capistrano - Dana Point section, Orange County, California. Microfossil samples collected during this study are marked on the right side of the stratigraphic column whereas selected samples reported by White (1956) are marked on the left side of the column. See tables 1 and 2 for details of microfossil occurrence and abundance.

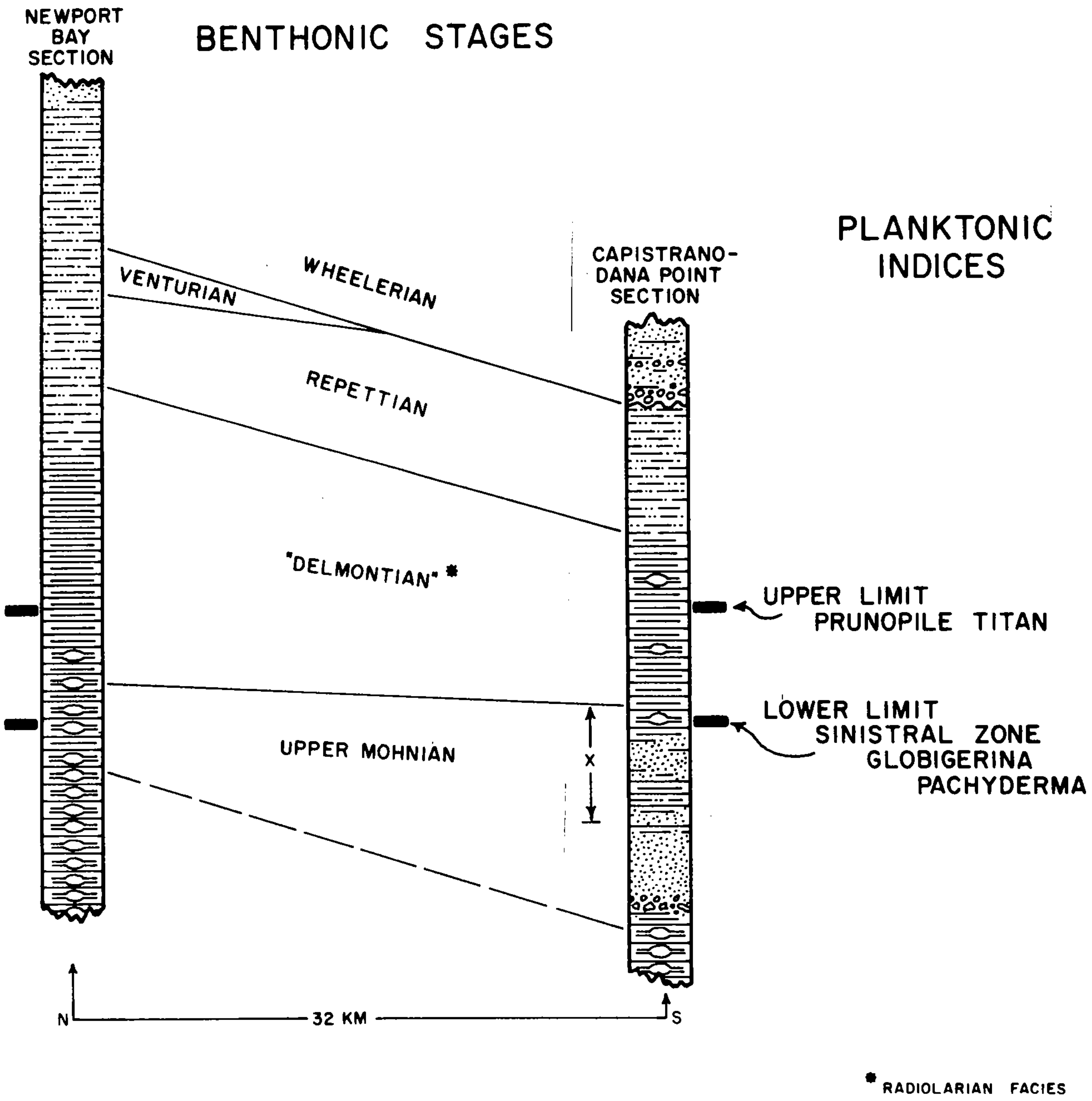

Figure 12 — Planktonic correlation of the Newport Bay — and Capistrano - Dana Point sections, Orange County, California after Ingle (1963, 1967). Using the selected planktonic criteria as "time lines" demonstrates the time transgressive nature of the boundary between "Delmontian" and Repettian age sediments in this area. The thickness of upper Mohnian sediments in the Capistrano - Dana Point section not classified as turbidites is shown by "x".

DIATOM, SILICOFLAGELLATE, RADIOLARIAN, CALCAREOUS NANNOFOSSIL, AND FORAMINIFERAL BIOSTRATIGRAPHY OF THE MIDDLE AND LATE MIOCENE AND PLIOCENE OF NEWPORT BACK BAY, NEWPORT BEACH, CALIFORNIA.

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One of the most fossiliferous and continuous stratigraphic section in western North America is located in the Newport Back Bay area, Newport Beach, California. This section includes the Middle and Late Miocene Monterey Shale, the Late Miocene and Early Pliocene Capistrano Formation and the Middle to Late Pliocene and Pleistocene Fernando Formation. The age assignments based on foraminifers (Lipps 1964, Ingle 1972 and Warren 1972); calcareous nannofossils (Wilcoxon); radiolarians (Casey); diatoms, silicoflagellates and ebridians (Wornardt) are compared and summarized. The ages of the various samples vary somewhat with the different microfossil group studied.

The classic stratigraphic section exposed in the cliffs on the east and west side of the Back Bay in Newport Beach is unique, because: (1) it is well exposed, very accessable, and essentially continuous from the Middle Miocene to Early Pleistocene; (2) the different litholgic units make up about 3,500 feet of section, including: the Monterey Shale, largely siliceous and diatomaceous shale; Capistrano Formation, mainly massive mudstones and sandy siltstones; and the Fernando Formation, a sandy siltstone and siltstone unit. (3) no less than 12 different fossils groups are preserved in the sediments, including diatoms, silicoflagellates, ebridians, radiolarians, benthonic and planktonic foraminifers, calcareous nannofossils, dinoflagellates, spores and pollen, mollusks and marine mammals.

PREVIOUS WORK

Ingle (1962) compiled a stratigraphic distribution chart of 172 foraminiferal taxa from the Middle Miocene to Pleistocene from Newport Back Bay. Subsequently, Ingle (1967, 1971, and 1972) published a stratigraphic column representing the lithology and formations of this section. He collected 86 samples (fig. 1, 2) from approximately 3,300 feet of measured section. He assigned these samples to various formations and to the standard California Provincial benthonic foraminiferal stages, as follows: SAMPLES 1-3—Hallian Stage; 4-19—Wheelerian Stage; 20-26—Venturian Stage; 27-39—Repettian Stage; 40-68—"Delmontian" Stage; 69-78—Late Mohnian Stage; 79-84—Early Mohnian Stage; 85-86—Late Luisian Stage.

Although 47 of 86 samples were essentially barren of foraminifers, Ingle (1962) reported benthonic and planktonic foraminifers in samples 1-12, 25-38 and 73-86.

Ingle (1972) recorded the last occurrence of an important late Miocene radiolarian, *Prunopyle titan*, up to and including sample 57. He assigned a tentative age of Early "Delmontian" to this sample.

Casey (1972) reported *Prunopyle titan* in the Experimental Moho as high as sample EM 6-2, 30-33 cm. and assigned a Delmontian age to this sample. Bandy and Ingle (1971) reported *Prunopyle titan*, about 20 cm. above Casey's sample, in EM 6-2, 9-12 cm. and assigned a Delmontian age to this sample.

Casey (1972) reported this radiolarian species up to and including samples 19 and 20 in the Malaga mudstone, in Palos Verdes Hills, California. He assigned sample 19 to the Late Miocene and 20 to the Early Pliocene mainly on the first appearance of *Lamprocyclas heteroporos*. The first occurrence of this species ". . . must be at or very near the Miocene-Pliocene boundary in the North Pacific . . . " according to Casey (1972, p. 322). He also stated that, "*Prunopyle titan* may last occur just below or coincident with the first occurrence of *Lamprocyclas heteroporos* in Southern California." (Casey, 1972, p. 125).

In 1972, Warren, listed fifty species of foraminifers from about 1400 feet of stratigraphic section representing the Monterey Shale, in Newport Back Bay. He assigned (fig. 1, 3). the following samples to various benthonic foraminiferal Zones.

NEW 58-WNPB 36 *Bolivina hughesi* Zone
TM 17-NEW 57 *Bulimina uvigerinaformis* Zone
TM 14-NEW 27 *Brizalina modeloensis* Zone
NEW 5-NL 8 *Siphogenerina collomi* Zone

He also subdivided the *Bulimina uvigerinaformis* Zone into the *Concavella gyroidinaformis* subzone (TM 17-NEW 42) and the *Brizalina woodringi* subzone (NEW 43-NEW 57).

Warren (1971) placed the top of the Mohnian above sample WNPB 36 but stated that, "It should be noted that the presence of *Brizalina rankin* and *Bulimina delreyensis* in this interval might suggest that the upper part [samples WNPB 13, 18, 20, 30 and 36] could be assigned to the Delmontian Stage" (p.31).

According to Kleinpell (1972, p. 350), " I think, in this Newport section I would be inclined to call the uppermost bed in A. D. Warren's section Delmontian on the basis of the presence of *Bulimina delreyensis* and *Bolivina rankini*, which have a pretty good record."

It is interesting to note that the last (highest) sample that contained foraminifers in the Late Mohnian, according to Ingle (1962, 1972), was sample 73. This sample is slightly above WNPB 13 of Warren (1972). It is also interesting to note that the highest sample that contained foraminifers assigned to the Latest Mohnian by the Union Oil Company was UO 356. This sample occurs just below Warren's sample WNPB 12.

Lipps (1964) reported 20 species of planktonic foraminifera from the Luisian and Mohnina Stages from the section in Newport Back Bay, Newport Beach, California (fig. 1, 4). He assigned samples 1-22 to the Luisian Stage and samples 23-36 to the Mohnian Stage. He correlated the Luisian portion of this section with the Lower *Globorotalia fohsi* Zone in Trinidad. He further assigned the Luisian to the Burdigalian Stage and the Mohnian portion of this section to the Helvetian.

Lipps and Kalisky (1972) discussed the occurrence of calcareous nannoplankton in the Newport Back Bay section. They assigned the Luisian portion of the section to the NN 5 Zone (Standard Calcareous Nannofossil Zone) and the Mohnian portion of the section to be "equivalent to the NN 6 to at least NN 8 zones" (p. 250). Lipps and Kalisky (1972) also correlate NN 5 with the Standard Planktonic Foraminiferal Zonation Zones N 7 (in part), 8, 9, 10, and 11 (in part). They also correlated NN 6 with the planktonic foraminiferal zones N 11 (in part) and N 12; NN 7 with N 13; and NN 8 with N 14.

PRESENT STUDY

The samples used by Wilcoxon, Casey and Wornardt in the present paper were collected by Union Oil Company geologists including the present author (figs. 1, 5). About 30 of the same samples, NL 5 - UO 376 were studied by Wilcoxon, Casey and Wornardt. Wilcoxon reported calcareous nannofossils from the lowest sample NL 5 through UN 1373. All other samples were barren. Casey reported radiolarians from sample NL 5 through UN 1373. Later Casey (private communication) reported radiolarians from samples UO 358-UO 376. Wornardt reported diatoms, silicoflagellates and ebridians (figs. 6-7) from NL 5 through U 370.

Wilcoxon (1969) reported 19 species

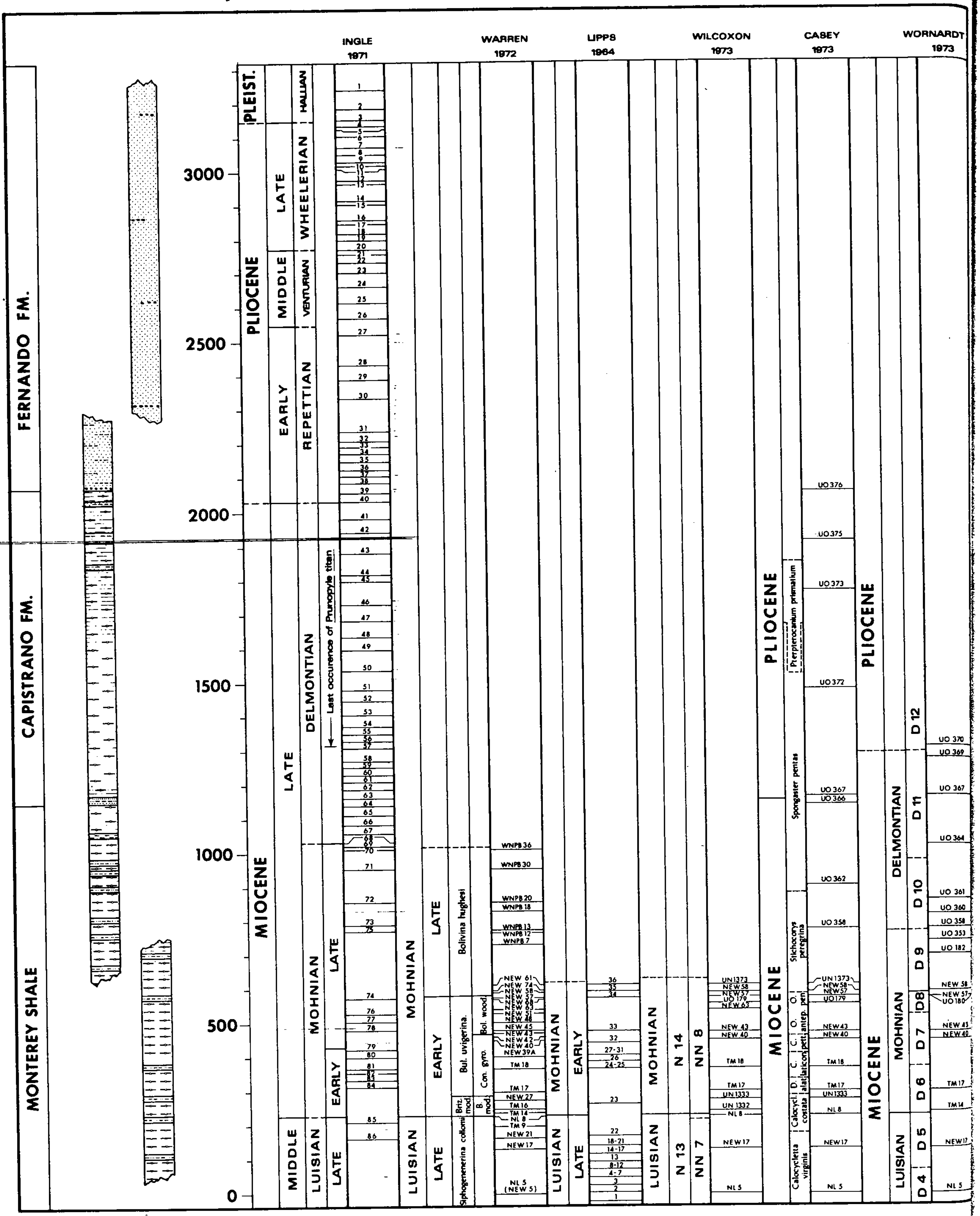

FIG. 1 AGE ASSIGNMENTS AND CORRELATIONS OF LATE CENOZOIC SAMPLES FROM NEWPORT BEACH, BACK BAY, CALIFORNIA

of calcareous nannofossils from the Late Luisian (samples 1-11) and Mohnian (12-17) Stages in the Newport Back Bay section. He reported *Discoaster kugleri* from samples 2, 5, 7, 8, 9, and 11 from the Luisian Stage. He did not find this species in any samples assigned to the Mohnian Stage.

In the present study (see fig. 1, 5) Wilcoxon also reported *Discoaster kugleri* (private communication) from samples NL 5, NEW 17, and NL 8 of Luisian Age. He did not find this species in any Mohnian samples UN 1332 -UN 1373.

Lipps (1968) reported *D. kugleri* only from the Mohnian portion of the section exposed at Newport Back Bay. Warren (1972) reported "Well preserved specimens of *Discoaster kugleri* have been noted in sample NEW 48 from the *Brizalina woodringi* Subzone of the late lower Mohnian Stage at Newport Lagoon." (p. 36). He did not find this species in any samples from the Luisian Stage NL 5-NL 8. There are three explanations for this discrepancy (1) the occurrence of *Discoaster kugleri* in the Mohnian portion of the Newport section is due to reworking; (2) the range of *D. kugleri* must be extended; (3) this easily recognizable species was misidentified.

Wilcoxon (1969) correlated the Luisian portion of this section with the *Globorotalia fohsi lobata* and *Globorotalia fohsi robusta* Zones. In the present paper he assigned the Luisian portion of the section to the NN 7 Zone.

Wilcoxon (1969) assigned samples 12-17 to the Mohnian Stage. In the present paper, he assigned samples UN 1332 -Un 1373 to the Mohnian Stage. Sample NL 8 contained non-diagnostic calcareous nannofossils, according to Wilcoxon (private communication). In 1969 and in the present paper Wilcoxon reported *Discoster bollii* in samples 12, 13, 14, and 16 in 1969 and in samples UN 1332 to about New 43 in the present study. This species seems to be restricted to the Mohnian Stage. According to Wilcoxon (1969, p. 951) "In Trinidad that species occurs only in samples above the *G. fohsi* zones, and in the Mohole drilling Parker assigned samples containing that species to the Mohnian." Therefore Wilcoxon (1969) assigned the Mohnian portion of his section to be equivalent to the *Globorotalia mayeri* and *Globorotalia menardii* Zones. In the present study Wilcoxon assigned samples UN 1332 - UN 1373 to the NN8 and N 14 zones. Lipps and Kalisky (1972) correlated NN 7 with N 13 and NN 8 with N 14.

Casey (1972) reported eight species of radiolarians from 12 samples collected by "Mr. A. Price under the guidance of Dr. J. Lipps, so they duplicate many of the localities of Lipps (1964." (p. 119). The age of the samples used by Casey ranged from Luisian to Mohnian, *Cannartus (?) petterssoni* Zone and the *Ommatartus penultimus* Zone. He stated that the Cannartus (?) petterssoni Zone is equal to the Late Luisian Stage. The Mohnian Stage is equivalent to the *Ommatartus antepenultimus*, *O. penultimus* and the *Stichocorys peregrina* (in part) Zones. The Delmontian Stage is equivalent to the *Stichocorys peregrina* Zone (in part) to part or the entire *Spongaster pentas* and may extend into the *Pterocanium prismatium* Zones. The Repettian and Venturian stages may be equivalent to most of the *Lamprocyclas heteroporos* Zone of Hays. They may also be equivalent to the *Spongaster pentas* (in part) and most of all the *Pterocanium prismatium* Zone of Riedel.

Casey (1973) and further study (private communication) reported radiolar in 20 samples from Newport Back Bay section (figs. 1, 5). He assigned samples NEW 5 [NL 5] to UO 366 to the Miocene and UO 367 to 376 to the Pliocene. He assigned the following samples to various radiolarian zones:

UO 373 *Terpterocanium prismatium* Zone
UO 362-UO 372 *Spongaster pentas* Zone
NEW 58-UO 358 *Stichocorys peregrina* Zone
NEW 43-NEW 57 *Ommatartus penultimus* Zone
Ommatartus antepenultimus Zone
NEW 40 *Cannartus (?) petterssoni* Zone
Tm 18 *"Cannartus laticonus"* Zone
TM 17 *Dorcadospyris alata* Zone
NL 8-UN 1333 *Calocycletta costata* Zone
NL 5-NEW 17 *Calocycletta virginis* Zone

The age and radiolarian zonal assignment of these well disciplined samples is a very valuable asset to detailed and overall knowledge of radiolarian biostratigraphy.

Note that Casey (fig. 1) places the Miocene-Pliocene boundary between samples UO 366 and UO 367. This is based largely on the stratigraphic first appearence of *Lamprocyclas heteroporos* (private communication). It is interesting to point out that this species and *Prunopyle titan* occur together (joint occurrence of species) at or near the Miocene-Pliocene contact in the Newport Beach Back Bay and Malaga Cove section.

According to Casey (fig. 1) the Miocene and Pliocene boundary would fall in the Early Delmontian of Ingle (1971); above the Late Mohnian of Warren (1972); and the Late Delmontian of Wornardt.

The author studied the diatoms, silicoflagellates and ebridians from samples NEW 5 -NEW 17 (Late Luisian); TM 14-NEW 57, UO 180 (Early Mohnian); NEW 58-UO 353 (Late Mohnian); UO 358-UO 364 (Early Delmontian); UO 367-369 (Late Delmontian), and UO 2370 (Early Pliocene) ? (figs. 1, 5). A preliminary checklist for the Newport Back Bay area is found in figures 6 and 7. Most of the species found in this section have been previously published by Hanna and Grant (1926), Lohnman (1931), Hanna (1932), Lohnman (1938); Wornardt (1967a, 1967b, 1969a, 1969b, 1970c, 1970d, 1971, 1972a.).

CONCLUSIONS

(1) The Luisian-Mohnian boundary seems to be rather significant among the diatoms, silicoflagellates, radiolarians, benthonic and planktonic foraminifers and calcareous nannoplankton.

(2) The Early Mohnian-Late Mohnian boundary seems to be somewhat less significant point in time for the different microfossil groups.

(3) The Mohnian and Delmontian Boundary seems to be the most controversial (fig. 1).

(4) The Miocene-Pliocene boundary does not coincide with the study by Ingle (1971), Casey and Wornardt (present paper). This is not difficult to understand if we realize that some of these groups are plants (diatoms silicoflagellates, and ebridians and calcareous nannoplankton) and others are animals (foraminifers and radiolarians) and that all of these groups did not evolve at the same rate at the same time.

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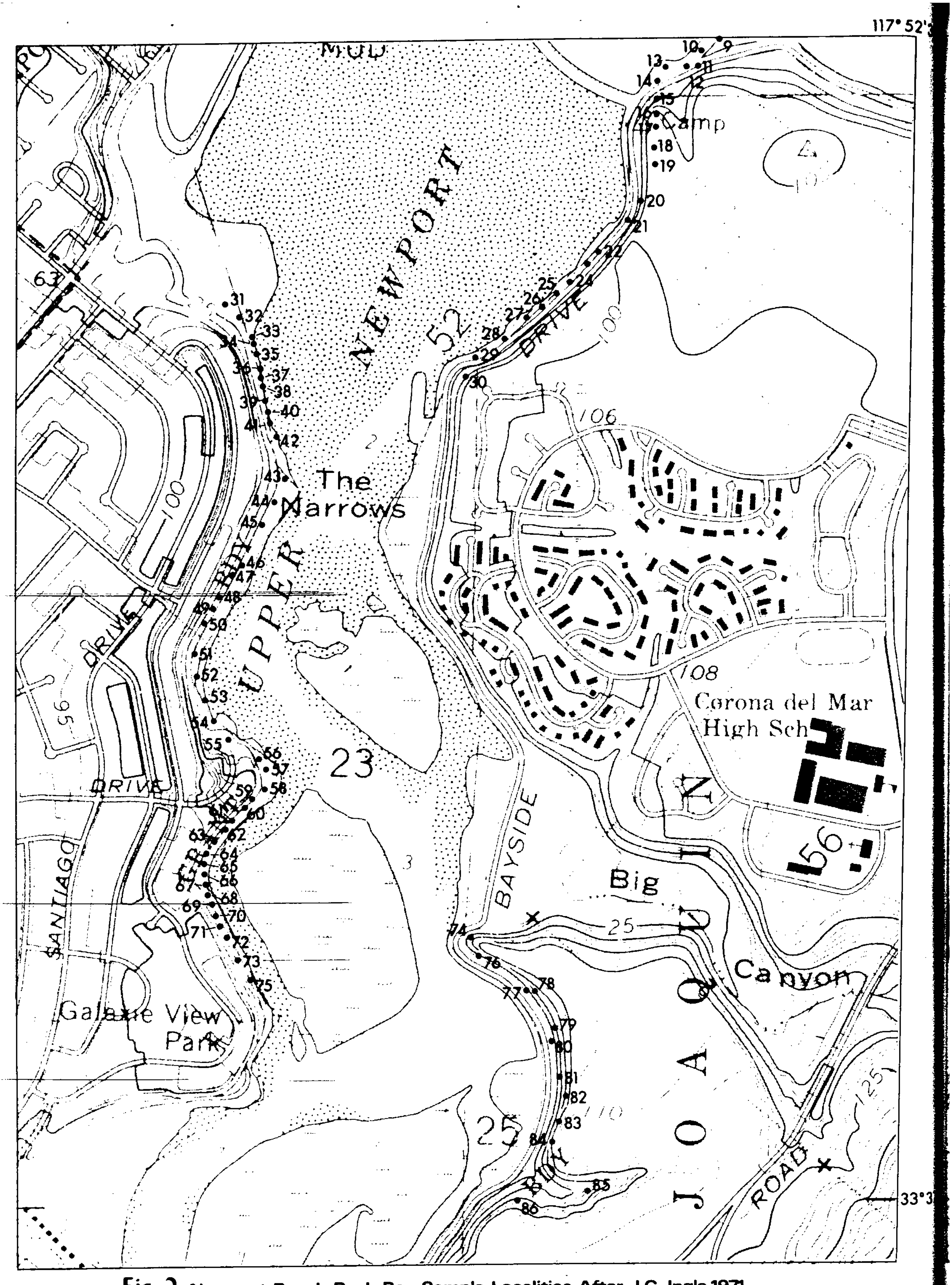

Fig. 2 Newport Beach Back Bay Sample Localities After J.C. Ingle,1971

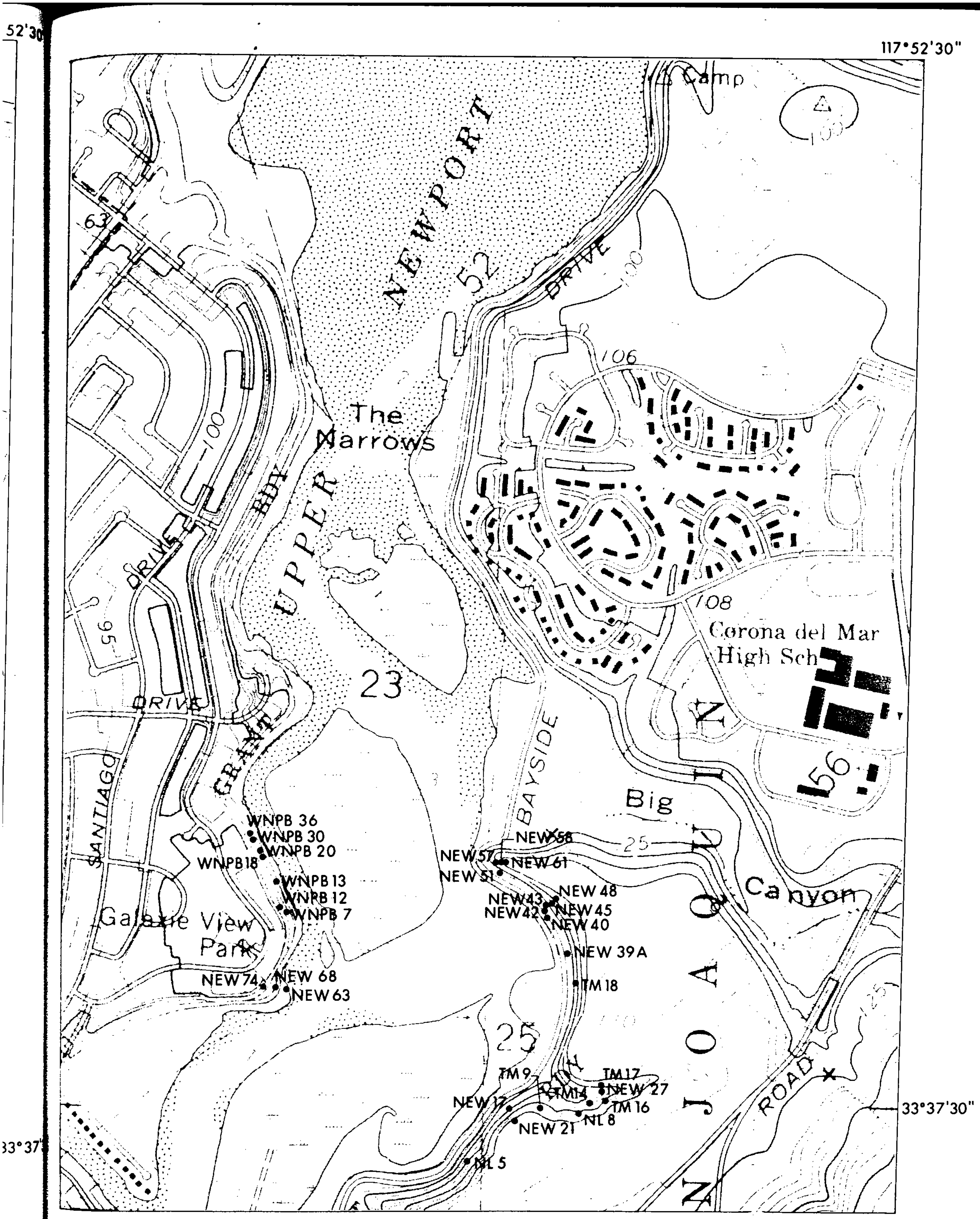

Fig. 3 Newport Beach—Back Bay Sample Localities After A.D.Warren,1972

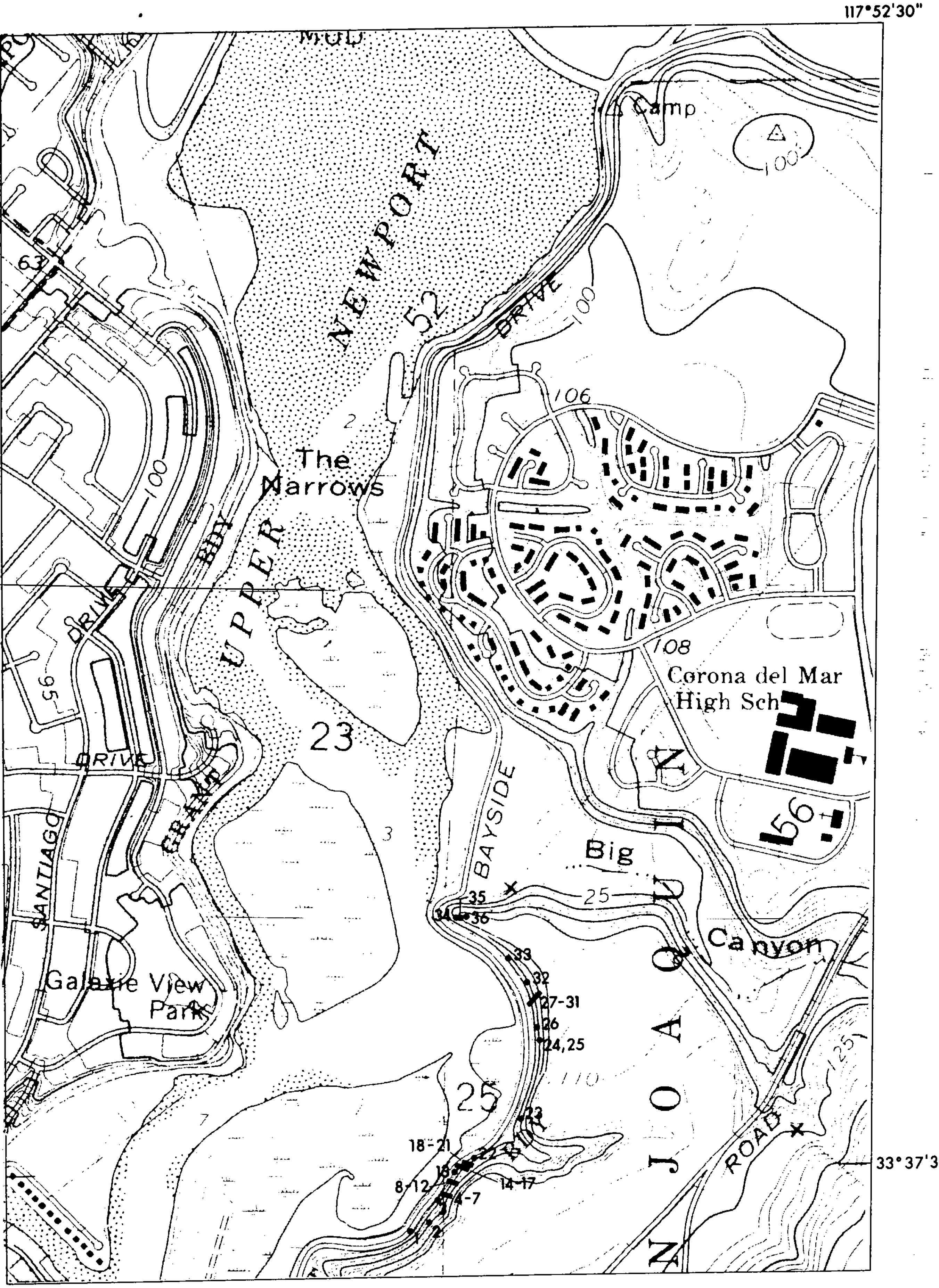

Fig. 4 Newport Beach Back Bay Sample Localities After J.Lipps,1964

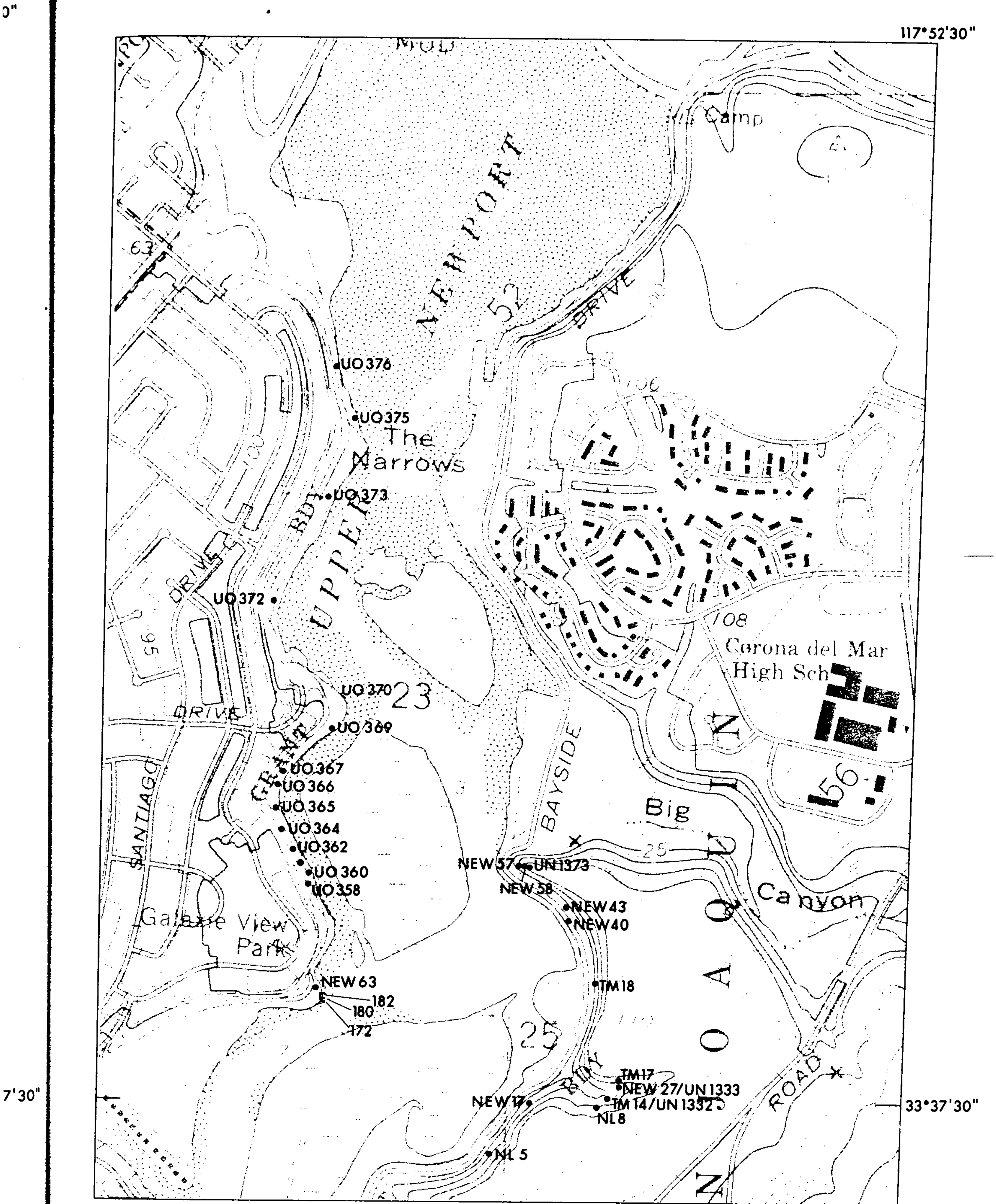

Fig. 5 Newport Beach—Back Bay Sample Localities of Casey, Wilcoxon and Wornardt

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SPECIES \ SAMPLES	NEW 5	NEW 17	TM 14	TM 17	NEW 40	NEW 43	NEW 57	NEW 58	UO 182	UO 353	UO 358	UO 360	UO 361	UO 364	UO 367	UO 369	UO 370			
Actinocyclus ingens	X	X	X	●	●											●				
A. cubitus		/																		
Actinoptychus janishisi								/												
A. perisetosus	X	/																		
A. stella v. clevi									●											
Arachnoidiscus manni	/				/			●												
Amphora crassa		/			/		●													
A. marina		●			●		●													
Asterolampra marylandica		●					●													
Asteromphalus darwini												/		●						
A. dubius		●																		
A. hookeri		●																		
A. robustus								●			/									
Aulacodiscus brownei				●	●		●							●						
A. kittoni								●						●						
A. margaritaceus					●															
Auliscus caelatus				●	●								●	●		/	●			
A. stockhardtii					/															
Biddulphia angulata	●	/		/	/															
B. aurita		●		●			●	●			●	/								
B. deodora		●			●				●											
Ceratulus imperator				/			●	●						●						
Chaetoceros cinctus		/	●				/				●	/	●			X				
Coscinodiscus flex				●																
C. temperi	●																			
C. yabei				/																
C. gigas v. diorama										●		●								
C. fulguralis		●			●		●													
C. nodulifei		●																		
C. vetutissimus	X	●			●		●		●			●								
Cocconeis triumphis							●													
C. vitrea	●																			
Denticula hustedti	●	●	●	●	●	●	●	●	●											
D. lauta	X	/	●																	
D. sp. 1		●						●												
Dimmeregramma scutulum		●		●	●															
Entopya australis v. gigantea					●		●		●					●	●					
Glyphodesmus driveri		●						●												
G. sigmoideus								●												
G. williamsonii							●									●				
Glyphodiscus grunowii							●		●							●				
G. stellatus																/				
Goniothecium rogersii	●	●	●		/								●							
Hemiaulus polymorphus	X	/		●							●	●	●							
Hemidiscus cuneiformis									●		X	/				●	●			
H. simplicissius							●					X								
Liradiscus ellipticus					●							●								
L. oblongus						●		●									●			
L. ovalis	/															●				
Lithodesmium californicum		●			●					●	●	●								
L. minusculum					●			●								●				
Mediaria splendida	/	/																		
M. splendia var. 1										/										

FIG. 6. CHECKLIST OF SELECTED DIATOMS, SILICOFLAGELLATES AND EBRIDIANS FROM THE MIDDLE TO LATE MIOCENE, BACK BAY, NEWPORT BEACH

SAMPLES / SPECIES	NEW 5	NEW 17	TM 14	TM 17	NEW 40	NEW 43	NEW 57	NEW 58	UO 182	UO 353	UO 358	UO 360	UO 361	UO 364	UO 367	UO 369	UO 370
Nitzschia cylindrica											/	X				/	
N. fossilis											●	/					
N. jousea																●	
N. porteri							●		●			●					
N. reinholdi																/	
N. reinholdi v. P											/						
N. sp. R	/								/								
N. sp. C				●													
Opephora schwartzii	/	/		/	●		/		●								
Perry innocens				●													
Plagiogramma antillarum					●												
P. fascinatum	●						●	●									
Pleurosigma manni		/						●									
Raphidodiscus marylandiscus	/																
Raphoneis angustata				●			●		●					●			●
R. cocconeiformis		●		●													
R. sachalinensis					●							●					
Rouxia californica		X	●		●		/	/		/	/	/					
R. sp. D	/																
R. sp. N	X			●													
R. peragalli	●	X															
R. yabei	●	●						●									
Rutilaria epsilon													●				
R. sp. E							●										
R. sp. F								●									
Sceptroneis caduceus	/																
Stephanogonia polyacantha		/															
S. actinoptychus												●					
Synedra duhemi		●		●													
S. jouseana		●		●													
Thalassiosira antiqua											/	/					
T. decipiens												/					
T. nativa												●					
T. preconvexa					●												
T. oestrupi																	●
Triceratium condecorum	/	/															
Silicoflagellates																	
Cannopilus hemisphaericus	/	/	●		●	/	●										
C. sphaericus		●			●	●											
Dictyocha ausonia	X													/			
D. ausonia v. 1														X		/	
D. crux	X	/		●		●											
D. crux v. 1											●	●					
D. fibula											/	/		●			
D. fibula v. octacanthus	●	●															
D. fibula v.pentagonalis												●			/		
D. speculum		●		●	/		/			●		/	●		●	/	/
M. circulus					●		/		●			●	●				
M. circulus v. apiculata					●		●										
M. elliptica							/	●	●								
Paradictocha polyactis		●															
Ebridians																	
Ammodichium rectangulare	/	/			●						/	●					
Ebriopsis antiqua		●															
E. crenulata		●		●							/	/					
Parathranium tenuipes		X													/		

FIG. 7. CHECKLIST OF SELECTED DIATOMS, SILICOFLAGELLATES AND EBRIDIANS FROM THE MIDDLE TO LATE MIOCENE, BACK BAY, NEWPORT BEACH

PLATE 1

Fig. 1

Actinocyclus cubitus Hanna and Grant. Locality NEW 17, Late Luisian. x1000.

Fig. 2

Actinocyclus ingens Rattray. SEM, tilt 45°. Locality NEW 17, Late Luisian. x1000.

Fig. 3

Actinoptychus perisetosus Brun. Locality NEW 5, Late Luisian. x500.

Fig. 4

Arachnoidiscus manni Hanna and Grant. Locality NEW 58, Late Mohnian. x500.

Fig. 5

Aulacodiscus brownei Norman. SEM, tilt O°. Locality UO 180, Early Mohnian. x1500.

Fig. 6

Aulacodiscus kittoni Arnott. Locality NEW 58, Late Mohnian. x1000.

Fig. 7

Coscinodiscus vetustissimus Pantocsek. SEM, tilt O°. Locality UO 180, Early Mohnian. x1000.

Fig. 8

Coscinodiscus vetustissimus Pantocsek. SEM, tilt 45°. Locality UO 180, Early Mohnian. x1000.

Fig. 9

Coscinodiscus yabei Kanaya. High focus. Locality TM 17, Late Luisian. x1000.

Fig. 10

Coscinodiscus yabei Kanaya. Low focus. Locality TM 17, Late Luisian. x1000.

Fig. 11

Denticula hustedtii Kanaya and Simonsen. Locality TM 17, Early Mohnian. x1500.

Fig. 12

Denticula hustedtii Kanaya and Simonsen. Locality TM 17, Early Mohnian. x1500.

Fig. 13

Denticula lauta Bailey. Locality NEW 5, Late Luisian. x1500.

Fig. 14

Denticula sp. 1. Locality NEW 5, Late Luisian. x1500.

Fig. 15

Denticula sp. 1. Locality NEW 5, Late Luisian. x1500.

Fig. 16

Dimmeregramma scutulum Hanna. Locality NEW 40, Early Mohnian. x1500.

Fig. 17

Entopya australis v. *gigantea* (Greville). Locality UO 182, Late Mohnian. x500.

Fig. 18

Goniothecium rogersii Ehrenberg. Locality NEW 40, Early Mohnian. x500.

Fig. 19

Hemiaulus polymorphus Grunow. SEM, tilt 90°. Locality UO 358, Earl Delmontian. x1500.

Fig. 20

Glyphodesmus driver Hanna and Grant. SEM, tilt O°. Locality NEW 17, Late Luisian. x1500.

Fig. 21

Liradiscus ovalis Locality NEW 5, Late Luisian. x1500.

Fig. 22

Lithodesmium californicum Grunow. SEM, tilt O°. Locality UO 353, Late Mohnian. x1500.

PLATE 2

Fig. 1

Mediaria splendida Sheshukova-Poretskaya. NEW 17, Late Luisian. x1500.

Fig. 2

Mediaria splendida var. 1. SEM, tilt O°. Locality UO 353, Late Mohnian. x1000.

Fig. 3

Nitzschia porteri Frenguelli. Locality UO 182, Late Mohnian. x1500.

Fig. 4

Nitzschia jouscae Burckle. Locality UO 369, Late Delmontian. x1500.

Fig. 5

Nitzschia cylindrica Burckle. Locality UO 360, Early Delmontian. x1500.

Fig. 6

Nitzschia reinholdi Kanaya and Koizumi. Locality UO 369, Late Delmontian. x1500.

Fig. 7

Nitzschia reinholdi var. P. Locality UO 358. Early Delmontian. x1500.

Fig. 8

Plagiogramma antillarum Cleve. Locality NEW 40, Early Mohnian. x1500.

Fig. 9

Rhaphoneis sachalinensis Sheshukova-Poretskaya. SEM, tilt O°. Locality UO 180, Early Mohnian. x1500.

Fig. 10

Rouxia californica M. Peragallo. SEM, tilt O°. Locality UO 353, Late Mohnian. x2000.

Fig. 11

Rouxia californica M. Peragallo. SEM, tilt 45°. Locality UO 180, Early Mohnian. x2000.

Fig. 12

Rouxia sp. N. SEM, tilt O°. Locality NEW 17, Late Luisian. x5000.

Fig. 13

Rouxia peragalli Brun and Heribaud. SEM, tilt O°. Locality NEW 17, Late Luisian. x2000.

Fig. 14

Rouxia peragalli Brun and Heribaud. SEM, tilt 45°, Locality NEW 17, Late Luisian. x2000.

Fig. 15

Rouxia yabei Hanna. Locality NEW 58, Late Mohnian. x1500.

Fig. 16

Rouxia peragalli Brun and Heribaud. Locality NEW 17, Late Luisian. x1500.

Fig. 17

Sceptroneis caduceus Hanna. SEM. Tilt 45°. Locality NEW 17, Late Luisian. x2000.

Fig. 18

Synedra dehemi Hanna and Grant. Locality NEW 17, Late Luisian. x1500.

Fig. 19

Synedra jouseana Sheshukova-Poretskaya. Locality NEW 5, Late Luisian. x1500.

Fig. 20

Stephanogonia polycantha Forti. Locality NEW 17. Late Luisian. x1000.

Fig. 21

Triceratium condecorum Brightwell. SEM, tilt O°. Locality NEW 17, Late Luisian. x2000.

Fig. 22

Thalassiosira decipens Grunow Joergensen. SEM, tilt O°, Locality UO 360, Early Delmontian. x5000.

PLATE 3

Fig. 1

Cannopilus hemisphaericus (Ehr.). High focus. Locality UO 360, Early Delmontian. x1000.

Fig. 2

Cannopilus hemisphaericus (Ehr.). Low focus. Locality UO 360, Early Delmontian. x1000.

Fig. 3

Dictyocha ausoni Deflandre. Locality UO 364. Early Delmontian. x1000.

Fig. 4

Dictyocha crux var. 1. SEM, tilt O°. Locality UO 358, Early Delmontian, x2000.

Fig. 5

Dictyocha crux (Ehr.). SEM, tilt 45°. Locality NEW 17, Early Mohnian. x2000.

Fig. 6

Dictyocha fibula Ehr. SEM, tilt O°. Locality UO 360, Early Delmontian, x2000.

Fig. 7

Dictyocha speculum var. *pentagonus* Lemmermann. High focus. Locality UO 360, Early Delmontian. x1000.

Fig. 8

Dictyocha speculum var. *pentagonus* Lemmermann. Low focus. Locality UO 360, Early Delmontian. x1000.

Fig. 9

Mesocena elliptica Ehr. SEM, tilt O° Locality NEW 57, Late Mohnian, x1000

Fig. 10

Mesocena circulus var. *apiculata* Lemmermann. SEM, tilt O°. Locality NEW 57. Late Mohnian, x1000.

Fig. 11

Ebriopsis crenulata Hovasse. SEM, til O°. Locality UO 358, Early Delmontian. x2000.

Fig. 12

Parathranium tenuipes Hovasse. SEM tilt 90°. Locality NEW 17, Early Mohnian. x2000.

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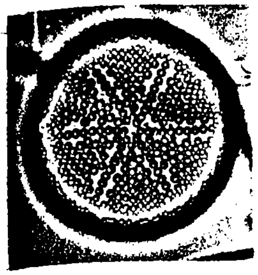
PLATE 1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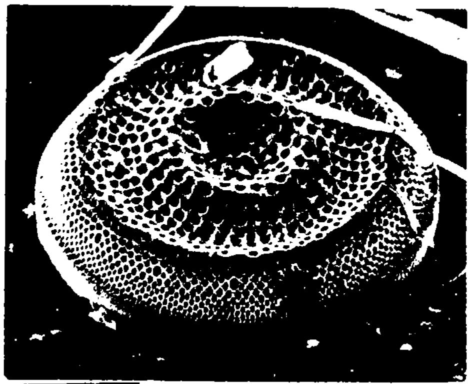
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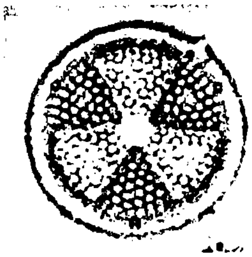
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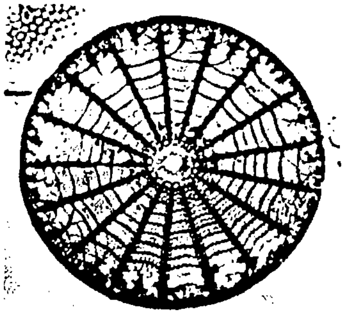
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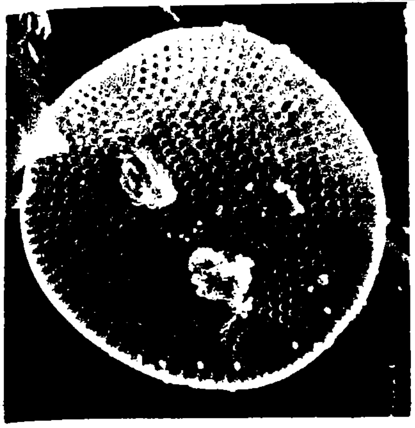
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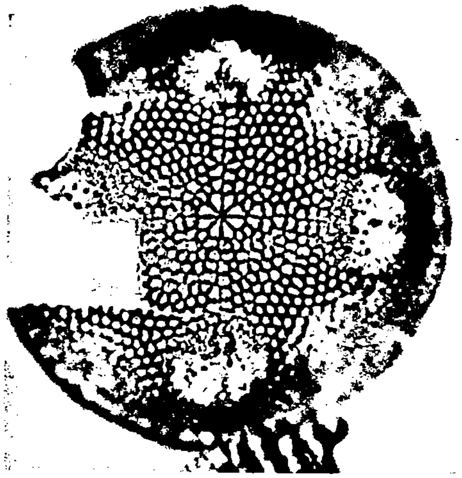
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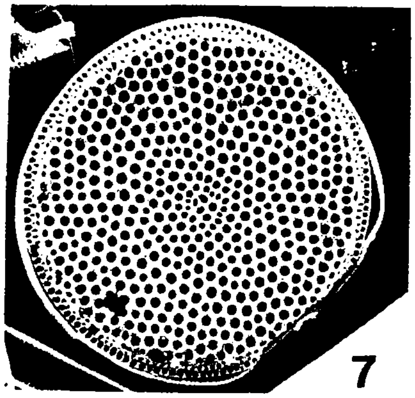
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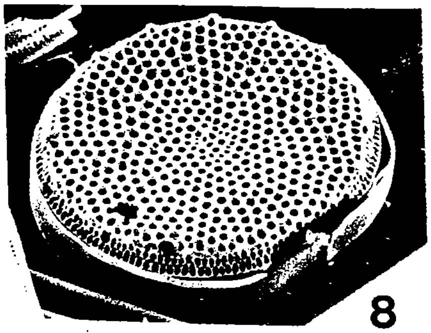
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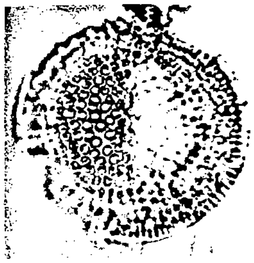
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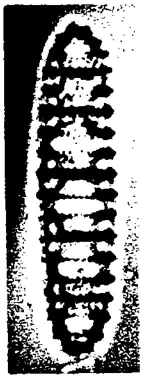
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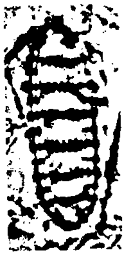
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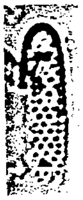
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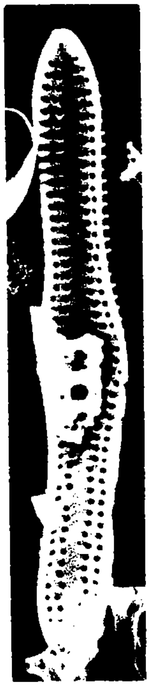
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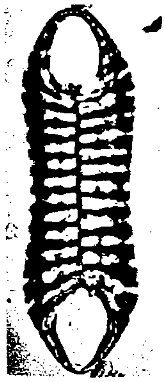
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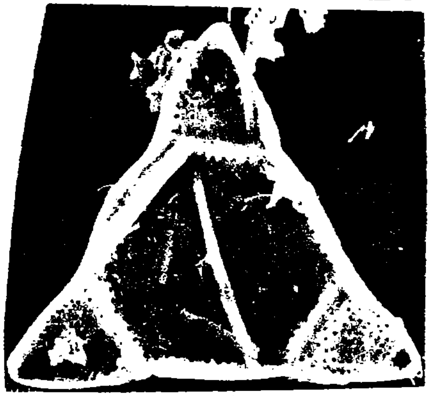
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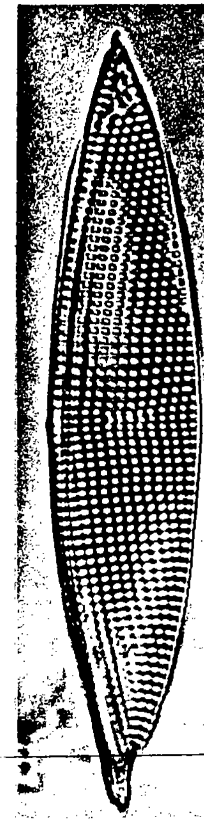
PLATE 2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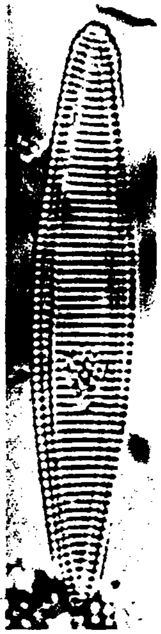
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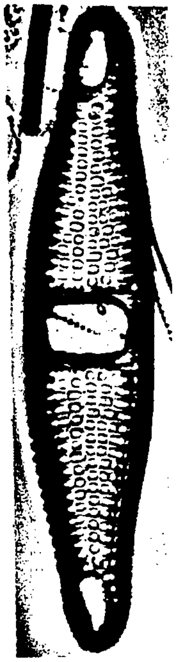
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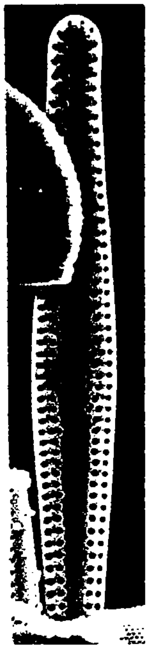
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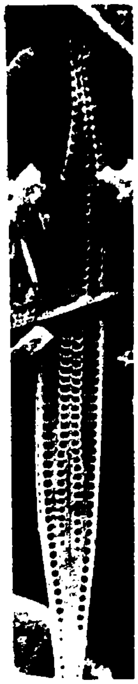
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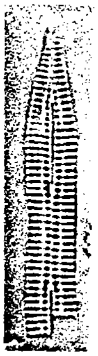
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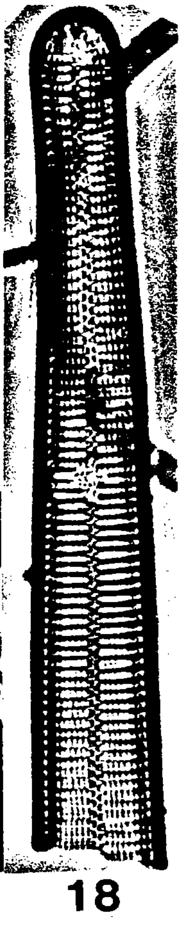
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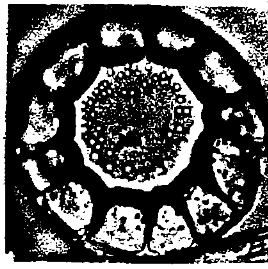
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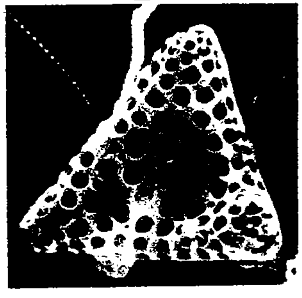
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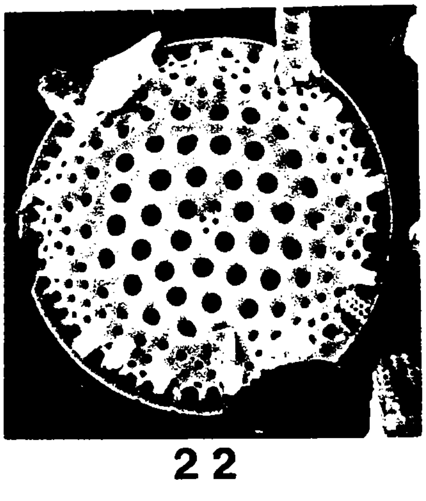
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PLATE 3


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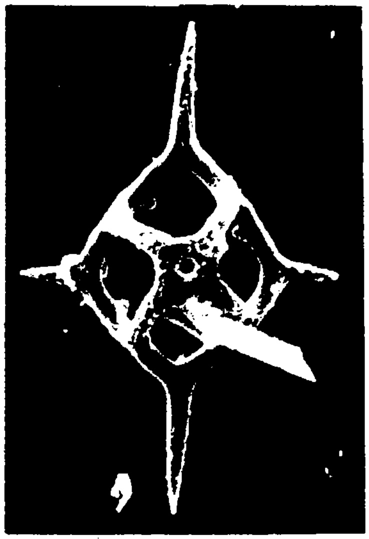
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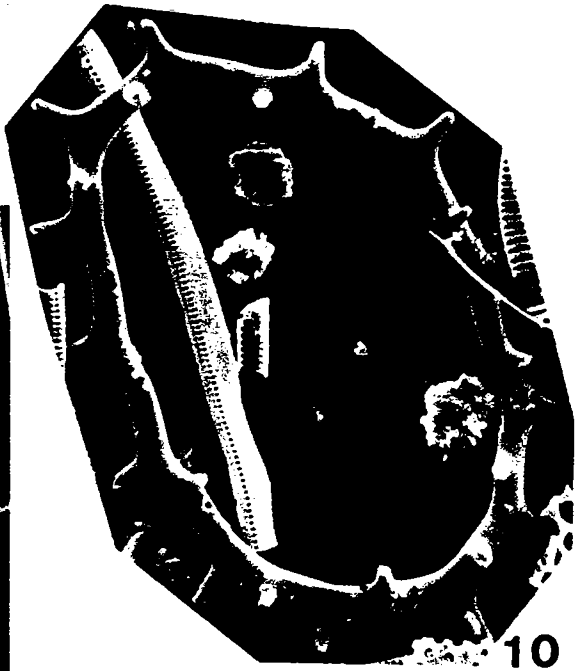
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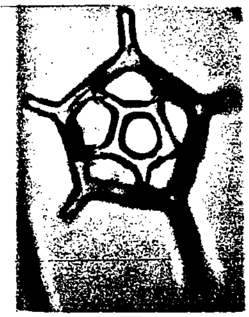
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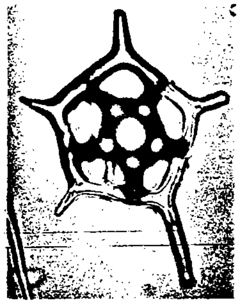
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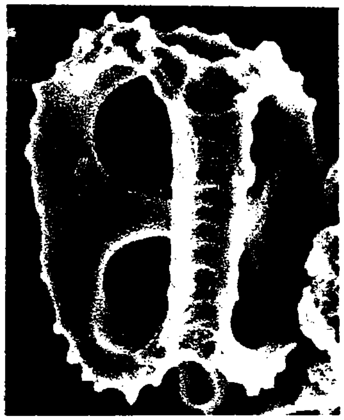
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SAN ONOFRE BRECCIA AS EVIDENCE FOR THE WESTERN BOUNDARY OF THE PENINSULAR RANGES BLOCK[1]

By
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South of the Newport Beach oil field on a continuation of the Newport-Inglewood trend, the major evidence for an abrupt basement boundary at the western edge of the Peninular Ranges is provided by the San Onofre Breccia (Woodford, 1925). This poorly sorted sedimentary breccia contains abundant clasts of Catalina Schist, yet is found overlying the sedimentary sequence of Late Cretaceous to middle Miocene age which itself overlies Peninsular Ranges basement. It is found in the San Joaquin Hills, the coastal area between Laguna Beach and San Onofre, in the La Mission area south of Tijuana, Baja California (Minch, 1967), and in deep wells in the Huntington Beach and Sunset Beach oil fields (Fig. 1). As restricted above, no San Onofre Breccia is found in the Los Angeles Basin north and west of Sunset Beach. Conglomerates and sandstones with Catalina Schist debris directly overlie Catalina Schist basement in the western Los Angeles basin (where they are called the "Schist-conglomerate") and are interbedded with Miocene strata in the Palos Verdes Hills. The "Schist-conglomerate" is time-transgressive. It contains a molluscan fauna of late Miocene age at Playa del Rey oil field (Corey, 1936), but underlies shales with a Luisian microfauna at Wilmington and Inglewood oil fields (Wissler, 1943). Blueschist debris is found in middle and upper Miocene strata in the Palos Verdes Hills (Woodring and others, 1946), and some of this material is of the same age as the San Onofre Breccia (Yerkes and others, 1965). Because these beds overlie Catalina Schist and not eastern basement, they have no bearing on the Miocene position of the boundary between Catalina Schist and Peninsular Ranges basement.

The narrow facies distribution of the San Onofre Breccia as restricted here and the evidence for a western source of the Catalina clasts indicate that at the time the San Onofre was deposited on the western edge of the Peninsular Ranges, Catalina Schist basement was exposed nearby to the west (Fig. 2A). From Sunset Beach south to the La Mission area, the Peninsular Ranges-Catalina basement boundary, based on the San Onofre Breccia evidence, lies approximately along the southeastward extension of the Newport-Inglewood zone. The absence of San Onofre Breccia along the zone northwest of Sunset Beach and the presence of greenschist-facies basement directly underlying middle Miocene beds in two areas east of the Newport-Inglewood zone (Las Cienegas and Brea-Olinda, Yeats, 1973), suggest that the basement boundary diverges from the Newport-Inglewood zone at some point north of Sunset Beach and passes in a northerly direction east of the deepest part of the central Los Angeles basin (dotted line, Figure 1; Figure 2A).

The significance of the western boundary of the Peninsular Ranges in the subsequent structural evolution of the Newport-Inglewood fault zone and producing trend (Yeats, 1973) is illustrated in Figure 2.

Figure 1 — Inferred basement anisotropy in Catalina Schist based on fault trends in oil fields (from Yeats, 1973). Northerly-trending faults are predominantly normal; westerly-trending faults, predominantly reverse. Strike-slip faults of Newport-Inglewood zone not shown. Fine dot pattern denotes San Onofre Breccia outcrops southeast of Huntington Beach; finedotted circles show wells containing San Onofre Breccia. Dotted line shows suggested western boundary of Peninsular Ranges basement with its Cretaceous to early Miocene cover.

Figure 2 — Structural evolution of Newport-Inglewood fault zone (from Yeats, 1973). A (left) — Beginning of breakup of Peninsular Ranges; Channel Island and Santa Monica blocks drift westward, forming tectonic ridges of Catalina Schist in between. San Onofre Breccia spreads northeast from tectonic schist ridge onto edge of Peninsular Ranges. Normal fault systems develop in Catalina Schist and Peninsular Ranges. B (center) — Fault systems comprising basement anisotropies are propagated upward into overlying sedimentary blanket. Pacific plate moves northwest with respect to Peninsular Ranges, but strain is distributed across Catalina terrane ("soft" boundary), except for southwest boundary of Peninsular Ranges, a zone of high-ductility contrast. Faults are normal or reverse, depending upon orientation. C (right) - Lateral slip along Peninsular Ranges southwest boundary leads to propagation of slip across the lower ductility contrast basement of western Los Angeles basin and to localization of strain along the Newport-Inglewood fault in the basement.

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[1] *Slightly modified from "Newport-Inglewood Fault Zone, Los Angeles Basin, California:" Am. Assoc. Petroleum Geologists Bull., January, 1973.*

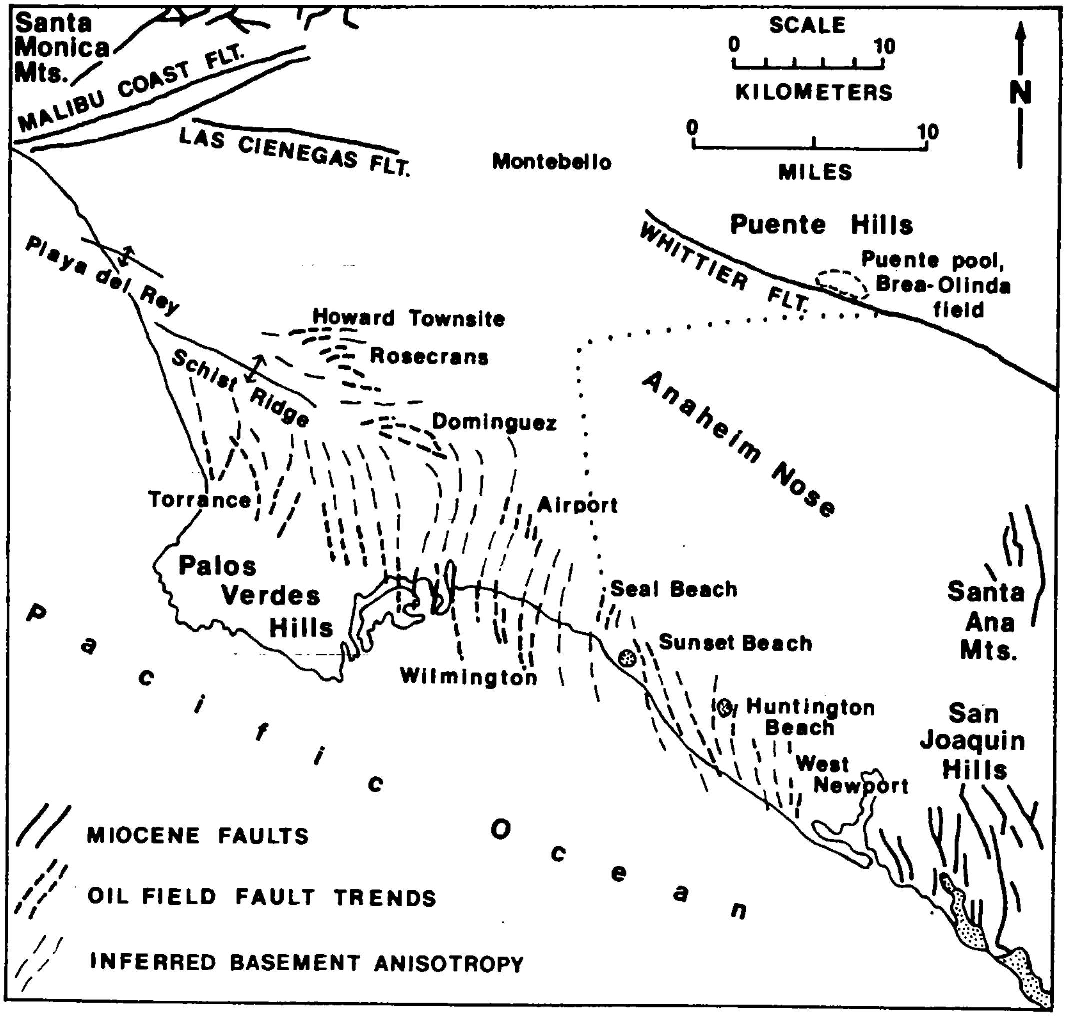
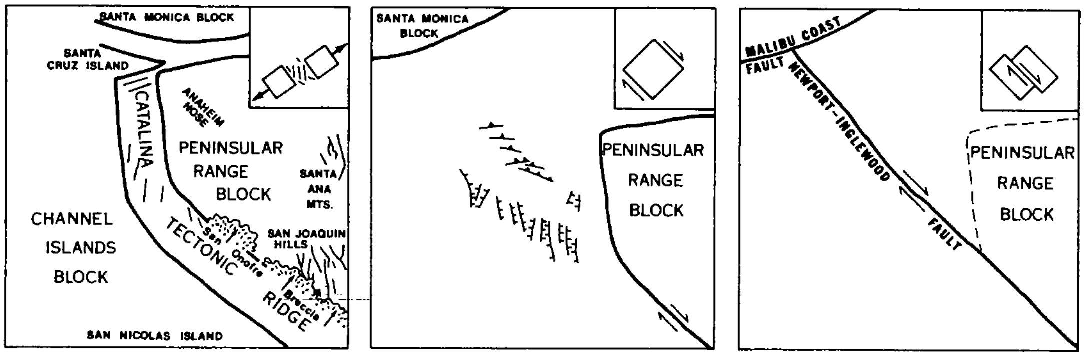


Figure 1



A. Early middle Miocene

B. End of Miocene

C. Late Pliocene and Quaternary

Figure 2

LITHOFACIES IN THE SAN ONOFRE BRECCIA, LAGUNA BEACH TO DANA POINT, ORANGE COUNTY, CALIFORNIA: A PRELIMINARY REPORT

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The middle Miocene San Onofre Breccia is a heterogeneous sequence of breccia, conglomerate, sandstone and mudstone. The most distinctive features of the formation are breccia beds with outsize clasts and very poor sorting, and an abundance of glaucophane schist and other clasts from a metamorphic terrane similar to that on Catalina Island and in the Palos Verdes Hills (Ellis, 1919, p. 57; Woodford, 1925, p. 236-237). Woodford (1925, p. 204-205) distinguished breccia types in the formation on the basis of matrix composition and color, but did not define lithologic facies. Breccia types described by Woodford include those with a gray sandy matrix, a gray earthy matrix, or a red or brown earthy matrix. Earthy matrix consists of a poorly sorted mixture of sand and silt probably with some clay. In the present study, this matrix type is termed mud-matrix.

In more recent studies of the San Onofre Breccia (Woodford, and others, 1954; Vedder, and others, 1957; Vedder, 1971), the distinction between lithologic units follows Woodford's matrix classification. In the present study, matrix differences and other important bedding characteristics are used to interpret three lithofacies within the formation. In ascending stratigraphic order these are: graded sandstone facies, sandy breccia and conglomerate facies, and mud-matrix breccia facies (red-brown and gray). The facies intertongue but usually are superpositionally exposed in this order (figures 1, 2).

GRADED SANDSTONE FACIES

Beds of the graded sandstone facies with a maximum total thickness of 520 meters, are exposed in the seacliff from Halfway Rock to Arch Beach and up to 1.8 kilometers inland (figure 2). The contact with the underlying Topanga Formation, as exposed on the beach at Halfway Rock, is placed at the lowest bed containing schist boulder conglomerate and breccia- conglomerate lenses within an interval of sandstones and shales, that are similar above and below the contact.

The graded sandstone facies is characterized by normally graded feldspathic sandstone beds containing scattered mudstone clasts and subangular to rounded schist pebbles and cobbles. The beds are up to 2 meters thick. Individual bedding units are massive with a sharp basal contact, and grade from pebbly, very coarse-grained to fine-grained sandstone or siltstone. Some beds display horizontal or low angle cross-lamination near the top, but others are entirely laminated. Laminated beds are up to .5 meters thick. Sandstone beds are intercalated with thin, dark-gray laminated mudstone that commonly exhibits flame and rip-up structures or occurs within the sandstone as chips and slabs. Breccia and breccia-conglomerate beds are present at the base of the facies and within its upper part as exposed along the sea cliff. They are irregular in thickness, commonly occur in channels or lenses and include pebble to boulder-size clasts.

The basal and mud-matrix conglomerate and breccia-conglomerate beds at Halfway Rock (figure 3) are part of a disrupted sequence which includes very coarse-grained, fossiliferous, calcareous, feldspathic sandstone and gray laminated mudstone (figure 1). The mudstone is contorted, feldspathic sandstone beds are broken into irregular blocks, and the conglomerate and breccia-conglomerate contains churned-in thin mudstone beds and laminae. Sliding or slumping of the sequence caused the disruption soon after deposition.

SANDY CONGLOMERATE AND BRECCIA FACIES

The sandy conglomerate and breccia facies occurs in a belt up to 1.8 kilometers wide at the north but narrowing southward from Arch Beach to South Laguna (figure 2). Inland, it is repeated by faulting in a parallel belt of rocks. The upper part of the facies is repeated east of the South Laguna Fault and is well exposed along the shoreline. The section between Arch Beach and South Laguna attains a maximum thickness of about 230 meters. It transitionally overlies the graded sandstone facies in the seacliff but sharply overlies it in the hills to the east. As shown at Arch Beach, the rocks are a crudely bedded, relatively massive sequence of sand-matrix pebble and boulder breccia (clasts to 2.5 meters in diameter) and coarse-grained, massive sandstone beds containing pebbles, cobbles and boulders (figure 4). Southeast of Aliso Beach the beds within this facies become sandier and clasts become more rounded and decrease in size to cobbles. Oysters, pectens, and barnacles are commonly found in the upper part of the sequence. Tongues of poorly sorted mud-matrix boulder breccia are present in the seacliff .5 and 1.0 kilometers southeast of Aliso Beach near the top of the sequence.t

At Mussel Cove, yellow-gray sandstone intertongues with intercalated redbrown and gray mud-matrix silty sandstone, siltstone, and cobble breccia. The underlying strongly cross-bedded sandstone contains pebble-cobble conglomerate lenses and beds that lack fine-grained material; apparently they are reworked and winnowed mud-matrix breccia tongues.

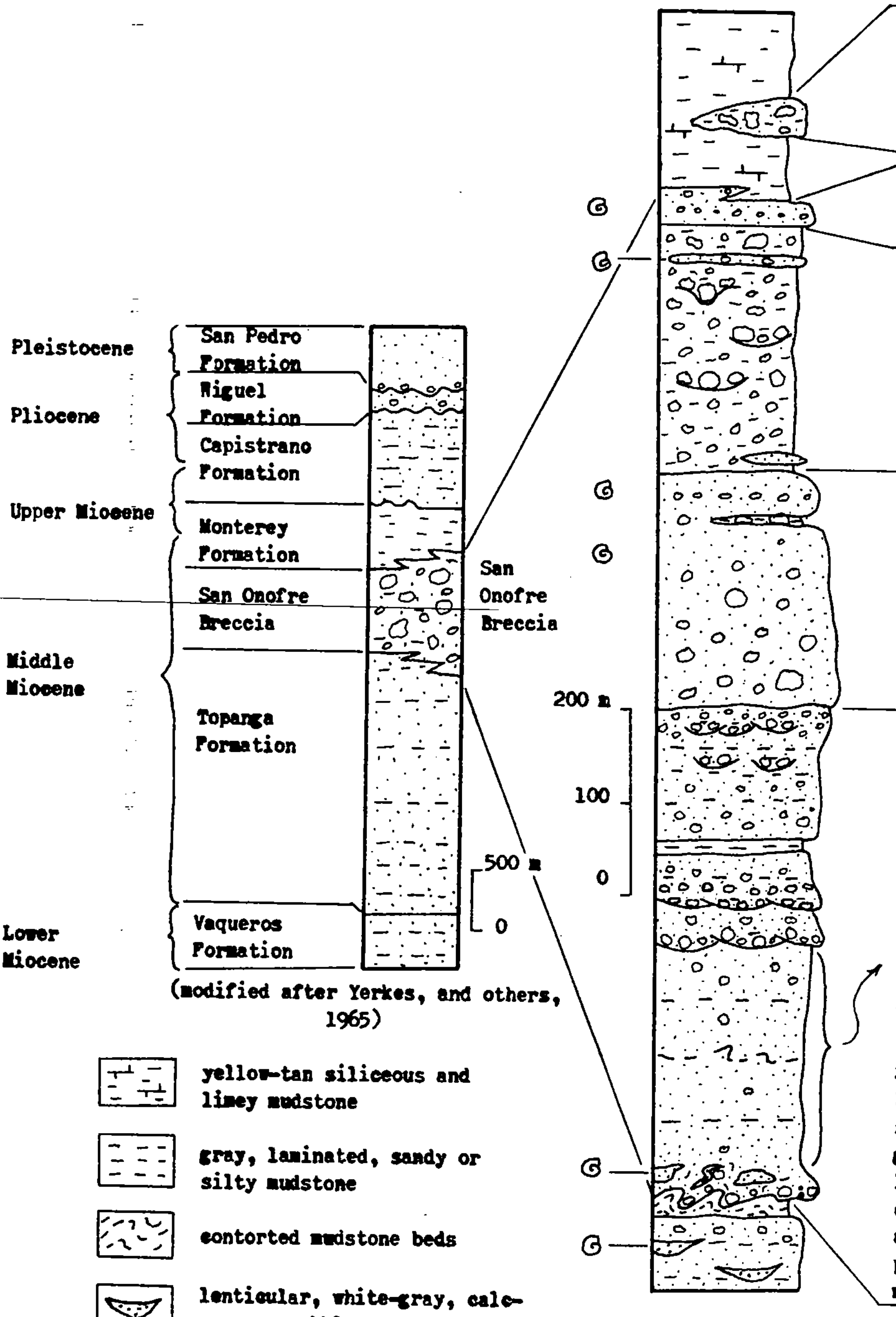
MUD-MATRIX BRECCIA FACIES (RED-BROWN AND GRAY)

The mud-matrix breccia facies is exposed from South Laguna to the South Laguna Fault, between Mussel Cove and the mouth of Salt Creek, and at Dana Point (figure 2). Between Mussel Cove and Salt Creek it attains a maximum thickness of 285 meters. Breccia beds in this facies contain clasts of pebble- to boulder-size up to a maximum diameter of 4.0 meters (Some 5.5 meter clasts are weathered out and lie on the beach). Characteristics of beds within the facies are well displayed at Dana Point. Beds are inversely graded, contain isolated large boulders, and have sharp basal contacts that show little small scale scouring (figure 5). Parallel clast orientation occurs in some beds which, in addition to the lack of small scale scouring, poor sorting, and unsupported framework suggests that beds were deposited as high concentration debris flows (Fisher, 1971, p. 924). Similar bedding occurs in debris flow deposits on recent alluvial fans. Some breccia beds are channeled into underlying breccia beds such as the well exposed, densely packed boulder breccia 30 meters west of the breakwater on the south side of Dana Point. An 8.5 meter thick yellow-gray, mollusc-fragment rich, medium-grained sandstone tongue containing cobble conglomerate lenses occurs in the sequence at Dana Point. This bed is similar to intertonguing sandstone at Mussel Cove.

On the west side of Dana Point, calcareous, very fossiliferous sandstone and sand-matrix conglomerate and breccia beds unconformable overlie redbrown and gray mud-matrix breccia beds with an angular difference of 30-50°. A depositional slope of 30-50° is improbable for the mud-matrix breccia sequence (with the intercalated conformable sandstone tongue), thus it appears that the red-brown breccia sequence was tilted prior to planation and deposition of sandy coarse-grained sediment.

COMPOSITE STRATIGRAPHIC COLUMN AND LITHOFACIES IN THE SAN ONOFRE BRECCIA, LAGUNA BEACH TO DANA POINT, ORANGE COUNTY, CALIFORNIA

C. J. Stuart
February, 1973



(modified after Yerkes, and others, 1965)

Mud-matrix breccia facies
pebbly mudstone, mud-matrix sandstone and mud-matrix pebble to boulder breccia within the Monterey Formation; intercalated with limey mudstone at the base

Sandy breccia and conglomerate facies
intertongued with the Monterey Formation east of Wood Canyon

Mud-matrix breccia facies
coarsest debris is commonly in lenticular or channelized beds; red and gray coloration is variable even within single beds; tan sandstone tongues are present at Dana Point and at the base of the interval at Mussel Cove

Sandy breccia and conglomerate facies
fossiliferous cse-gr sandstone is more abundant and cobble-size clasts predominate at the top of the interval; gray-red mud-matrix boulder breccia tongues are present near the top of the interval between Aliso Beach and Mussel Cove

Graded sandstone facies
characterized by graded sandstone beds up to 2 meters thick and gray laminated mudstone; upper conglomerate and breccia beds have a mud-matrix or sand-matrix

very coarse-grained to fine-grained massive graded sandstone and horizontal or low-angle cross-laminated sandstone beds are intercalated with scoured, ripped-up and loaded, thin mudstone beds; complex contortion of some mudstone beds

25 meter thick disrupted sequence at the base of the interval consists of mud-sand-matrix schist breccia, very coarse-grained feldspathic sandstone and gray laminated mudstone; mudstone beds are contorted and broken-up, sandstone beds are broken into irregular blocks, and parts of the interval are completely mixed together

- yellow-tan siliceous and limey mudstone
- gray, laminated, sandy or silty mudstone
- contorted mudstone beds
- lenticular, white-gray, calcareous, pebbly v. cse-gr ss
- gray, calcareous, conglomeratic, med-gr ss
- gray, calcareous, sand-matrix bca or cg.
- channelized bca or cg
- red-brown, brown or gray, very poorly sorted bca, containing mud-matrix (sand, silt, and clay) intercalated with mud-matrix ss, and sst
- Ⓖ megafossils present, commonly *Ostrea sp.* (titan?), *Balanus sp.*, and *Lyropecten crassicardo*

FIGURE 1

CONCLUSIONS

The lithology and distribution of facies described above are suggestive of a shoreline environment encompassing non-marine or shallow marine alluvial fan deposits (mud-matrix breccia facies), shallow marine shelf deposits (fossiliferous sandy conglomerate and breccia facies), and possibly deeper water or else more distal deposits (graded sandstone facies). Sediment was transported by subaerial and subaqueous debris flow, slumping and sliding, turbidite, and traction mechanisms.

ACKNOWLEDGEMENTS

This work has been supported by a Geological Society of America Research Grant, and funds from the Department of Geological Sciences, University of California, Santa Barbara. J. G. Vedder has generously provided unpublished data. R. V. Fisher reviewed the present manuscript.

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Figure 3—Graded sandstone facies, basal breccia and conglomerate sequence at Halfway Rock. Breccia in foreground contains mud-matrix with angular pebble-size metamorphic debris and rounded albite-chlorite schist (black) boulders. Boulder conglomerate in the upper part of the photo is channeled into irregular coarse-grained sandstone lenses.

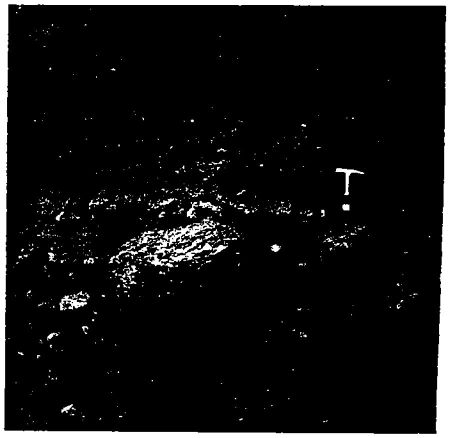
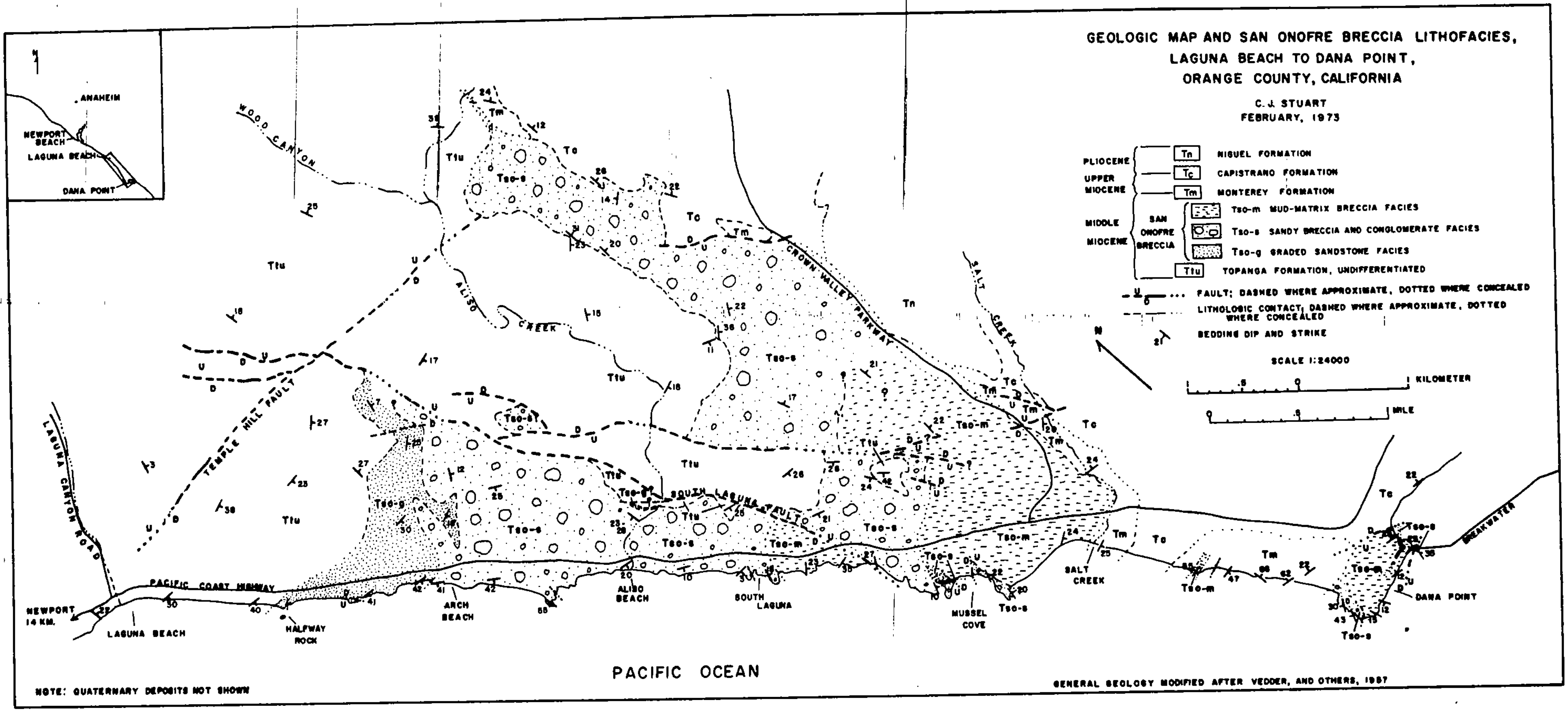


Figure 4—Sandy breccia and conglomerate facies, seacliff .6 kilometers northwest of Aliso Beach. Typical exposure of facies with isolated schist boulder in sandy pebble-cobble breccia bed. Massive breccia bed is overlain by low-angle cross-bedded angular schist pebble very coarse-grained sandstone. Note thin bed and laminae truncation from left to right.

Figure 5—Mud-matrix breccia facies (red-brown), seacliff at the southeast corner of Dana Point. 1-2 meter thick inversely graded, poorly sorted breccia beds. Isolated boulders such as in the lower right corner are common. Middle bed displays a sharp basal contact, well developed inverse grading, and is, in part, composite, since a truncated breccia-filled channel is present toward the upper right. Pebbly, sandy siltstone is present above coarser parts of breccia beds. The staff is 1.5 meters long.

FIGURE 2



GEOLOGIC MAP AND SAN ONOFRE BRECCIA LITHOFACIES,
LAGUNA BEACH TO DANA POINT,
ORANGE COUNTY, CALIFORNIA

C. J. STUART
FEBRUARY, 1973

NOTE: QUATERNARY DEPOSITS NOT SHOWN

GENERAL GEOLOGY MODIFIED AFTER VEDDER, AND OTHERS, 1957

SUMMARY OF GEOLOGY OF THE SAN JOAQUIN, HILLS[1]

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The San Joaquin Hills district borders the southeast margin of the Los Angeles basin and forms a roughly triangular expanse of hills and adjoining lowlands that extend southeast from near the Santa Ana River to Dana Point and thence north to the foothills of the Santa Ana Mountains.[2]

Land forms that roughly demark large structural elements in the southeastern part of the Los Angeles basin are Santa Ana Gap, Newport Mesa, San Joaquin Hills, Tustin Plain, Santa Ana Mountains, and Capistrano Trough. The coastal belt and the main drainage systems are terraced by well-defined erosional and depositional platforms that are slightly deformed. As many as eight surf-cut terraces are recognizable in the San Joaquin Hills; all are inferred to have been formed during Pleistocene time. Incised river channels that have been drowned and buried occur near the mouth of the Santa Ana River, at Newport Bay, and at Laguna Beach and Doheny Beach, Presumably this back-filling of river channels has taken place since the Wisconsin lowstand of sea level. Landslides are common features near San Juan Capistrano and along major fault zones. Wide beaches backed by tidal marshes, narrow beaches with steep sea cliffs, and small pocket beaches are the dominant shoreline features along different segments of the coast.

Most of the mapped rock units and the older subsurface sections are correlated with similar stratigraphic units exposed in the Santa Ana Mountains based on lithologic resemblance and paleontologic evidence. There are striking differences, however, in thickness and lithofacies in several equivalent units of formation rank.

The sedimentary rocks of the San Joaquin Hills-San Juan Capistrano area were derived from two distinctly different basement rock sources; one to the east and northeast, the other to the west and south. The western basement rock complex (Catalina Schist) consists primarily of thinly-foliated and corrugated glaucophane-lawsonite-chlorite-albite schists and related rocks that now are exposed only on Santa Catalina Island and in the Palos Verdes Hills. Similar rock types constitute the basement rock floor of the Los Angeles Basin southwest of the Newport-Inglewood fault zone and are present over much of the continental borderland off southern California. The eastern basement rock complex includes metasedimentary, metavolcanic, and plutonic rocks that together form much of the Peninsular Ranges.

Clastic rocks that are older than middle Miocene presumably were derived entirely from the east, and in parts of the section may have come from source areas much farther east and north than the Santa Ana Mountains. Post-middle Miocene sedimentary rocks contain varying amounts of clastic material derived from both the eastern and western basement rock sources; but, in general, the western schist detritus diminishes in volume in the formations that are younger than late Miocene and may be dominantly recycled from the middle Miocene sedimentary formations.

The main basin of deposition seems to have originated in late Cretaceous time and was followed by alternating subsidence and shallowing through Tertiary into Quaternary time. The seas in the eastern and Southeastern part of the basin reached their maximum lateral extent during the Miocene epoch.

The exposed stratigraphic sequence ranges in age from Paleocene to Holocene and is composed of a thick succession of marine and nonmarine sedimentary rocks, which at places are cut by igneous intrusive rocks. This succession attains a maximum composite thickness of 22,000 feet in which abrupt facies changes are evident. Concealed rocks penetrated by wells near El Toro include the Bedford Canyon Formation of Jurassic age and the Santiago Peak Volcanics of early Cretaceous (?) age. Sandstone, siltstone, and conglomerate beds in the Trabuco, Ladd, and Williams Formation of Late Cretaceous age attain a combined maximum thickness of approximately 4,200 feet in the subsurface beneath the San Joaquin Hills.

Early Tertiary rocks are subdivided into the Silverado Formation of Paleocene age and the Santiago Formation of Eocene age; both are exposed in an upfaulted block near the north edge of the San Joaquin Hills and contain marine and nonmarine sandstone, conglomerate, and claystone beds. Part of the overlying nonmarine Sespe Formation may be as old as Eocene. The Silverado Formation is approximately 1,875 feet thick, but the thickness of the incompletely exposed Santiago Formation is not known.

Late Tertiary sedimentary rocks comprise 15 named stratigraphic units that, in part, intertongue and intergrade. Nonmarine strata of the Sespe Formation underlie marine beds of the Vaqueros Formation in the San Joaquin Hills, but the two units are intertongued in the foothills of the Santa Ana Mountains. The Vaqueros Formation ranges from 2,700 to 3,750 feet thick and is early Miocene in age. A gradational contact forms the boundary between the Vaqueros Formation and the overlying Topanga Formation except in the northeastern part of the area where an erosional unconformity separates them. In the western part of the area the Topanga Formation is subdivided in ascending order into the Bommer Member, the Los Trancos Member, and the Paularino Member, all of middle Miocene age. In upward sequence these members are in turn dominantly sandstone; siltstone; and interbedded sandstone, breccia, and siltstone. The lower member is 2,400 feet thick, the middle, 3,100 feet thick, and the upper, 1,500 feet thick. Southeast of Laguna Canyon, where it is as much as 3,500 feet thick, the Topanga Formation is not subdivided; east of El Toro Air Station it is less than 600 feet thick. All Tertiary strata in the San Joaquin Hills that are younger than the Bommer Member contain varying amounts of Catalina Schist detritus indicating a western source area for at least part of these sediments.

The San Onofre Breccia, a distinctive coarse clastic unit composed chiefly of Catalina Schist detritus, unconformably overlies the Topanga Formation. The upper part in places is intertongued with the Monterey Shale, and much of the unit may be the stratigraphic equivalent of the Paularino Member of the Topanga Formation. The San Onofre Breccia is very lenticular and may be as much as 3,000 feet thick at South Laguna; it lenses out northward and is not present in the El Toro area. Both marine and nonmarine strata are included in the breccia; all are middle Miocene in age. The bulk of the San Onofre Breccia was derived from the south and west from exposures of Catalina Schist that may have lain near the present trace of the Newport-Inglewood fault zone.

Outcrops of the Monterey Shale extend from Upper Newport Bay southward along the coast to Laguna Beach and from the vicinity of El Toro to Dana Point. Another south-trending belt of outcrop lies east of Oso Creek and Arroyo Trabuco. The characteristic lithologies are marine siltstone, claystone, and shale, with minor amounts of sandstone and breccia. Locally the formation rests on the San Onifre

[1] Reprinted from Vernon, J. and Warren, A.D. (Eds.), 1970, Geologic guidebook, southeastern rim of the Los Angeles Basin, Orange County California. Amer. Petrol. Geologists, Pacific section, Los Angeles, p. 15-39.

[2] See maps accompanying the road log section of this guidebook.

Breccia with a gradational contact, but elsewhere it laps onto older rocks. In the northeast part of the area, the Monterey Shale is separated from the lithologically similar La Vida Member of the Puente Formation by an arbitrary boundary. The Monterey Shale ranges in age from middle to late Miocene and varies in thickness from 300 feet to 1,500 feet. In the foothills of the Santa Ana Mountains, the Puente Formation is subdivided into the La Vida Member, which is composed chiefly of siltstone, and the Soquel Member, which is composed chiefly of sandstone; both members are of late Miocene age and are lateral equivalents of parts of the Monterey Shale and Capistrano Formation. The La Vida Member is approximately 375 feet thick and the Soquel Member, about 900 feet thick. Similar strata have been penetrated by wells beneath Newport Mesa, where nearly 2,300 feet of section is assigned to the Puente Formation.

The Capistrano Formation is distributed over much of the area between El Toro and Capistrano Beach, and strata equivalent to the lower part are present at Newport Bay and near Reef Point. It is unconformable on older rocks along the west side of the Capistrano syncline but elsewhere the lower contact is gradational with the Monterey Shale. The bulk of the Capistrano Formation is composed of mudstone, but north of Arroyo Trabuco the Oso Member, which is dominantly sandstone, forms most of the unit. The formation may be as much as 2,500 feet thick in the southern part of the Capistrano syncline, where it ranges in age from late Miocene to early Pliocene. In the central part of the Capistrano syncline, marine and nonmarine sedimentary rocks that unconformably overlie the Monterey Shale and Capistrano Formation are assigned to the Niguel Formation. Sandstone and conglomerate beds that constitute most of the formation seem to grade seaward into strata that have not been differentiated from the upper part of the Capistrano Formation. The Niguel Formation contains late Pliocene mollusks and is about 300 feet thick in the type area north of San Juan Capistrano.

In the cliffs along Upper Newport Bay a succession of fine-grained clastic rocks that is assigned to the Fernando Formation (USGS usage) is unconformable on or faulted against the Capistrano Formation. The Fernando Formation here contains strata of both early and late Pliocene age, and the exposed section is about 1,050 feet thick. Folded sandstone, conglomerate, and siltstone beds in very limited exposures at the north end of Upper Newport Bay and at the west edge of Newport Mesa are the only surface expression of the San Pedro Formation. The San Pedro Formation is of early Pleistocene age and may be as much as 1,000 feet thick beneath Newport Mesa.

Marine and nonmarine terrace deposits, which include the Palos Verdes Sand on the lowest emergent surf-cut platform, border much of the coastal area, and stream terrace deposits form the margins of many large stream channels. Although deformed, all of the terrace deposits are assigned to late Pleistocene age. Late Pleistocene and Holocene alluvium is present on the floors of the main stream channels.

Igneous dikes, sills, and flows disrupt the sedimentary succession in the San Joaquin Hills but are restricted to the area west of Laguna Canyon. All are Miocene in age and probably are limited to the last half of the epoch. These rocks are separated into three types: pyroxene-diabase dikes and sill-like bodies, augite-hypersthene andesite flows and flow breccias, and augite-andesite sills and dikes.

The main structural features in the San Joaquin Hills district are the complexly faulted anticline of the central San Joaquin Hills and the Capistrano syncline that borders it on the east. Four large fault zones, on which there has been recurrent movement, transect the area. From west to east these are the Newport-Inglewood fault zone, Pelican Hill fault zone, Shady Canyon fault, and Cristianitos fault. The Newport-Inglewood fault zone lies mainly offshore but cuts the subsurface section beneath the western part of Newport Bay. It has as much as 2,000 feet of vertical separation, with movement down on the southwest; there has been many times this amount of dislocation in the lateral sense. Recurrent displacement, perhaps with reversals of vertical separation, occurred in Miocene through Pleistocene time. The Pelican Hill fault zone, which extends from Upper Newport Bay to northwest Laguna Beach, has a vertical as well as an inferred lateral component of movement that has been recurrent in Miocene and Pliocene time. The Shady Canyon fault is a pre-late middle Miocene normal fault that has a stratigraphic separation of 5,000 feet with the southwest side downthrown. Two episodes of movement during middle miocene time are suggested by the emplacement and dislocation of diabase intrusions along the fault. The Cristianitos fault, which trends northwest along the east edge of the area, is a normal fault that may be increasingly large to the southeast. Stratigraphic separation of 875 feet is estimated where the fault cuts across Arroyo Trabuco with relative movement down on the west.

A structural high of basement and Cretaceous rocks is present beneath the foothill area east and southeast of El Toro Air Station. This partly buried feature presumably is the southeastward continuation of a structure that brings Cretaceous rocks to the surface in the foothills of the Santa Ana Mountains.

LUISIAN AND MOHNIAN BIOSTRATIGRAPHY OF THE MONTEREY SHALE AT NEWPORT LAGOON, ORANGE COUNTY, CALIFORNIA[1]

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INTRODUCTION

A large, but incomplete, section of Miocene Monterey Shale is exposed in bluffs, canyons and roadcuts around the margin of Newport Lagoon in Orange County, California. The oldest exposure of the formation is in the axis of an anticline along the southeast edge of the lagoon. The youngest exposures of Monterey Shale occur on the north wall of Big Canyon and in bluffs on the west side of the lagoon where the formation is in contact with the overlying Capistrano Formation (See Vedder, Yerkes and Schoellhamer, 1957). During the summer of 1969, this section was measured, collected and staked by R. L. Fleisher, M. B. Mickey and W. J. Zinsmeister. The line of section was started at the base of exposed Monterey Shale on the southeast shore. The first traverse was from the axis of an anticline on the east side of the lagoon northward into Little Canyon and thence northward to the top of a topographic nose on the south side of Big Canyon. The second traverse was from the axis of an anticline in the Dover Cliffs on the west side of the lagoon westward along the bluff about three eighths of a mile. The third traverse was started on the north limb of the anticline on the west side of the lagoon and was carried northwest to the contact between the Monterey Shale and the Capistrano Formation. After the initial survey, additional samples were collected by M.B. Mickey, J.N. Wesson and the author. A total of 230 samples from the Monterey Shale were collected, processed and examined for fossil benthonic Foraminifera. By correlating on the basis of benthonic foraminifers and certain key lithologic horizons noted in the field, it was possible to combine the three traverses into one composite stratigraphic section for the exposed Monterey Shale. Total thickness of the composite section is approximately 1400 feet. Except for the basal 200 feet which appear to be totally barren, the section is very rich in microfossils including calcareous nannoplankton, diatoms, radiolarians, silicoflagellates and ebridians and both planktonic and benthonic foraminifers. However, no calcareous microfossils were noted in the uppermost 100 feet of the Monterey Shale at this locale.

Campbell and Clark (1944) reported the occurrence of 42 species of radiolarians in four samples from the upper Mohnian Stage of the Newport Bay area. Lipps (1964) documented the occurrence of 20 species of planktonic foraminifers in 36 samples from the Luisian and Mohnian Stages on the east side of Upper Newport Bay. Wilcoxon (1969) published on the occurrence of 19 species of calcareous nannoplankton in 17 samples from the Luisian and Mohnian Stages on the east shore of Newport Bay. In order to further document the presence of Luisian and Mohnian Stages at Newport Lagoon, this paper will treat largely with the vertical distribution of 50 species of calcareous benthonic Foraminifera in 35 samples from the Monterey Shale on the east and west shores of Newport Lagoon (See Figure 1). Also to be mentioned are the observed occurrences of three species of calcareous nannoplankton.

BIOSTRATIGRAPHY

Kleinpell (1938) divided the Miocene of California into six stages and fourteen zones based on the vertical distribution of benthonic Foraminifera. Using Kleinpell's criteria it is possible to prove the presence of at least a portion of two of the stages and four of the foraminiferal zones within the Monterey Shale at Newport Lagoon. One foraminiferal zone in the lower Mohnian Stage can be further divided into two subzones.

The oldest fossiliferous sediments of the Monterey Shale at Newport Lagoon were found approximately 200 feet above the exposed base of the formation in a roadcut on the east shore. From that point northward to bluff and gully exposures along the south wall of Little Canyon, an interval of approximately 265 stratigraphic feet was measured which contains abundant Luisian foraminifers (See Figure 2). Species recorded from this interval, but not higher, include *Anomalina salinasensis, Brizalina advenastriatella, B. imbricata, Dentalina obliqua, Pullenia miocenica, Saracenaria beali, Siphogenerina collomi, S. reedi, Valvulineria californica californica* and *V. miocenica*. This interval is interpreted to represent all or part of the *Siphogenerina collomi* Zone of the upper Luisian Stage.

Overlying the Luisian sediments is a 40 to 50 foot interval in Little Canyon containing the first and last occurrences of *Brizalina modeloensis (sensu stricto), Suggrunda californica* and *Virgulina (Virgulinella) miocenica*. Also present, but not restricted to the interval, are *Baggina californica, Bulimina uvigerinaformis, Cassidulina monicana* and *Concavella gyroidinaformis*. This section is interpreted to represent the *Brizalina modeloensis* Zone of the lower Mohnian Stage.

Northward form Little Canyon to a topographic nose at the south wall of Big Canyon is a 315 to 325 foot interval of which the lower half is poorly exposed. This interval represents the *Bulimina uvigerinaformis* Zone of the lower Mohnian Stage which can be readily divided into two subzones. The lower of the two subzones is designated the *Concavella gyroidinaformis* Subzone and is approximately 200 to 210 feet thick at this locality. The base of this subzone is marked by the last occurrence of *Brizalina modeloensis*, the top by the last occurrence of *Concavella gyroidinaformis*. Also present, but not restricted to the subzone, are *Baggina californica* and *Bulimina uvigerinaformis*. The upper subzone is here designated the *Brizalina woodringi* Subzone which is approximately 105 to 110 feet thick. The base of the *Brizalina woodringi* Subzone is marked by the last occurrence of *Concavella gyroidinaformis;* the top of the subzone and the top of the lower Mohnian are marked by the last occurrence of *Bulimina uvigerinaformis (sensu lato)*. Also present in the upper part of the *Brizalina woodringi* Subzone, but not restricted to it, are *Bolivian hughesi, Brizalina benedictensis, B. bramlettei, B. girardensis, B. granti, B. vaughani, B. woodringi* and *Nonion* goudkoffi; an undescribed variety of *Discorbinella valmonteensis* appears to be restricted to the upper part of the subzone at this locality. The *Brizalina woodringi* to the upper part of the Subzone at this locality. The *Brizalina woodringi* Subzone is also present in the oldest strata exposed in the axis of an anticline on the west shore of the lagoon.

Overlying the *Bulimina uvigerinaformis* Zone of the lower Mohnian Stage in bluffs on the west shore is an interval approximately 470 feet thick which is interpreted here as representing all or part of the *Bolivina hughesi* Zone of the upper Mohnian Stage. It should be noted that the presence of *Brizalina rankini* and *Bulimina delreyensis* in this interval might suggest that the upper part could be assigned to the Delmontian Stage. However, the presence of *Brizalina bramlettei, B. californica, B. decurtata, B. granti and B. woodringi* in the two highest samples containing Foraminifera is considered sufficient evidence to justify

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[1] Reprinted from Stinemeyer, E.H. (Ed.), 1972, The Pacific Coast Miocene biostratigraphic symposium, March 9-10, 1972, Bakersfield, California. Pacific Section, Soc. Economic Paleontologists and Mineralogists, Los Angeles, p. 27-36.

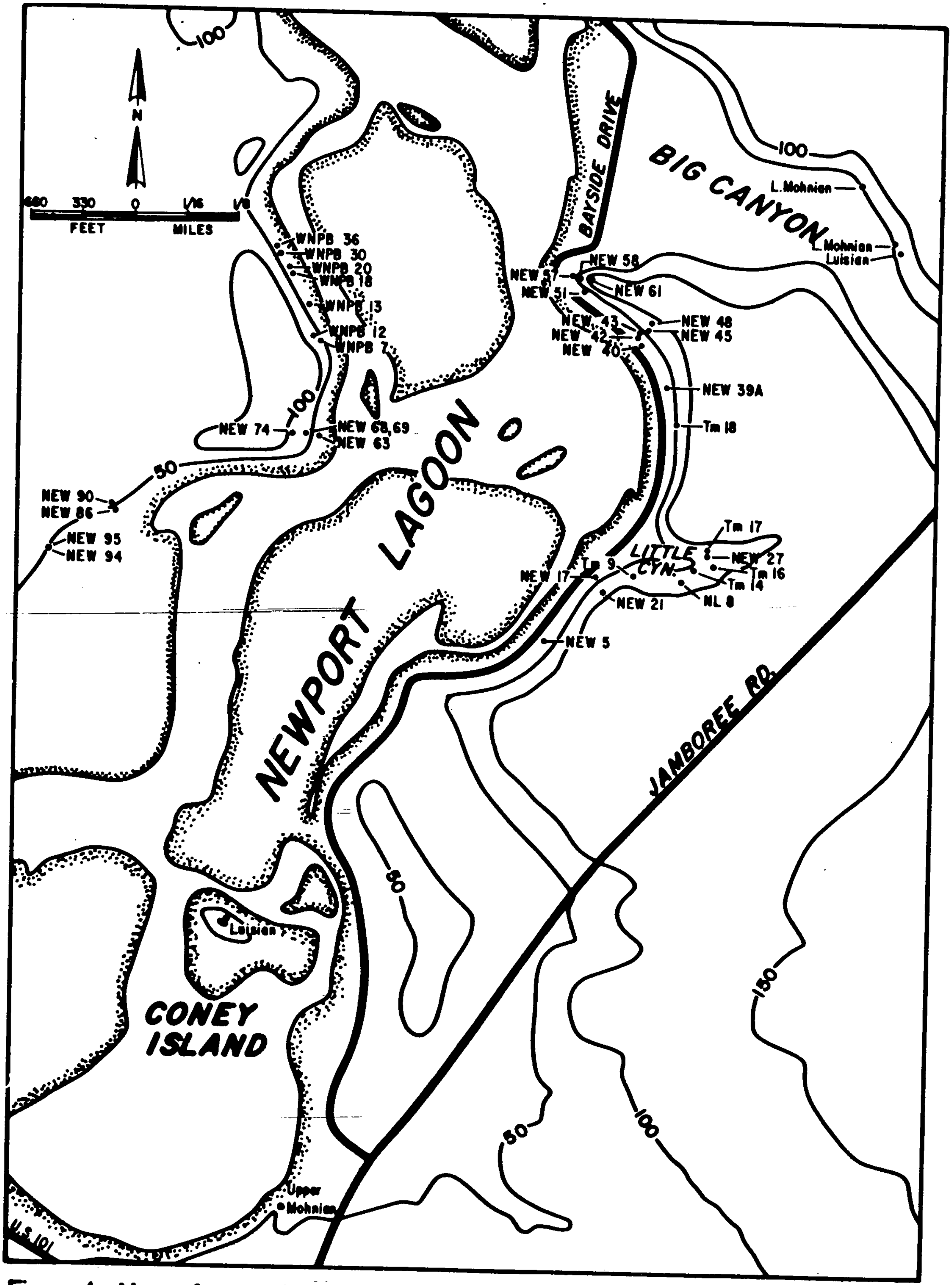

Figure 1. Map of a portion of Newport Lagoon showing the sample localities referred to in the text and several other Mohnian and Luisian outcrops.

the interpretation of upper Mohnian Age. Some other species noted in the interval are *Bolivina hughest, B. sinuata, Brizalina benedictensis, B. girardensis, Buliminella semihispida, Cassidulinella renulinaformis, Discorbinella valmonteensis (sensu stricto), Nonionella* sp. and *Uvigerina hannai.*

Lying above sediments of demonstrable Mohnian Age is a 100 foot thick interval of the uppermost Monterey Shale which is in turn overlain by the Capistrano Formation. No foraminifers were noted in samples from this interval and, therefore, no definite age assignment has been determined for the youngest Monterey Shale at Newport Lagoon. White (1956) reported that the lower portion of the Capistrano Formation approximately 14 miles southeast of Newport Lagoon contains a foraminiferal assemblage belonging to the upper Mohnian Stage of the Miocene. That being the case, it would seem likely that the uppermost Monterey Shale at Newport could very well be of upper Mohnian Age.

In addition to studies of foraminiferal distribution which have been completed, a review of the distribution of nannoplankton in the Monterey Shale at Newport Lagoon is being carried out. Results of this review to date indicate that *Cyclococcolithina neogammation* ranges throughout the upper Luisian Stage and upward into the lower Mohnian Stage to very near the top of the *Concavella gyroidinaformis* Subzone. The last occurrence of *Cyclococcolithina neogammation* was noted in sample NEW 40; sample NEW 42 was devoid of calcareous nannoplankton while sample NEW 43 and higher samples contained abundant nannoplankton, but no *C. neogammation.* Another fossil coccolith, *Reticulofenestra pseudoumbilica,* was found to have its first occurrence in sample Tm 14 very near the base of the *Brizalina modeloensis* Zone of the lowermost Mohnian Stage; the last occurrence of *R. pseudombilica* in the Monterey Shale at Newport was noted in sample WNPB 36, the highest sample containing calcareous microfossils. Data gathered from other areas indicate that the total vertical ranges of both of the above coccoliths are not represented in the Monterey Shale at Newport. *Cyclococcolithina neogammation* is known to occur in sediments much older than those of the Luisian Stage and *Reticulofenestra pseudoumbilica* is known to be present in sediments much younger than those of the Mohnian Stage. It will be interesting to see if other investigations will confirm the overlapping ranges of *C. neogammation* and *R. pseudoumbilica* in the lower Mohnian from other areas of study. *Sphenolithus heteromorphus,* a fossil sphenolith, was found to occur sporadically throughout the upper Luisian Stage at Newport Lagoon. The last occurrence of *S. heteromorphus* was noted in sample NL 10; sample NL 10, containing an excellent Luisian foraminiferal fauna, is six feet above sample NL 8 and an estimated three feet below sample Tm 14. Thus it appears that *S. heteromorphus* ranges no higher than the uppermost Luisian Stage at Newport Lagoon.

Bramlette and Wilcoxon (1967) have shown that, in the Cipero section of Trinidad, *Sphenolithus heteromorphus* ranges to the top of the *Globorotalia fohsi barisanensis* Zone while *Cyclococcolithina neogammation* ranges to or near the top of the *Globorotalia fohsi* Zone. The observed occurrence of these two nannofossils at Newport Lagoon would suggest that the upper Luisian could be equivalent to the upper part of the *Globorotalia fohsi barisanensis* Zone and that the *Concavella gyroidinaformis* Subzone and *Brizalina modeloensis* Zone of the lower Mohnian together constitute the equivalent of the *Globorotalia fohsi fohsi* Zone. This interpretation is in conflict with that of Wilcoxon (1969) who equates the Luisian at Newport with the *Globorotalia fohsi lobata* and *Globorotalia fohsi robusta* Zones while considering the Mohnian to be equivalent to the *Globorotalia mayeri* and *Globigerina menardii* Zones. Wilcoxon bases his interpretation largely on the restricted occurrences of *Discoaster kugleri* and *Discoaster bollii* in the Luisian and Mohnian respectively as noted in his samples from Newport and suggests that *Sphenolithus heteromorphus* may have a more extensive vertical range than indicated from studies of the Trinidad material. Lipps (1968), however, reports that *Discoaster kugleri* has been noted in sediments of Mohnian age. So far, neither *Discoaster kugleri* nor *Discoaster bollii* have been noted in samples from Newport Lagoon reviewed for this report. Should the interpretation of Wilcoxon be correct, then the vertical ranges of both *Cyclococcolithina neogammation* and *Sphenolithus heteromorphus* will have been shown to be more extensive than as noted in the Cipero section of Trinidad. There is, of course, the equally logical possibility that *Discoaster kugleri* and *Discoaster bollii* might range into zones older than those to which they are restricted in Trinidad. For the time being, it would seem proper to say that the upper Luisian Stage at Newport Lagoon is at least equivalent to a part of the *Globorotalia fohsi* Zone *(sensu lato)* of Trinidad. Meanwhile, our knowledge of the geographical and vertical distribution of the calcareous nannoplankton is being increased rapidly and significantly by data from individual workers and from the JOIDES program. As our understanding of the ranges of the various nannofossil species becomes more precise, it will be possible to resolve with greater certainty such questions as the correlation of the stages of the California Tertiary with sections in other parts of the world.

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MONTEREY SHALE																																	FORMATION
M. MIOCENE					LATE MIOCENE																												EPOCH
LUISIAN					MOHNIAN																												STAGE
UPPER					LOWER															UPPER													
Siphogenerina collomi					Brizalina modeloensis			Bulimina uvigerinaformis												Bolivina hughesi													ZONE
								Concavella gyroidinaformis					Brizalina woodringi																				SUBZONE
NEW 5	NEW 17	NEW 21	Tm 9	NL 8	Tm 14	Tm 16	NEW 27	Tm 17	Tm 18	NEW 39A	NEW 40	NEW 42	NEW 43	NEW 45	NEW 48	NEW 51	NEW 63	NEW 68	NEW [illegible] NEW 87	NEW 58	NEW 74	NEW 61	NEW 66	NEW 90	NEW 94	WNPB 7 NEW 95	WNPB 12	WNPB 13	WNPB 18	WNPB 20	WNPB 30	WNPB 36	SAMPLE NUMBER
227	368	402	442	464	473	492	514	538	605	655	697	717	722	737	761	789	795	827	830	842	862	866	924	958	998	1006	1034	1047	1108	1133	1248	1300	FOOTAGE ABOVE BASE OF EXPOSED MONTEREY SHALE
																																	SELECTED SPECIES
F	A	A																															Brizalina advena ornata
A	R																																Brizalina imbricata
R	R	F						F																									Nonion costiferum var.
R	F	A	A	A																													Pullenia miocenica
A	C	C	C	C																													Valvulineria californica californica
A	F	C	R	F																													Valvulineria miocenica
	R	F	F	R		R		F		R	F	R																					Brizalina californica var.
	VR	R		F																													Siphogenerina reedi
		F	C		R			F		F	F	F																					Baggina californica
		R	F	R																													Dentalina obliqua
			A	R																													Anomalina salinasensis
			R	A																													Brizalina advena striatella
			R	F																													Saracenaria bealli
				F																													Siphogenerina collomi
					C								F	C	C	R	R		R	R													Bolivina hughesi var.
					R					R								C	C	F	C	F	F				R	F			F	F	Brizalina bramlettei
					C	C	C																										Brizalina modeloensis
					F	R	C			R																							Nonion costiferum
					C	C	C	R	F	A	C					F	R	F	F		R												Uvigerina hootsi
					R	R	C																										Virgulina (Virgulinella) miocenica
						R	C	R		R																							Cassidulina monicana
							C	F		F	R					C	C	C	C														Bulimina uvigerinaformis
							C	R	F	C	A	F																					Concavella gyroidinaformis
							F																										Megastomella capitanensis
							C																										Nonion multicameratum
							C																										Suggrunda californica
											R		F	C	C																		Hanzawaia illingi
											R	R					C		F														Uvigerina angelina
												F																					Pullenia moorei
														F	C		F	C	F													R	Brizalina californica
																	VR	R	VR	F	R	F		F			F	F					Brizalina girardensis
																	A	C	C	C	F	A	F	C	F		C	F	R	C	C	C	Brizalina woodringi
																	R	C	F														Discorbinella valmonteensis var.
																	R	F	F	F	F	R			R		R	C					Nonion goudkoffi
																		F	F		R	C											Bolivini hughesi
																		R	R	C		A					F			VR			Brizalina benedictensis
																		F	F	A							A			A	C	A	Brizalina granti
																		C	C	F	F		F		F		F	F			R	R	Brizalina vaughani
																		C	A	R		C		F			F						Cassidulina modeloensis
																		F	F	F		C											Hopkinsina magnifica
																				R			F		F			F			C		Brizalina decurtata
																				C	C	C	C		C			R	VR				Discorbinella valmonteensis
																				R	R	F		C	F		C	R			F		Bolivina sinuata
																					F												Cassidulinella renulinaformis
																								F			F	R					Buliminella semihispida
																								C			C			F		A	Uvigerina hannai
																											R						Rotalia garveyensis
																												C					Bulimina delreyensis
																														F	F	C	Nonionella sp.
																																F	Brizalina rankini

Frequency Symbols:
A = Abundant
C = Common
F = Few
R = Rare
VR = Very Rare

FIGURE 2.
CHECKLIST OF SELECTED FORAMINIFERA FROM THE MONTEREY SHALE AT NEWPORT LAGOON.

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APPENDIX A: MIOCENE BENTHONIC FORAMINIFERA

The names of species included on the checklist (Figure 2) are listed below alphabetically, each followed by a reference containing an adequate illustration of that particular species. Note that these references are not in all cases the original references for the species.

Anomalina salinasensis Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 347, pl. 13, fig. 1.

Baggina californica Cushman, 1926, in Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 324, pl. 13, fig. 3.

Bolivina hughesi Cushman, 1926, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 117, pl. 14, fig. 7 (holotype reillustrated).

Bolivina hughesi var. = *Bolivina sinuata* Galloway and Wissler, var. *alisoensis* Cushman and Adams, 1935, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 121, pl. 11, figs. 22-24.

Bolivina sinuata Galloway and Wissler, 1927, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 120, pl. 14, figs. 19, 20.

Brizalina advena ornata (Cushman) = *Bolivina advena* Cushman, var.*ornata* Cushman, 1925, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 98, pl. 10, figs. 17, 18.

Brizalina advena striatella (Cushman) = *Bolivina advena* Cushman, var. *striatella* Cushman, 1925, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 98, pl. 10, fig. 22.

Brizalina benedictensis (Pierce) = *Bolivina benedictensis* Pierce, 1956, Jour. Pal., vol. 30, no. 6, p. 1307, pl. 142, fig. 9.

Brizalina bramlettei (Kleinpell) = *Bolivina bramlettei* Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 267, pl. 21, figs. 9-11.

Brizalina californica (Cushman) = *Bolivina californica* Cushman, 1925, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 100, pl. 11, figs. 1, 2.

Brizalina californica var. = *Bulimina carnerosensis* Cushman and Kleinpell of Smith, 1960, U.S.G.S., Prof. Paper 294-M, p. 482, pl. 58, figs. 3, 4.

Brizalina decurtata (Cushman) = *Bolivina decurtata* Cushman, 1926, in Cushman 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 118, pl. 14, fig. 10.

Brizalina girardensis (Rankin) = *Bolivina girardensis* Rankin, 1934, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 101, pl. 11, fig. 10.

Brizalina granti (Rankin) = *Bolivina granti* Rankin, 1934, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 102, pl. 11, figs. 13, 14.

Brizalina imbricata (Cushman) = *Bolivina imbricata* Cushman, 1925, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 99, pl. 10, fig. 23.

Brizalina modeloensis (Cushman and Kleimpell) = *Bolivina modeloensis* Cushman and Kleinpell, 1934, in Cushman, 1937, Cushman Lab. Foram. Res., Spec. Pub. no. 9, p. 104, pl. 11, fig. 19.

Brizalina rankini (Kleinpell) = *Bolivina rankini* Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 280, pl. 22, figs. 4, 9.

Brizalina vaughani (Natland) = *Bolivina vaughani* Natland, 1938, Bull. Scripps Inst. Oceanog., Tech. Ser., vol. 4, no. 5, p. 146, pl. 5, fig. 11.

Brizalina woodringi (Kleinpell) = *Bolivina woodringi* Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 285, pl. 21, figs. 4, 5.

Bulimina delreyensis Cushman and Galliher, 1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 1, p. 25, pl. 4, fig. 8.

Bulimina uvigerinaformis Cushman and Kleinpell, 1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 1, p. 5, pl. 1, fig. 14.

Buliminella semihispida Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 250, pl, 20, figs. 8, 15, 16.

Cassidulina modeloenis Rankin, 1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 1, p. 23, pl. 3, fig. 12.

Cassidulina monicana Cushman and Kleinpell, 1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 1, p. 16, pl. 3, fig. 4.

Cassidulinella renulinaformis Natland, 1940, Jour. Pal., vol. 14, no. 6, p. 571, pl. 69, figs. 1-4, 7.

Concavella gyroidinaformis (Cushman and Goudkoff) = *Pulvinulinella gyroidinaformis* Cushman and Goudkoff, 1938, Contr. Cushman Lab. Foram. Res., vol. 14, pt. 1, p. 2, pl. 1, figs. 1, 2.

Dentalina obliqua (Linne) of Woodring, Bramlette and Kleinpell, 1936, in Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 212, pl. 11, fig. 7.

Discorbinella valmonteensis Kleinpell, 1938, Mio. Strat. of Calif. A.A.P.G. p. 350, pl. 21, figs. 14-16. See also *Holmanella* Loeblich and Tappan, Treatise on Invert. Paleont., pt. C, Protista 2, vol. 2, p. C760, fig. 625.

Discorbinella valmonteensis var. This variety differs from the typical of the species in having a less lobulate periphery, less inflation of the chambers and more finely perforate test.

Hanzawaia illingi (Nuttall) = *Cibicides illingi* (Nuttall) of Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 354, pl. 19, fig. 10 and pl. 20, figs. 18-20.

Hopkinsina magnifica Bramlette, 1950, U.S.G.S., Prof. Paper 222, p. 59, pl. 22, figs. 1-3, 5.

Megastomella capitanensis (Cushman and Kleinpell) = *Pulvinulinella capitanensis* Cushman and Kleinpell, 1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 1, p. 16, pl. 3, fig. 3.

Nonion costiferum (Cushman) = *Nonionina costifera* Cushman, 1926, Contr. Cushman Lab. Foram. Res., vol. 1, pt. 4, p. 90, pl. 13, fig. 2.

Nonion costiferum var. = *Nonion costifera* (Cushman) of Cushman and Laiming, 1931, Jour. Pal., vol. 5, no. 2, p. 104, pl. 11, fig. 9.

Nonion goudkoffi Kleinpell, 1938, Mio. Strat. of Calif. A.A.P.G., p. 231, pl. 20, figs. 2, 5.

Nonion multicameratum Cushman and Kleinpell = *Nonion pizarrensis* var. *multicameratum* Cushman and Kleinpell, 1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 1, p. 4, pl. 1, fig. 10.

Nonionella sp. This species may be identical to *Nonionella davanaensis* Pierce, 1956, Jour. Pal., vol. 30, no. 6, p. 1303, pl. 137, fig. 10.

Pullenia miocenica Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 338, pl. 14, fig. 6.

Pullenia moorei Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 340, pl. 18, figs. 11, 16.

Rotalia garveyensis Natland, 1938, Bull. Scripps Inst. Oceanog., Tech. Ser., vol. 4, no. 5, p. 147, pl. 6, fig. 6.

Saracenaria beali (Cushman = *Hemicristellaria* ~~beali (Cushman) of Klein~~pell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 206, pl. 11, figs. 10-12 and pl. 12, figs. 15, 16.

Siphogenerina collomi Cushman, 1925, in Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 300, pl. 15, fig. 11.

Siphogenerina reedi Cushman, 1926, in Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 303, pl. 11, fig. 2, pl. fig. 7, pl. 17, gifs. 9, 13.

Suggrunda californica Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 287, pl. 18, figs. 8-10.

Uvigerina angelina Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 292, pl. 18, fig. 12.

Uvigerina hannai Kleinpell = *Uvigerina californica* Hanna, 1928, Bull. A.A.P.G., vol. 12, no. 10, pl. 9, fig. 3. See also Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 294.

Uvigerina hootsi Rankin, 1934, Contr. Cushman Lab. Foram. Res., vol. 10, pt. 1, p. 22, pl. 3, figs. 8, 9.

Valvulineria californica californica Cushman = *Valvulineria californica* Cushman, 1926, Contr. Cushman Lab. Foram. Res., vol. 2, no. 3, p. 60, pl. 9, fig. 1.

Valvulineria miocenica Cushman, 1926, in Kleinpell, 1938, Mio. Strat. of Calif., A.A.P.G., p. 313, pl. 16, fig. 1.

Virgulina (Virgulinella miocenica Cushman and Ponton, 1932, Fla. Geol. Survey, Bull. no. 9, p. 81, pl. 12, fig. 9.

APPENDIX B: MIOCENE CALCAREOUS NANNOPLANKTON

Cyclococcolithina neogammation (Bramlette and Wilcoxon) = *Cyclococcolithus neogammation* Bramlette and Wilcoxon, 1967, Tul. Studies in Geol., vol. 5, no. 3, p. 104, pl. 4, figs. 3-5.

Reticulofenestra pseudoumbilica (Gartner) = *Coccolithus pseudoumbilicus* Gartner, 1967, Univ. of Kansas, Paleont. Contr., Paper 29, p. 4, pl. 6, figs. 3, 4.

Sphenolithus heteromorphus Deflandre, 1953, C.R. Acad. Sc. (Paris), vol. 137, p. 1785, figs. 1, 2. See also Bramlette and Wilcoxon, 1967, Tul. Studies in Geol., vol. 5, no. 3, p. 122, pl. 2, figs. 6-9.

ADDENDUM

Well preserved speciments of *Discoaster kugleri* have been noted in sample NEW 48 from the *Brizalina woodringi* Subzone of the late lower Mohnian Stage at Newport Lagoon. The occurrence of *D. kugleri* and the observed distribution of *Cyclococcolithina neogammation* and *Sphenolithus heteromorphus* at Newport are fully compatible with the vertical distribution of these three nannofossils in the Cipero section of Trinidad as reported by Bramlette and Wilcoxon (1967). This lends strength to the contention that the upper Luisian may be equivalent to the upper part of the *Globorotalia fohsi barisanensis* Zone and that the *Concavella gyroidinaformia* Subzone and *Brizalina modeloensis* Zone of the early and middle lower Mohnian together may constitute the equivalent of the *Globorotalia fohsi fohsi* Zone. The presence of *Discoaster kugleri* in the late lower Mohnian Stage further suggests that this section at Newport is equivalent to all or a part of the *Globorotalia fohsi lobata* and *Globorotalia fohsi robusta* Zones.

The fact that *Discoaster kugleri* occurs in the late lower Mohninan at Newport Lagoon was not discovered until after the editor's deadline for submission of manuscripts necessitating the inclusion of this information in the form of an addendum.

A TENTATIVE RADIOLARINA ZONATION AND PALEO-OCEANOGRAPHIC INTERPRETATION FROM NEWPORT BAY, CALIFORNIA

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Radiolarian faunas from Newport Bay have been worked on by Campbell and Clark (1944), Ingle (1967), Bandy and Ingle (1970) and Casey (1972). Casey (1972), from work on Newport Bay and other southern Californian localities, suggested that the top of the Luisian is equivalent to the *Cannartus (?) petterssoni* Zone of Riedel and Sanfilippo (1970) and that the base of the Mohnian to the top of the Mohnian is equivalent to the following sequence of radiolarian zones: *Ommatartus* to part of the *Stichocorys peregrina* Zone. In this same paper Casey suggested that the Luisian represented a warm interval at Newport Bay and that the top of the Newport section he worked on represented another warm interval with a cool interval between.

The current authors have taken a more detailed look at this section and although we consider this study still in its early stages the following tentative results may be of interest to many micropaleontolgists and biostratigraphers.

Figure 1 enumerates the radiolarian occurrences in samples obtained from W.W. Wornardt Jr. (these same samples were used in the compilation chart of various investigators found elsewhere in this publication). From these data it is suggested that the section studied represents parts or all of the radiolarian zones from *Calocycletta virginis* to *Stichocorys peregrina*. The equivalence of the Upper Luisian with the *Calocycletta virginis* Zone is suggested by the presence of *Crytocapsella japonica, C. tetrapera,* and the absence of *Stichocorys delmontense* this latter species *(S. delmontense)* first appears in the section in sample NL 8 which is near the Luisian-Mohnian boundary and suggests the base of the *Calocycletta costata* Zone. The top of the *C. costata* Zone is suggested by the last occurrence of *Cannartus* cf. *violina*. The next "good" marker is the last occurrence of *Crytocapsella tetrapera* which may define the top of the *Cannartus(?) petterssoni* Zone. The boundaries between the *Dorcadospyris alata* — "*Cannartus laticonus*", and the "*Cannartus laticonus*" — *Cannartus(?) petterssoni* Zones have not been defined herein and parts or all of some of these zones may be missing in the Newport section. The only other "good" zone boundary appears to be the base of the *Stichocorys peregrina* Zone which is defined by the first occurrence *S. peregrina* in sample New 58. Figure 1 shows the same Series and Stage assignments that are used in the compilation chart shown elsewhere in this publication, also shown are the Foraminiferan Zones of Blow (1969) placed in relation to the Radiolarian Zones following Riedel and Sanfilippo (1970). The x's represent occurrences in the samples shown and the z's represent occurrences in some samples statigraphically near the samples but from other collections.

The abundance of radiolarians and relative absence of planktonic foraminiferans in the Upper Luisian, Lower Mohnian and much of the Upper Mohnian suggest a deep water environment of deposition. Ingle (1972) suggested water depths between 2000 and 3000 meters for this part of the Newport section. Our observations agree with those of Ingle. Paleotemperatures using radiolarian ratios are difficult to determine for this part of the section (Casey, 1972). An attempt has been made on Figure 1 to show the general paleotemperature trends. It appears that the paleotemperatures were in general warmer (as much as 5 degrees centigrade above the average summer sea surface temperatures) than the southern Californian waters, as they appear today. Two cooler intervals appear at about the Luisian-Mohnian and Lower Mohnian-Upper Mohnian transitions. The upper cooler interval appears a few degrees cooler than the average summer sea surface temperatures that we see off southern California today. The paleotemperature curve shown on Figure 1 is a modification of the curve of Casey (1972).

Although the radiolarian zonation and paleo-oceanographic interpretations herein stated are believed to be a refinement of the work of Casey (1972) this current study is a continuing study and future results will no doubt refine these observations stated herein. There are three reasons why these results have to be tentative at the present time and they are, (1) a direct correlation with Riedel and Sanfilippo's zonation is difficult because their zonation is many based on warm water radiolarians which are sparse in the Newport section, (2) because of this the first and last occurrences of these already sparse forms may well represent local first or last occurrences due to local water mass intrusions or exclusions, and (3) Riedel and Sanfilippo's zonation herein used (1970) is still itself being refined (with such changes as the elimination of the *Cannartus laticonus* Zone and the extension of some ranges such as the lower extent of the range of Stichocorys *delmontense* into the *Calocycletta virginis* Zone (Riedel and Sanfilippo, 1971).

It is herein suggested, however, that the Newport section (especially the lower part) may be older than has been suggested by many previous workers. This same suggestion was made by Lipps (1964) in his work on planktonic foraminiferans from Newport Bay and others.

Figures of many of the radiolarians mentioned above may be found in Plate 1, and localities of the samples mentioned may be found on the compilation chart of various authors found elsewhere in this publication.

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SERIES	MID.MIO.			LATE MIOCENE								
STAGE	LUISIAN			LOWER MOHNIAN							U.MOH.	
SUGGESTED RADIOLARIAN ZONES	Calocycletta virginis		Calocycletta costata		Dorcadospyris alata	"Cannartus laticonus"	Cannartus (?) petterssoni	Ommatartus antepenultimus	Ommatartus penultimus		Stichocorys peregrina	
FORAM ZONES	6	7	8	9	10	13	15	16	17		18	
SAMPLE NOS	NL 5	NEW 17	NL 8	UN 1333	Tm 17	Tm 18	NEW 40	NEW 43	UO 179	NEW 57	NEW 58	UN 1373
Cannartus cf. violina	X	Z	Z	X								
collosphaerids	Z			X			X					
Cyrtocapsella japonica	Z											
Cyrtocapsella tetrapera	Z		X				X					
Dorcadospyris sp.		X	X	X								
Eucyrtidium calvertense	X			X			X	X	X	X	X	
Lychnocanium grande					X	X	X	X		X	X	
Ommatartus hughesi												X
Prunopyle titan					X	X	X	X	X			
Stichocorys delmontense			X	X		X	X		X	X	X	
Stichocorys peregrina											X	X
Theocyrtis redondoensis	X	X	X	X	X	X	X	X		X	X	

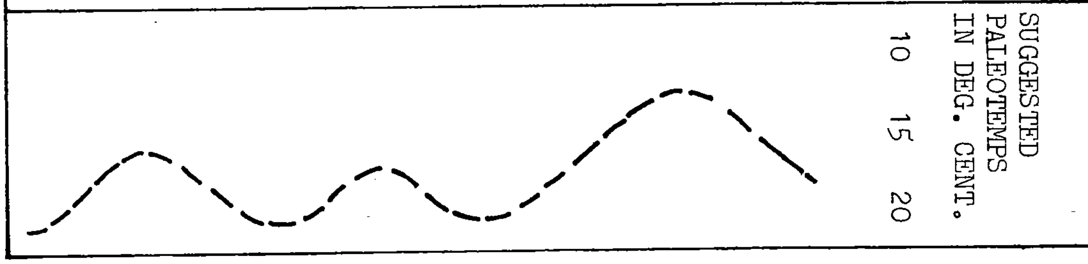
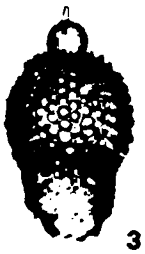


FIGURE 1


1


2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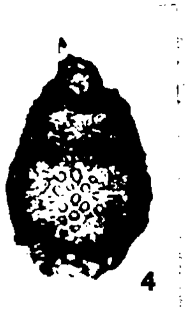
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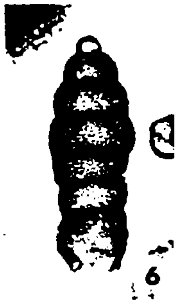
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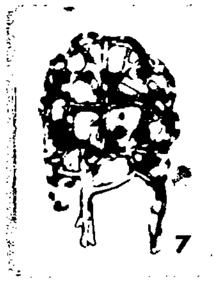
7


8


9


10

PLATE 1

Miocene Biostratigraphic Symposium, Pac. Sec. S.E.P.M., Bakersfield, Calif., U.S.A., 255-283.

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PLATE 1 — Some radiolarians found in the Newport Bay section. (photographs from either Newport Bay or Malaga Cove as stated)

1 — Cyrtocapsella tetrapera Haeckel (from Newport Bay)

2 — Lychnocanium grande Campbell and Clark (from Malaga Cove)

3 — Theocyrtis redondoensis Campbell and Clark (from Malaga Cove)

4 — Cyrtocapsella japonica (Nakaseko) (from Newport Bay)

5 — Stichocorys delmontense (Campbell and Clark) (from Malaga Cove)

6 — Stichocorys peregrina Riedel (from Malage Cove)

7 — Dorcadospyris sp. (from Newport Bay)

8 — Prunopyle titan Campbell and Clark (from Malaga Cove)

9 — Eucyrtidium calvertense Martin (from Newport Bay)

10 — Cannartus cf. violina Haeckel (from Newport Bay)

THE DOHENY CHANNEL — A MIOCENE DEEP-SEA FAN-VALLEY DEPOSIT, DANA POINT, CALIFORNIA[1]

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INTRODUCTION

The Doheny Channel in the lower part of the Capistrano Formation (Miocene-Pliocene) at Dana Point, California has been interpreted as a deep-sea fan-valley (Bartow, 1966; Normark and Piper, 1969; Piper and Normark, 1971). The easily accessible exposure of this channel and its deposits at the Dana Point Harbor provides an excellent opportunity to see a portion of an ancient fan-channel in cross-section.

The original sea-cliff exposures of the Doheny Channel (Bartow, 1966; Normark and Piper, 1969) have been recently destroyed by construction of the Dana Point Harbor. The stratigraphic relationships, however, can be seen more clearly in the new artificial cuts than in the original sea-cliffs. Piper and Normark (1971), in a very recent paper based on a re-examination of the Capistrano Formation in the new cuts. have discussed the sediments of the deep-sea fan, including those of the Doheny Channel. This paper presents a description of the Doheny Channel and its deposits which integrates all previous published descriptions, as well as recent observations of the new cuts by the writer.

DOHENY CHANNEL

The cuts at the Dana Point Harbor provide a cross-section of part of the west wall and channel fill of the north-south trending channel. The channel was cut into siltstones and interbedded fine-grained sandstone of the lower part of the Capistrano Formation (Fig. 1). Many of the 40-9- cm thick, graded, fine-grained sandstone beds that are interbedded with the siltstones show sedimentary structures typical of turbidites. Sparse foraminiferal faunas from the siltstones indicate that the sediments were deposited in water depths of more than 600 m (Bartow, 1966).

The visible section of the channel wall is steep, with the exception of several terrace-like steps which were apparently developed on more resistant cohesive mud layers. The lower part of the channel is cut into siltstones containing thin lenses of sandstone 10-50 cm thick which wedge out 20-30 m away from the wall. These interbeds are not as abundant as in the original sea-cliff exposure, but can be seen on close examination. Most of these wedges are fine-grained laminated sandstone interbeds (usually intervals *b*, *c*, and *d* of the Bouma sequence) which are truncated by the channel and may represent overbank deposits. The few thin, coarse-grained sandstones occuring in the siltstones at the channel margin are probably sandstone sills.

The overall dimensions of the channel are not known because the top, bottom, and east side are not exposed. However, comparison of the exposed portion with profiles of apparently similar modern fan-valleys (Normark and Piper, 1969) suggests that the channel is probably several hundred meters to a kilometer wide.

The channel fill consists of two facies which are designated facies A (the "chaotic" facies of Piper and Normark, 1971) and facies B (the "bedded" facies of Piper and Normark, 1971). Facies A, which consists of massive, very thick-bedded, coarse-grained to very coarse-grained, commonly pebbly sandstones, fills the lower part of the channel. This sandstone appears to be poorly bedded and ungraded, but a few very thick, graded beds with sharp channeled bases can be seen. This part of the channel fill is characterized by large clasts of siltstone up to 100 cm in diameter. One slab, unfortunately no longer exposed, measured more than 8 m long by 1.5 m thick. These large clasts usually do not rest on bedding surfaces, but occur singly or in clusters at any level within the thick massive sandstones.

Some of the thicker graded beds are composed, from the base upward, of the following units: (1) massive, coarse-grained sandstone, pebbly at the base, grading abruptly into; (2) fine-grained, parallel-laminated sandstone; (3) fine-grained sandstone with convolute lamination and ripple-drift lamination; and (4) parallel-laminated, silty sandstone. The basal unit (interval *a* of the Bouma sequence) may comprise most (up to 90%) of the sequence, with the finer-grained units (intervals *b*, *c*, and *d*) condensed to 20-30 cm at the top. This fine-grained top is commonly missing as a result of either nondeposition or scouring by subsequent currents. Interrupted (or repetitive) grading is present in the *a* interval of a few beds, and load deformation structures may be seen locally at the base.

A discontinuous layer of siltstone 10-50 cm thick occurs near the top of the facies A sandstones in the eastern

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[1] Reprinted from Bergen, T. (Ed.), 1971, Geologic guidebook Newport Lagoon to San Clemente, California. Pacific Section, Soc. Economic Paleontoligsts and Mineralogists, Los Angeles, p. 43-49.

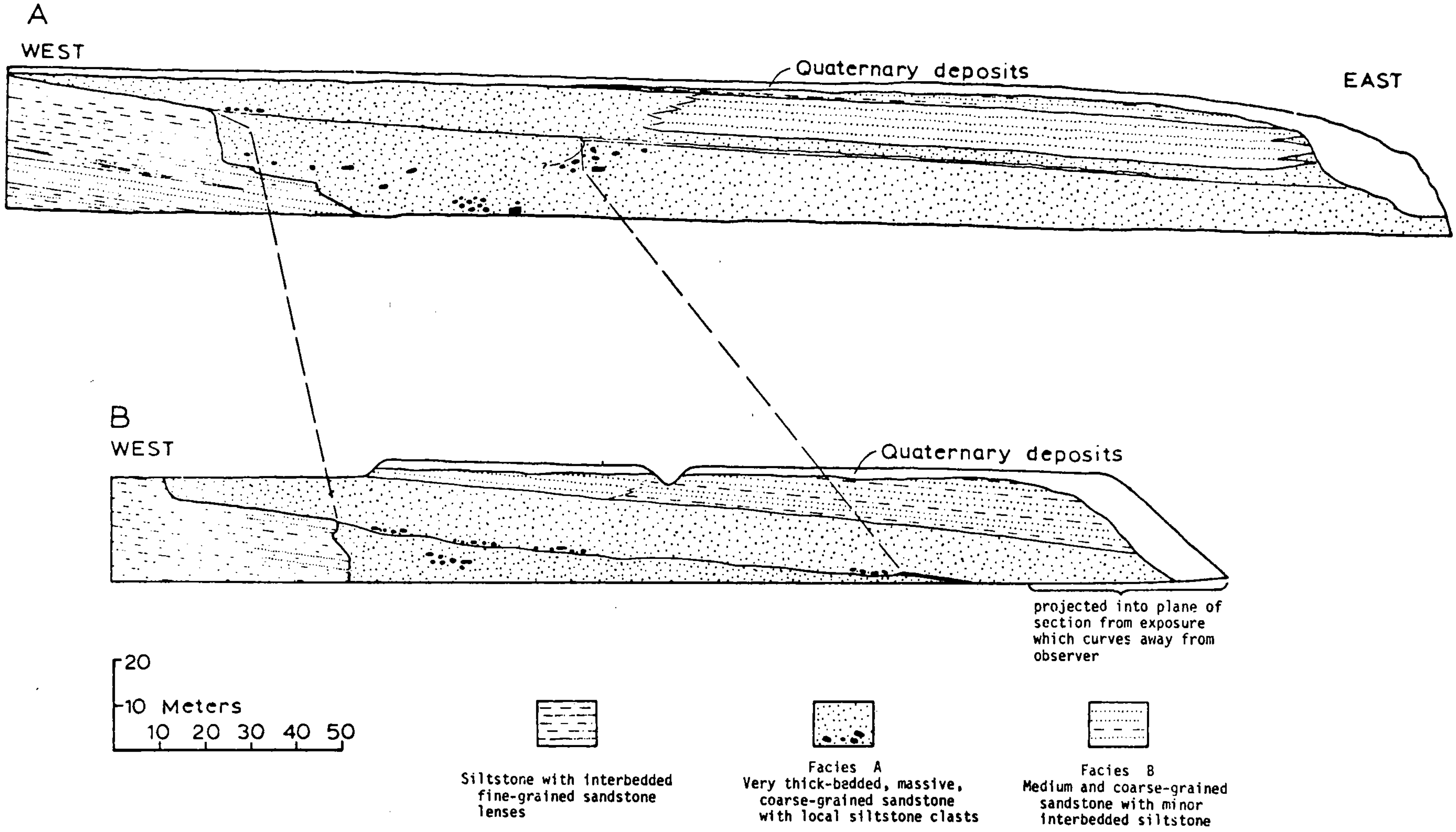

Fig. 1. - Diagrammatic cross-section through part of the Doheny Channel (modified from Bartow, 1966; Piper and Normark, 1971). A, original sea-cliff; B, present artificial cuts at Dana Point Harbor.

part of the exposure; only a small part of this layer is visible in the present cuts (Fig. 1). This layer, which has been partially stripped away by erosion, has been truncated near the middle of the exposure and is absent in the western part of the channel. This horizon is overlain by about 10-15 m (7-8 m in the old sea-cliff) of very thick-bedded, coarse-grained sandstone, which is, in turn, overlain by facies B sandstones and siltstones (Piper and Normark, 1971, Fig. 3).

Facies B consists of medium- and coarse-grained, graded sandstones averaging about 1 m thick with occasional siltstone interbeds. The sandstones typically exhibit Bouma turbidite sequences, with convolute lamination common in the c interval. Siltstone interbeds are prominent in the present exposure of this facies, but were not as common in the original sea-cliff.

The siltstone beds are absent from facies B near the western channel wall (Fig. 1B) and the sandstone beds appear thicker, perhaps as a result of amalgamation. Similarily, facies B sandstones in the original sea-cliff (Fig. 1A) were truncated by very thick sandstones of facies A in the western part of the channel (Piper and Normark, 1971). Sandstones of facies B in the old sea-cliff also interfingered eastward with coarser-grained sandstones of facies A at the east end of the exposure (Normark and Piper, 1969).

Komar (1970) discussed a small conglomerate-filled channel near the base of the original sea-cliff, at the point where it turned inland at the extreme eastern end. Normark and Piper (1969) and Piper and Normark (1971) also mentioned this small channel. Komar states that this conglomerate-filled channel could be followed inland (north) for at least 300 m. This would indicate that the channel has no appreciable dip to the north because the south end was near the base of the cliff. The Capistrano Formation, including the Doheny Channel fill, dips north to northeast at 15°-20°; therefore, this conglomerate-filled channel can not be part of the Doheny Channel fill. It is, instead, a Quaternary gravel related to the present San Juan Creek, which is adjacent to, and parallel with, the small conglomerate-filled channel, as shown by Vedder, Yerkes, and Schoellhamer (1957).

DISCUSSION

Paleocurrent measurements (Bartow, 1966) indicate that currents from the northeast quadrant transported the fan sediments; the apex of the fan was probably at the mouth of a submarine canyon several kilometers distant. Petrographic studies of the channel-fill sands indicate a provenance area to the north or northeast.

A model for deep-sea fan growth based on studies of the La Jolla and San Lucas (Baja California) fans has been postulated by Normark (1970). According to this model, the upper part of a fan is characterized by a large leveed valley which conducts the coarser sediments to the midfan area. In the midfan area, a "suprafan" is built by rapid aggradation where currents leave the leveed channel. The "suprafan" has a number of smaller distributary channels which lack persistent levees; they shift through time as a result of the rapid sedimentation.

Not enough can be seen of the Doheny Channel to place the Dana Point exposures in the Normark model with any degree of certainty, but the abundance of fine-grained sandstone wedges interbedded with the siltstones of the channel wall suggests that these wedges are penecontemporaneous overbank deposits. If this is true, most of the channel wall represents levee deposits and the exposure is that of a large channel on the upper fan. This is, however, somewhat at variance with the interpretations of Piper and Normark (1971) who believe that considerable compaction had taken place in the silts before the channel was cut. The predominance of coarse-grained sediment and the absence of siltstones in the western part of the channel, as well as the steepness of the channel wall, suggests that the thalweg (deepest part of the channel) was against the west wall at this point.

Normark's depositional model, as well as descriptions in the literature of ancient submarine channel deposits (see Stanley, 1969, for bibliography), indicates that deep-sea channel deposits are typically linear sand bodies that are relatively broad and flat in cross-section. These bodies may be several kilometers long and more than a kilometer wide, with a thickness of from 50 to several hundred meters. The deposits of the Doheny Channel are an example of this type of sand body and provide a useful reference for the identification of other fan-channel deposits in the Tertiary basins of California.

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CLASSIFICATION OF WATER-LAND CLASTIC SEDIMENTS

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All sedimentary processes have one common element, namelt gravitational force. But before gravity can begin its work, potential energy must be imparted to large masses of rock by elevating it substantially above sea level. This upthrust stores in the rock a tremendous amount of potential energy which is converted into kinetic energy as each rock fragment weathers off and becomes a clastic sediment. Each sedimentary particle continues to have potential energy subject to gravity until it reaches its ultimate destination which is the lowest place in the adjacent sea. Nature abhors both an elevation and a depression and works unceasingly through gravitational force to change them into a flat plain.

Gravity is the driving force of sedimentation, but in some processes gravity acts directly on the sediments while in others it energizes an agent which moves the particles. Although many variations may exist, there are four principal generic processes of aqueous sedimentation which produces distintive deposits which are, Gravitites, Tractionites, Turbidites and Hemipelagites (Table 1).

A *GRAVITITE* is a bed of unsorted clastics, ranging from clay size to boulders, deposited by a sedimentary flow impelled by gravity alone. The sediments move down a slope of sufficient gradient at speeds from slow creep to enormous velocity. Internal bedding is massive and particle arrangement is random. There is no grading, sorting or orientation of particles because sediments are in grain-to-grain contact which prevents sorting.

Fossils, if present, are randomly oriented and scattered throughout the heterogeneous mass. A gravitite may be clean with little or no matrix or muddy with much matrix or intermediate between these two extremes.

A *TRACTIONITE* is a bed of progressively well sorted, winnowed clastics of sand size or larger deposited by moving water which sweeps or bounces them along the bottom. Although their source material can contain a complete range of sediment sizes from clay to boulders, tractionites preserved in the stratigraphic column are generally of sand size or larger because they are transported more slowly as they are swept or bounced along while the silt-clay fraction is rapidly carried off in suspension by the moving water. The preserved tractionite, therefore, is usually clean with little if any matrix.

Because moving water tends to create strong well bedded linear patterns, a tractionite is characterized by this type of bedding. Generally grading is poor to none. If present it is produced by a gradually waining flow velocity. Sediment transport by upland river systems generally produce poor local sorting while lateral sorting is good with particles in general becoming progressively smaller as sediments are carried from the mountains to the sea.

Moving water also orients particles. Ripple marks and imbricated cobbles are common. Tractionites are commonly developed in marine environments and exhibit the same characteristics as those deposited subaerially. In marine water transport peleycepod valves are oriented with their convex side pointing upward. In this position they have maximum resistance to being moved by water.

Lower Pliocene sands exposed in Wheeler Canyon, Ventura Co. Calif. contain beautifully developed current rippled sands interbedded with marine silts containing in-place foraminifera which indicates ocean depths of more than six thousand feet. Recent deep ocean bottom photographs reveal that the same type of ripple marks are developing on the sea floor.

A *TURBIDITE* is well graded sedimentary unit deposited rapidly from the suspended load of a turbidity current and includes all of the intervals resulting from a single flow. The sediments grade upward from coarse particles in a siltclay matrix at the bottom to a pelitic interval of silt and clay at the top. Turbidites are graded laterally as well as vertically with the graded sequence being made up of progressively finer particles with distance from the point of origin.

A turbidity current is a four phased process. The *first phase* is erosional provided that the surface over which the current flows is sufficiently unconsolidated.

The high degree of turbulence in the gyrol at the head of the current causes the erosion. The eroded silt and clay added to the flow matrix may help to prolong the suspension of the coarser particles. Flute marks generally form in the proximal area while sole marks are more prevalent in the distal area.

The *second phase* produces the graded sand interval - Bouma's A zone. This deposition occurs in the rear part of the head gyrol where the energy level is too low to hold the coarser sand in suspension. The large grains fall out first followed by progressively smaller ones. Matrix in this part usually ranges from 10 to 30 percent. Bedding is absent in this part.

The *third phase* is a traction regime in which the current-bedded intervals are laid down - Bouma's - B, C and D zones. This part is usually composed of finer sand with a silt clay matrix deposited by a current following the head gyrol with sufficient velocity to move particles grain-by-grain which creates linear bedding. Often good bedding is not present in the C zone. This is particularly true in Ventura basin Pliocene turbidites. A possible reason for this is that most of the carbonaceous particles drop out in this interval. These particles are generally much larger and lighter than the smaller, heavier sand grains in the B and D intervals. This larger size with lower specific gravity may create turbulence which prevents lamination in the C interval.

The *fourth phase* deposits the peletic interval which caps a turbidite sequence. These very fine sediments settle from suspension after the current stops.

Very few if any indigenous fossils, such as foraminifera etc., occur in turbidites. Those found are reworked from older strata or shallower ecologic areas. Therefore they are unreliable for age dating and ecologic determinations.

Most pelecepod valves transported by turbidity currents are oriented with their convex side pointed downward. This position is reverse to those transported and deposited in a traction regime.

The reason for this reverse orientation is that a convex valve falling through a liquid achieves its minimum fall resistance in this position. Shell orientation therefore provides a good criteria for distinguishing tractionites from turbidites.

The degree of bottom erosion by a turbidity current is controlled primarily by the length of time between flows. A second flow following a few minutes after the first will erode and incorporate much of the deposit laid down by the first flow. Laboratory experiments in small tanks shown that after one hour of settling time the settled surface of the first flow is subjected to very little erosion.

A *Hemipelagite* is a layer of marine sediments formed by the slow accumulation on the sea floor of biogenic material and fine terrigenous particles. The terrigenous constituents are both

TABLE 1 - CLASSIFICATION OF WATER LAID CLASTIC SEDIMENTS

		GRAVITITE	TRACTIONITE	TURBIDITE	HEMIPELAGITE
TRANSPORT	Agent	Gravity alone	Moving water	Fluid density differential	Moving water or gravity alone
	Particle Size	Grain-to-grain contact	Fine suspended; grain-to-grain	Suspended	Suspended
DEPOSIT	Matrix	Variable; 0-100%	Variable	Essential	Nearly all matrix
	Bedding	Massive	Linear	Linear and massive	Linear
	Vertical Grading	None	Poor to none	Good	None
	Sorting	None	Vert.; poor Lat.: good	Sand; poor Other; good	None
	Particle Orientation	Absent	Present	Present	Absent
	Erosion	Erosive	Erosive	Erosive	Non-erosive

air-borne sediments such as silt and clay discharged by rivers into a larger standing body of water.

The biogenic constituents found in Hemipelagite consist of the fallout of planktonic shells continuously raining down and the normal benthonic material developed on the sea floor. Consequently in a turbidite sequence only the Hemipelagite capping contains indigenous species which can be used for age and ecologic determinations.

While a hemipelagite deposit usually caps a turbidite it is not part of the turbidite sequence but actually marks an interval of quiet between turbidity current flows. The thickness of the hemipelactic layer is a function of the length of time which this type of sedimentation occurs without interruption.

Outcropping sections to be studied on the field trip to Newport Lagoon, Dana Point and San Clemente contain excellent examples of these four generic sedimentary types.

NEWPORT LAGOON AREA

Most of the marine sediments in the Newport Lagoon area are Hemipelagites composed of marine shells - mostly foraminifera diatoms, radiolaria etc., in a silt clay matrix. Some of the well bedded Miocene shales may be distal turbidite deposits.

DANA POINT AREA

The San Onofre Breccia exposed at Dana Point are classed as *Gravitites.* A few beds contain some evidence of traction transport.

DANA COVE AREA

The Capistrano Formation exposed in the cliffs west of the channel are Gravitites with abundant evidence of transport by subsea sliding.

THE DANA COVE SUBMATINE CANYON SEDIMENTS

These sediments were for the most part deposited by traction transport and subsea sliding. Therefore, they are placed under Tractionite and Gravitites. Local cut and fill features are common. These are most likely developed by higher local water flow velocities and or slumping. Some channels are backfilled with large angular shale fragments deposited either by traction or gravity flow.

The thinly bedded silt sand clays in the eastern part of the channel contain large *Bathysiphons* which generally indicate water depths of deposition below 400 meters. These *Bathysiphons* appear to be indigenous because they are oriented parallel to the bedding planes. These fine sediments were probably deposited by a certical fallout of fine terrestial sediment flowing over the surface of the ocean. Some beds may be classed as distal turbidites.