CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

# DEPOSITIONAL ENVIRONMENTS OF THE VAQUEROS FORMATION IN THE BIG MOUNTAIN AREA, VENTURA COUNTY, CALIFORNIA

A thesis submitted in partial satisfaction of the requirements for the degree of Master of Science in

Geology

by

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January, 1981

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ABSTRACT

DEPOSITIONAL ENVIRONMENTS OF THE VAQUEROS FORMATION
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The Vaqueros Formation (Oligocene - lower Miocene), exposed in a northward-dipping homocline in the Big Mountain area, Ventura County, California, is a transgressive-regressive sequence which conformably overlies the Sespe Formation and is unconformably overlain by the Conejo Volcanics in the west and the Calabasas Formation in the east. Three members are distinguished: a lower sandstone, siltstone, and limestone sequence; a middle sandy siltstone; and an upper sandstone, siltstone, and limestone sequence.

In the lower member, the lowest sandstone and siltstone beds are beach and marsh deposits. Overlying these deposits are unfossiliferous sandstone and interbedded fossiliferous sandstone and siltstone which represent deposition in shoreface and transition zone environments. Limestone beds in the transition zone environment

which are composed of shell debris and interbedded siltstone are storm-lag deposits and those predominantly containing whole *Anomia, Terebra,* and *Pecten* shells are shoal deposits. Fossiliferous siltstone beds near the top of the lower member represent deposition in a shallow offshore shelf environment in water no deeper than 60 m.

Fossiliferous siltstone beds in the lower and upper thirds of the middle member are shallow offshore shelf deposits which were deposited in water no deeper than 60 m. Siltstone and mudstone in the middle third of the member represent deposition in a deep offshore shelf environment characterized by water depth not shallower than 150 m. Sandstone and siltstone beds at the top of the member are transition zone deposits.

Various rock types in the upper member are thoroughly mixed throughout the member. Unfossiliferous sandstone was deposited in a shoreface environment, interbedded fossiliferous sandstone and siltstone represent deposition in a transition zone where water depth ranged from 10 to 30 m, limestone beds composed almost entirely of *Crassostrea* shells were deposited as reefs in the transition zone, and fossiliferous siltstone was deposited in a shallow offshore shelf environment.

Pebbles in the upper member and thin section data indicate a sedimentary source terrane near the Big Mountain area. Volcanic glass shards and tuffaceous material in the Vaqueros suggest that active volcanism was occurring during deposition of this formation.

Prior to deposition of the Vaqueros in the Big Mountain area, there existed a relatively flat floodplain throughout most of the southern Ventura Basin. The initial Vaqueros transgression moved eastward and was marked by minor fluctuations in sea level. During this time, north-south trending, moderate-energy, wave-dominated sandy beaches and coastal salt marshes existed on the coastal plain. Evidence suggesting the presence of an east-west trending shoreline to the south of Big Mountain is inconclusive. During deposition of the upper portion of the middle member, a slow regression began that was the result of cyclic uplift. As uplift continued, the sea retreated north and west until deposition of the Vaqueros ceased.

# INTRODUCTION

## PURPOSE

The purpose of this investigation is to determine the sedimentary environments and paleogeography represented by strata of the upper Oligocene/lower Miocene Vaqueros Formation in the Big Mountain area, Ventura County, California by means of a detailed study of its lithology and paleontology. This investigation advances studies begun by Corey (1927) who reported on the stratigraphy and paleontology of the Vaqueros Formation at Big Mountain. Sedimentological and paleontological interpretations of data collected by the writer are used together with Corey's megafaunal data to identify the depositional environments of the Vaqueros Formation.

## LOCATION AND GEOGRAPHY

The Big Mountain area is in the south-central portion of the Oak Ridge-Santa Susana Mountains, 40 km east of Ventura and 7.2 km north of Simi, California (Fig. 1). The area is within the 7.5-minute Simi quadrangle (T. 3 N. - R. 18 and 19 W., San Bernardino Base and Meridian). Access is provided by State Highway 118 to Moorpark College and then north along numerous Union Oil Company of California roads for which access permission must be obtained.

The study area is on the southern flank of an east-west trending ridge that is separated from Oak Ridge by Happy Camp Canyon. Intermittent streams have incised narrow, steep-walled canyons that commonly contain excellent rock exposures. Elevations in the area range from 180 m to 700 m, although local relief rarely exceeds 200 m.

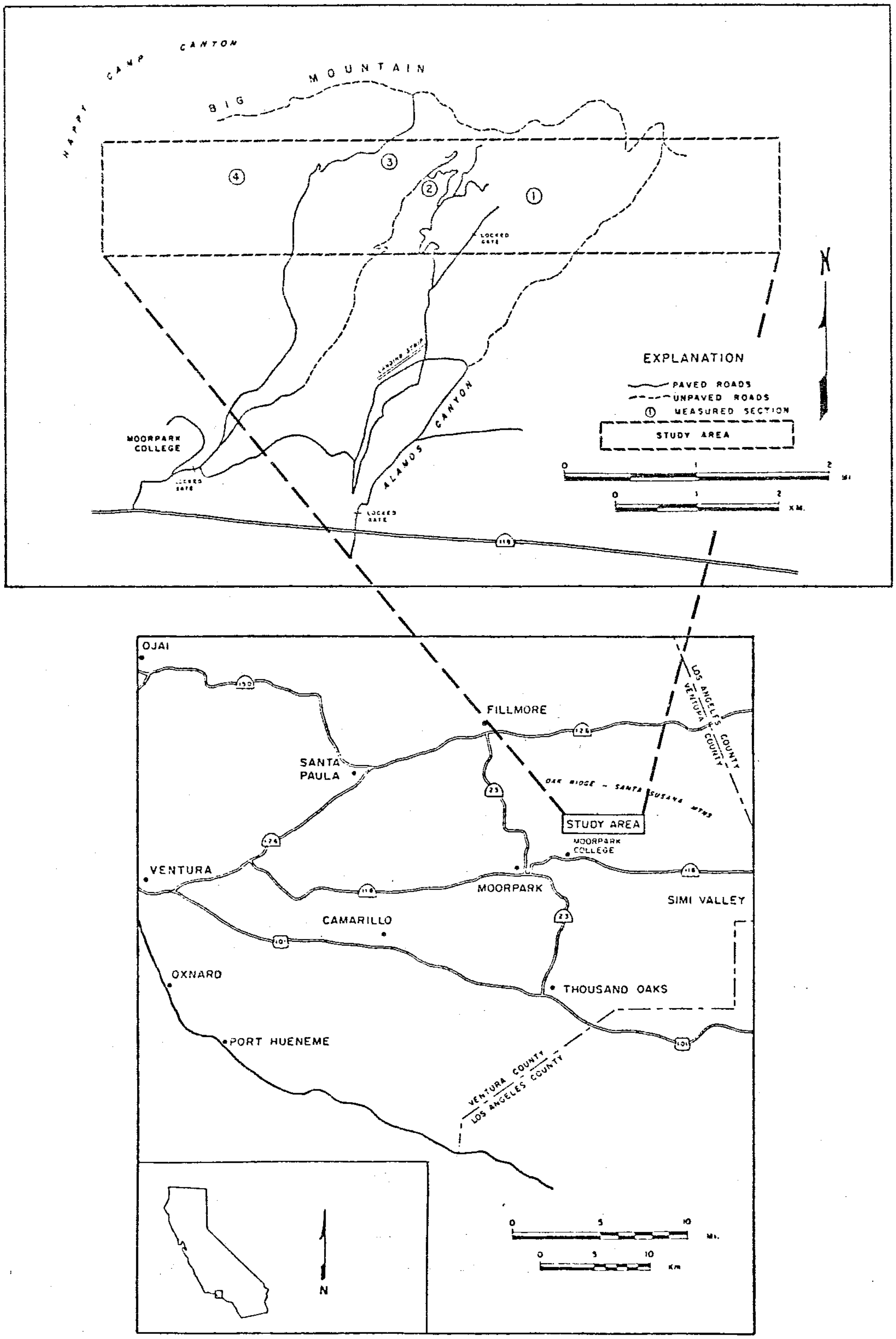


Figure 1. Index map of the Big Mountain area.

GEOLOGICAL SETTING

The Vaqueros Formation of Big Mountain was deposited in the southeastern portion of the Ventura Basin (Fig. 2) where it conformably overlies the Oligocene Sespe Formation. It is unconformably overlain by the middle Miocene Conejo Volcanics in the western part of the study area and by the Calabasas Formation, with a minor amount of volcanics, in the east.

The Vaqueros strata at Big Mountain are in a northward-dipping homocline that is bordered on the north by the Big Mountain syncline and on the south by the Simi anticline. Several major faults, including the Simi thrust and Oak Ridge reverse faults, transect the region. Surface sections of the Vaqueros, however, show minimal fault displacement.

PREVIOUS WORK

The first published geologic work on the Big Mountain area was completed by Eldridge and Arnold (1907). A more detailed study of the region was made by Kew (1924) and the most detailed geologic map of the area was prepared by Redin (1962). A generalized geologic map and geologic column were published by Hall and others (1967). In unpublished master's theses, Van Camp (1959) and Canter (1974) also examined aspects of the Big Mountain area.

Macrofauna of the Vaqueros Formation at Big Mountain was first discussed in detail by Corey (1927) and Loel and Corey (1932). A report by Cushman and LeRoy (1938) described 20 foraminiferal species collected in the study area. Edwards (1971, p. 135-142) briefly discussed the environment of deposition of the Vaqueros at Big

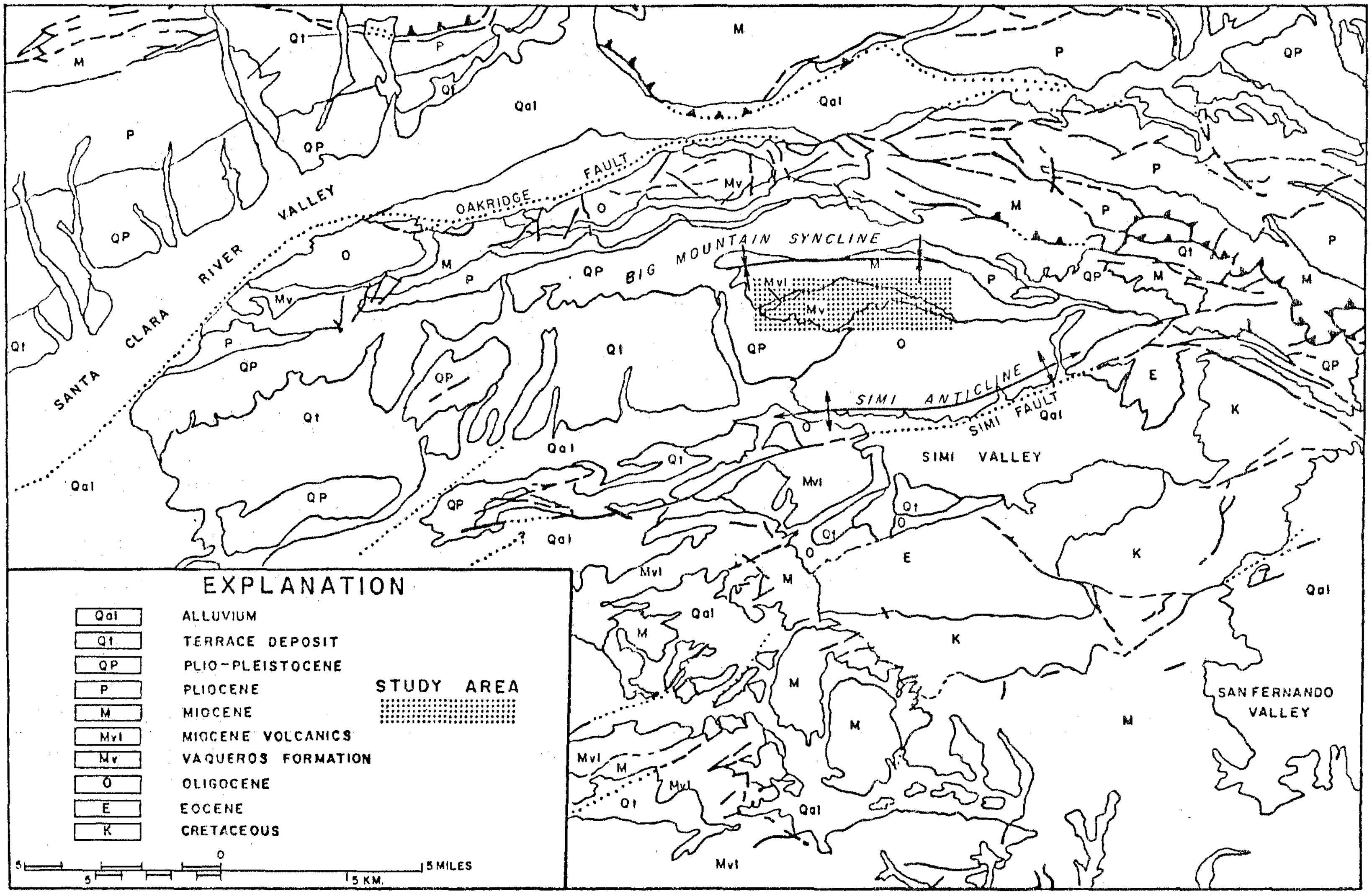


Figure 2. Regional geology of the Big Mountain area showing faults and gross rock unit distribution (adapted from Jennings and Strand, 1972).

Mountain in a regional study of the Vaqueros Formation.

## PROCEDURES

Approximately 35 days were spent in the field from Fall, 1978 to Spring, 1979. Four stratigraphic sections were measured by the Jacob staff method at locations chosen for maximum exposure (Plate I). In addition to field descriptions of the sections, additional paleontological samples were collected. Other field work included tracing mappable beds between sections and collecting paleocurrent data.

Laboratory work consisted of a petrologic description of 80 hand samples, preparation of 106 microfossil samples, microscopic petrographic analysis of 10 thin sections, the restoration of six cross-bedding attitudes to horizontal by rotation on a Wulff stereo net (Ragan, 1973, p. 100-101), and the identification of 23 pebbles and cobbles.

## ACKNOWLEDGEMENTS

I would like to thank Dr. A. E. Fritsche for his helpful guidance and criticism during the field work and writing stages of this thesis. Drs. I. P. Colburn and P. J. Fischer critically read the manuscript and offered helpful suggestions. I am also grateful to Greg Blake for the micropaleontology analysis, Sean Carey for the thin section analysis, John Donnelly for assistance with the drafting, Elaine Bauer and Elyse Kutz for typing the thesis, and Craig Munkres for his assistance in the field.

Field work and laboratory expenses were defrayed by a grant from

Union Oil Company of California.

I would specially like to thank, for their continual support and encouragement through the past months, Terry Budden, Steve Sterling, my parents, my in-laws, and Stephanie.

# STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

## INTRODUCTION

Nine major rock-stratigraphic units are recognized in the Oligocene to middle Miocene strata of the Big Mountain area (Table 1). The oldest unit, the Sespe Formation, is composed of tan to red sandstone and conglomerate with interbedded red and green shale (Flemal, 1966, p. 49-50). The three youngest stratigraphic units, a white foraminiferal sandstone, a superjacent shale, and a punky claystone, have been identified by various writers as belonging to the Monterey/Modelo Formation (Kew, 1924, p. 60-64; Van Camp, 1959, p. 28-31; Redin, 1962, p. 15-16). The remaining five intermediate stratigraphic units from oldest to youngest, consist of (1) interbedded fossiliferous sandstone, siltstone, and limestone, (2) a fossiliferous brown siltstone/mudstone, (3) a tan-colored sandstone, (4) basalt, and (5) a tan to red sandstone with a basal conglomerate.

The basalt unit lithologically is similar to and occurs in the same stratigraphic interval as the Conejo Volcanics described by Taliaferro and others (1924, p. 800-801) in the western Santa Monica Mountains and by Ehrenspeck (1972) in the eastern Conejo Hills, 6 km south of the study area. Yerkes and Campbell (1979, p. E17-E18) reclassified these rocks as a formation in the Topanga Group. The name Conejo Volcanics is used for the basalt lithosome by Redin (1962, p. 14) and by Canter (1974, p. 23-24), and is retained in this thesis.

<table>
<tr><th>Lithology</th><th colspan="2">This paper</th><th colspan="2">Canter (1974)</th><th colspan="2">Edwards (1971)</th><th colspan="2">Redin (1962)</th><th colspan="2">Van Camp (1959)</th></tr>
<tr><td>punky claystone</td><td rowspan="3">Modelo</td><td>claystone member</td><td rowspan="3">Modelo</td><td>claystone member</td><td colspan="2" rowspan="3">Modelo</td><td rowspan="3">Monterey</td><td>claystone member</td><td rowspan="3">Modelo</td><td>claystone member</td></tr>
<tr><td>siltstone and shale</td><td>shale member</td><td>shale member</td><td>shale member</td><td>shale member</td></tr>
<tr><td>white foraminiferal sandstone</td><td>sandstone member</td><td>sandstone member</td><td>sandstone member</td><td>sandstone member</td></tr>
<tr><td>sandstone with basal conglomerate</td><td colspan="2">Calabasas</td><td colspan="2">Topanga</td><td colspan="2">Topanga</td><td colspan="2">Topanga</td><td rowspan="5">Vaqueros</td><td rowspan="3">upper member</td></tr>
<tr><td>basalt</td><td colspan="2">Conejo Volcanics</td><td colspan="2">Conejo Volcanics</td><td colspan="2">Conejo Volcanics</td><td colspan="2">Conejo Volcanics</td></tr>
<tr><td>sandstone</td><td rowspan="3">Vaqueros</td><td>upper member</td><td colspan="2" rowspan="3">Big Mountain sequence</td><td rowspan="2">Rincon</td><td>sandstone member</td><td rowspan="3">Vaqueros</td><td>upper member</td></tr>
<tr><td>brown fossiliferous siltstone-mudstone</td><td>middle member</td><td>siltstone member</td><td>middle member</td><td>middle member</td></tr>
<tr><td>fossiliferous sandstone, silt-stone, limestone</td><td>lower member</td><td colspan="2">Vaqueros</td><td>lower member</td><td>lower member</td></tr>
<tr><td>buff to red sandstone and conglomerate</td><td colspan="2">Sespe</td><td colspan="2">Sespe</td><td colspan="2">Sespe</td><td colspan="2">Sespe</td><td colspan="2">Sespe</td></tr>
</table>

Table 1. Identification of major stratigraphic units in the Big Mountain area.

8

The overlying tan to red sandstone with the basal conglomerate unconformably overlies the Conejo Volcanics and the Vaqueros Formation, where the volcanics are absent. This lithosome is unconformably overlain by the Monterey/Modelo Formation. In the Santa Monica Mountains, 25 km to the southeast, strata which have a lithology similar to that of the tan to red sandstone and which occupy the same stratigraphic position above the Conejo Volcanics and below the Modelo Formations are named the Topanga Formation (Kew, 1923, p. 411-420). The Topanga Formation was reclassified in 1979 by Yerkes and Campbell as a Group composed of three formations. The stratigraphically highest unit, the Calabasas Formation, overlies the Conejo Volcanics and is subjacent to the Modelo Formation. The name Calabasas Formation is used in this thesis for the tan to red sandstone lithosome in the Big Mountain area.

The remaining three intermediate units are recognized as informal members of the Vaqueros Formation. Edwards (1971) classifies the middle and upper members as belonging to the Rincon Formation. However, these two informal members at Big Mountain are not similar lithologically to the Rincon Formation at its type locality, Los Sauces Creek, Ventura County, California. The siltstone at Big Mountain contains a much greater percentage of sand than the siltstone at Los Sauces Creek and is brown in color, whereas siltstone of the Rincon Formation at its type locality is black.

Lithologic properties of the stratigraphic units are classified using criteria from the following writers. Sorting and textural maturity were estimated and classified according to the criteria of Folk (1974, p. 102-105). Rounding classification is from Powers (1953). Rock color and codes are from Goddard (1970). Sandstone, siltstone, and carbonate rocks are named using the classification of Krumbein and Sloss (1963, p. 150-189). Sedimentary structures were identified and interpreted through comparisons with Reineck and Singh (1975). Provenance interpretations of sandstones were made in accordance with the criteria established by Folk (1974). Properties such as cement and mineral composition were visually estimated during microscopic and hand lens analysis.

Each megafossil locality is referred to by its California State University, Northridge (CSUN) locality number (Plate I). Fifty-two microfaunal samples of the 106 collected yielded identifiable types. Each microfaunal locality is referred to by the writer's initials (MB) followed by the year and sample number. These samples are stored at the Union Oil Company Paleontology Lab in Ventura, California.

## SESPE FORMATION

### STRATIGRAPHY AND LITHOLOGY

The Sespe Formation consists of poorly to moderately exposed, poorly consolidated, fine- to medium-grained sandstone with interbedded conglomerate. Color ranges from pale yellowish orange (10YR8/6) to pale red (10R6/2) and grayish green (5G5/2). Bedding is both tabular and lenticular with the latter commonly containing crossbeds. Individual bed thickness varies from .2 to 8 m. The conglomerate is composed predominantly of granitic and gneissic clasts with lesser amounts of quartzite.

The contact with the Vaqueros usually is covered and difficult to follow between outcrops. In the western portion of the study area, Pliocene strata of the Saugus Formation unconformably overlie the contact. The contact in the central and eastern portions of the area can be seen in those canyons having sheer walls. Kew (1924, p. 44) and Van Camp (1959, p. 23) report the contact in the Big Mountain area as conformable; however, subsurface work by Canter (1974, Plate XIV) and Hall and others (1967, p. 3) indicate that the contact is unconformable. Field relationships observed by the writer show an interfingering of the Sespe and Vaqueros, so that the lower contact seems to be conformable on a local scale. This interfingering of the two formations, best observed at CSUN locality 565 (measured section IA), is indicated by the presence of a 3-m-thick fossiliferous, medium- to fine-grained Vaqueros sandstone bed about 17 m below the uppermost occurrence of a Sespe green and red shale sequence. The basal 30 cm of a tan sandstone which is superjacent to this fossiliferous sandstone bed contains low-angle crossbedding overlain by thin laminations.

Although different writers (Woodford and others, 1953; Wilson, 1954) have identified similar sequences in other areas, no consensus has been reached on the delineation of the boundary between the Sespe and Vaqueros Formations. At present, the contact is placed either (1) just below the lowest occurrence of marine fossil beds, or (2) just above the highest occurrence of red beds. Unfortunately, these two criteria are seldom correlative. The lithologic similarity of the fossiliferous bed to nearby outcrops of the Vaqueros and the presence of a marine megafauna would suggest placing the contact at the base of this unit. The overlying tan sandstone and green and red shales, however, have been interpreted as being continental deposits of the Sespe Formation (E. A. Hall, pers. comm., 1979). Although a lack of marine fossils is a poor criterion for recognizing nonmarine strata, the lithologic similarities of these beds to other Sespe outcrops in the area suggest a nonmarine origin. In this thesis, the contact is placed at the highest occurrence of red beds because (1) the underlying rocks lithologically are similar to other nearby Sespe outcrops, and (2) the highest red bed occurs at the base of an abrupt increase in slope gradient.

## ENVIRONMENT OF DEPOSITION

The portion of the Sespe Formation within the study area and to the south was deposited in a fluvial and floodplain environment (Flemal, 1966, p. 177-181). To the north of the study area, along Oak Ridge, Flemal reported the presence of playa-lacustrine deposits as well as fluvial and floodplain deposits. The radial pattern of stream channels, many smaller channels, and the local derivation of sedimentary clasts were interpreted by Flemal as indications that the streams which entered the area were small. He further concluded that the presence of evaporite beds, bedded limestone, and fresh water faunas within the Sespe at Oak Ridge indicated that the streams occasionally filled small playa lakes.

The stratigraphic interval that contains the interfingering Sespe and Vaqueros beds represents a small fluctuation in sea level which occurred prior to the major transgression that deposited the overlying Vaqueros sediments. Vail and others (1977, p. 87) report that numerous changes in sea level occurred during late Oligocene through Miocene time. The 3-m-thick medium- to fine-grained sandstone bed described above containing marine fossils probably was deposited in a large open-marine sound or nearshore open-marine environment that may be analogous to those which are adjacent to the low-lying coastal plains of the Gulf Coast. Van Andel and Curray (1960, p. 352-353) report that medium- to fine-grained, moderately sorted sand is characteristic of a nearshore marginal marine environment. Although a similar sedimentation pattern occurs in a bay margin environment (Shepard and Moore, 1960, p. 124; Parker, 1959, p. 2126), the occurrence of *Polinices* sp. and *Macoma* sp. (Table 2) indicates an inlet, open-marine sound, or nearshore open marine environment (Parker, 1959, p. 2129-2132).

The sandstone overlying the marine bed perhaps represents a progradation of the paleoshoreline. The small-scale crossbedding and overlying thin laminations in the basal 30 cm of the tan sandstone may represent foreshore and/or backshore deposits similar to those described by Reineck and Singh (1975, p. 299-300) and Davis (1978, p. 272). The sediments overlying these possible beach deposits may have been deposited in the fluvial environments previously discussed.

In the prograding coastline, the major portion of the sand transported to the coast must be brought in by rivers (Reineck and Singh, 1975, p. 281). Because Flemal (1966, p. 181) reports that deltaic deposits in the Sespe Formation are minor or absent, it is

| | CSUN 565 |
|---|---|
| Gastropoda | |
| *Rapana vaquerosensis* | r |
| *Polinices* sp. | x |
| unidentified gastropod | x |
| Bivalvia | |
| *Clementia pertenuis* | c |
| *Macoma* sp. | c |
| unidentified bivalve | x |
| Arthropoda | |
| *Balanus* sp. | c |
| Vertebrata | |
| mammal bones | c |

c = common  r = rare  x = identified in the field

Table 2. Sespe-Vaqueros transition zone fossils.

suggested that the paleocoastline existed in a moderate to high energy environment; deltas are rare on moderate to high energy coasts (Bird, 1968, p. 177; Wright, 1978, p. 14). Sediments transported to a moderate to high energy coastline are dispersed by wave action and the sand and gravel fraction commonly is deposited in a beach environment (Bird, 1968, p. 177-178; Wright, 1978, p. 40).

## VAQUEROS FORMATION

### NOMENCLATURE

The Vaqueros Formation originally was described by Hamlin (1904) and was designated by him the Vaquero Formation. Subsequently the name evolved to the presently accepted term, Vaqueros. Hamlin described the formation in its type locality, Los Vaqueros Canyon, Monterey County, California as consisting of a coarse-grained, gray to light yellow, quartzose sandstone containing strata of granitic pebbles.

Although the original description of the Vaqueros Formation predominantly was based on its lithologic characteristics, some subsequent workers attempted to redefine the unit by developing chronostratigraphic and/or biostratigraphic limits for the formation (Eldridge and Arnold, 1907; Kew, 1919; Loel and Corey, 1932). A notable exception was Louderback (1913) who, in his paper on the Monterey series, claimed that it is possible to distinguish between the Vaqueros and Monterey or Modelo Formations on a strictly "lithologic basis" regardless of the fossil content within the series. In 1942, Thorup redefined the Vaqueros at the type locality as those rocks which overlie continental beds and underlie marine shale. He divided the formation into six members composed of a basal sandstone member overlain by three alternating shale and sandstone members and two uppermost sandstone members.

The Vaqueros Formation is recognized in the Big Mountain area by the writer on the basis of (1) a slight similarity in lithology to the Vaqueros of the type locality, (2) a stratigraphic position equivalent to the type locality where the Vaqueros overlies nonmarine deposits, and (3) a "Vaquerosian Stage" megafauna.

## AGE

In their report on the paleontology of the Vaqueros Formation, Loel and Corey (1932) defined the "formation" on the basis of biostratigraphic data. Their descriptions and definition of the Vaqueros fulfills the criteria listed by the Code of Stratigraphic Nomenclature for the use of the term stage, a time-stratigraphic unit. Addicott (1972, p. 8) reports that the "Vaqueros Stage" is characterized by the restricted stratigraphic occurrence of *Turritella inezana* Conrad, *Rapana vaquerosensis* (Arnold), and other mollusks. He further notes that the biozone of *Turritella inezana* Conrad is "one of the best indices for this stage" and the stage also is characterized by the taxonomic diversity of large pectinids such as *Lyropecten magnolia*. The presence of a *Turritella inezana* fauna in all three members of the Vaqueros at Big Mountain places the formation in the "Vaqueros Stage." Addicott (1972) reports that the "Vaqueros Stage" is considered equivalent to the late Oligocene to early Miocene epochs in Europe.

Microfaunal samples collected from the Vaqueros Formation at Big Mountain were identified by G. H. Blake of Union Oil Company. The presence of *Valvulineria casitasensis, Virgulina bramlettei, Textularia kewi,* and *Ammobaculites strathernensis* in samples collected throughout the formation indicates a late Zemorrian to early Saucesian microfaunal Age (Kleinpell, 1938). This time interval is correlative to the "Vaqueros Stage" (Addicott, 1972, p. 3). Bandy (1972, p. 135) states that the late Zemorrian to early Saucesian microfaunal Age is equivalent to the late Oligocene to early Miocene of Europe.

## GENERAL STRATIGRAPHIC STATEMENT

The three informal members of the Vaqueros Formation will be used as the primary units for stratigraphic descriptions and environmental interpretations. The mapped relationships between these units are illustrated in Figure 3. A more detailed view is shown on Plate II. The datum used in Figure 3 is a basal resistant sandstone in the upper member of the Vaqueros. The maximum thickness of the Vaqueros in the Big Mountain area is exposed near measured section II, where it is 310 m thick. A lesser thickness is exposed to the east due to unconformable overlapping by the Calabasas Formation. In the west, it is overlapped and covered by the Saugus Formation. In general, the lower and upper members are moderately well exposed, whereas the middle member is poorly exposed and covered.

## LOWER MEMBER

### INTRODUCTION

The lower member consists of six lithosomes: Lithosome A, interbedded siltstone and fine to medium sandstone; Lithosome B, medium to coarse sandstone; Lithosome C, fine to coarse sandstone; Lithosome D, fine to medium sandstone with minor amounts of interbedded coarse sandstone; Lithosome E, interbedded fine to medium sandstone, siltstone, and limestone; and Lithosome F, siltstone with minor amounts of fine to medium sandstone interbeds.

Lithosome A is located in the eastern half of the study area and is present only in the lower fourth of the member (Fig. 4). This lithosome ranges from 0 percent of the member at section III to a

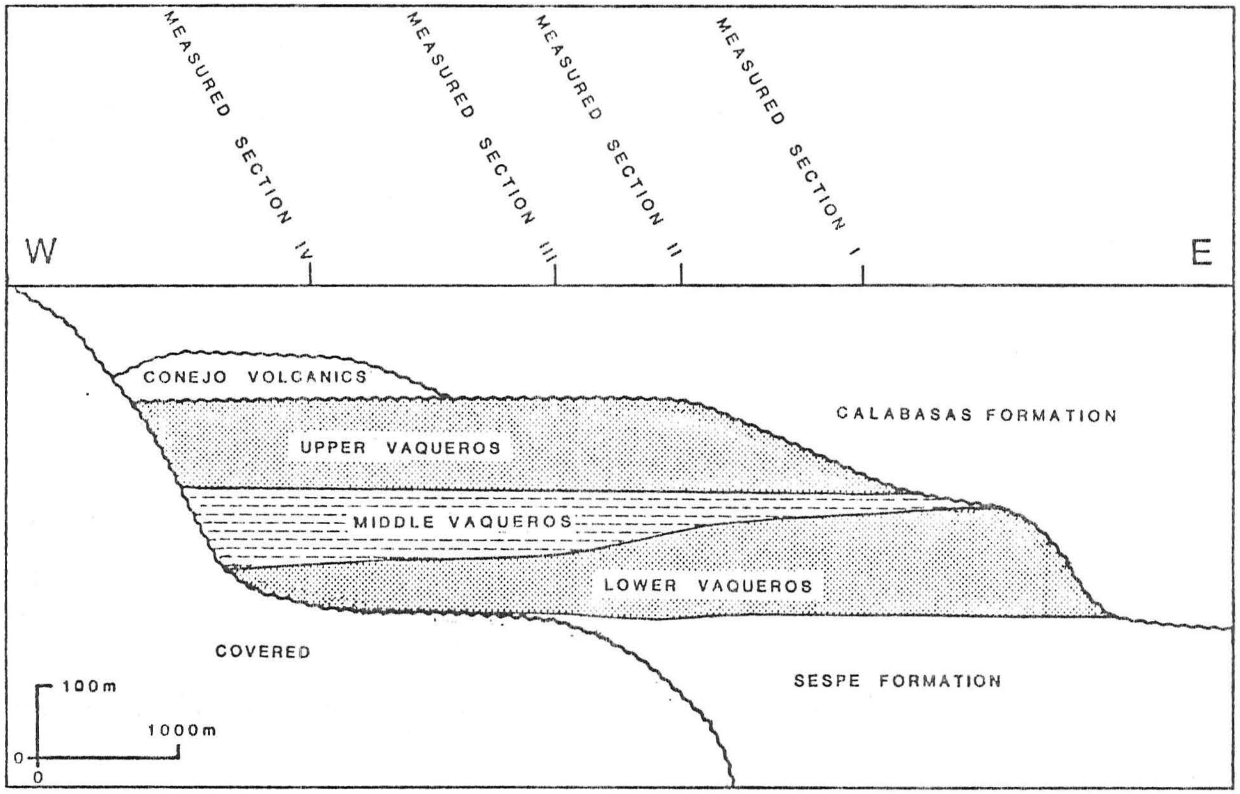


Figure 3. Lateral and vertical relationships of the three members of the Vaqueros Formation.

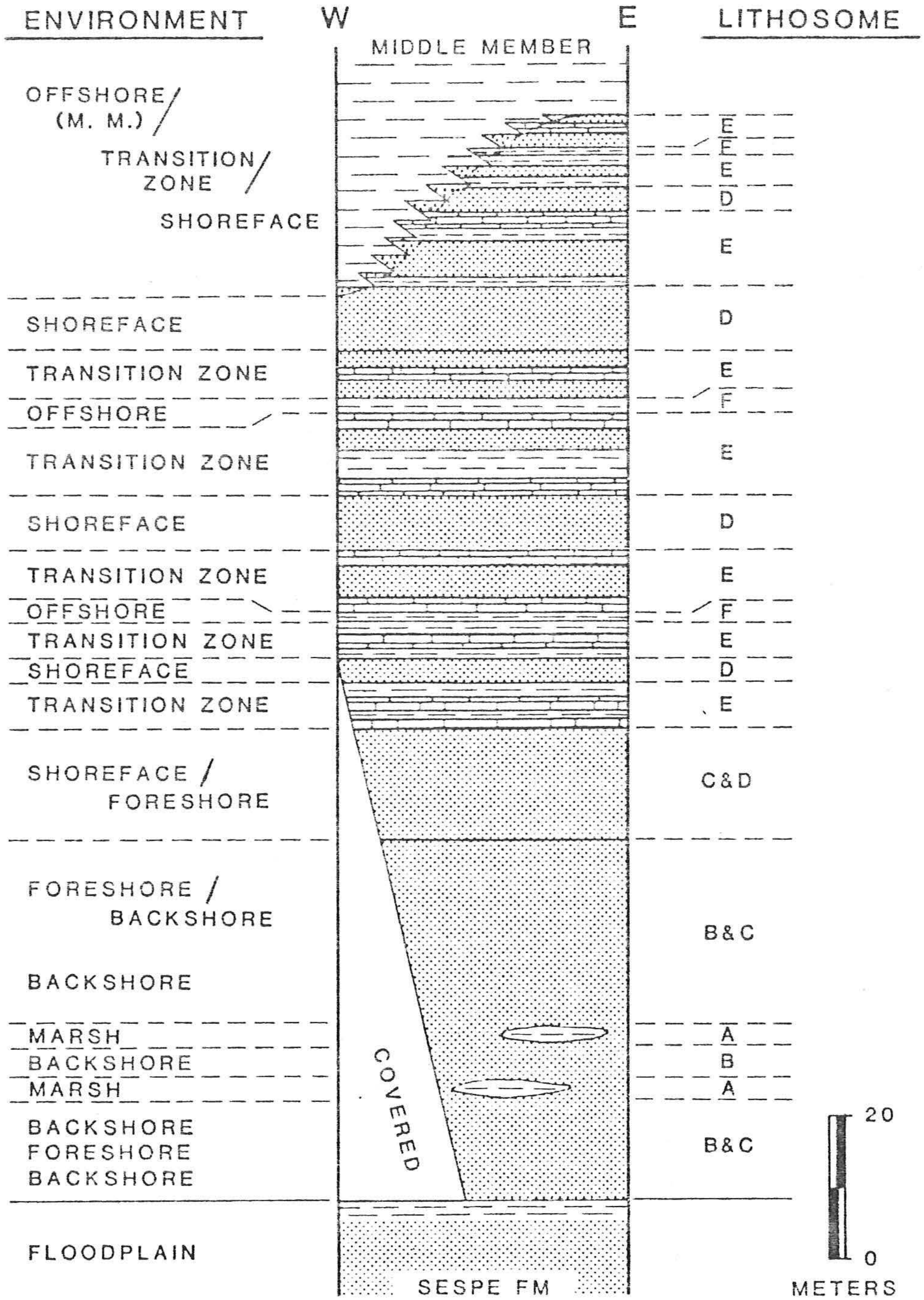


Figure 4. Generalized lithology and sedimentary environments of the lower member.

maximum of .2 percent of the member at section II. The siltstone and sandstone of this lithosome usually are interbedded with the sandstone of Lithosome B. Lithosome B also occurs in the eastern portion of the study area, ranges from 0 percent of the member at section IV to 12 percent at section II, and is concentrated in the lower third of the member. Rocks of Lithosome B are interbedded with those of Lithosomes A and C. The distribution of Lithosome C is limited to the central and eastern portions of the area. It occurs in the lower portion of the member and varies from 0 percent of the member at section IV to 12 percent at section I. Lithosome C is bounded by the bedsets of Lithosome B and/or Lithosome D. Lithosome D is present in the upper two-thirds of the member and ranges from 27 percent of the member at section I to 32 percent of the member at section IV. The bedsets of this lithosome are bounded by bedsets of Lithosomes C and/or E. Lithosome E varies from 35 percent of the member at section II to 53 percent at section IV and occurs only in the upper two-thirds of the member. Rocks of this lithosome are interbedded with those of Lithosome D and/or F. The presence of Lithosome F is variable, but usually occurs in the upper third of the member and ranges from 1 percent of the member at section II to 15 percent of the member at section IV. Lithosome F usually is bounded by rocks of Lithosome E.

The general shape of the lower member is tabular to broadly wedge-shaped. The member is overlapped by younger rocks in the west and is truncated by an erosional unconformity in the east. Unit thickness increases to the east with the maximum thickness reaching

148 m at measured section I and the minimum thickness, 136 m, at measured section II. Exposures generally are good and are best observed on cliff faces and along road cuts.

The gradational contact between the Vaqueros and the underlying Sespe, as previously stated, is placed at the top of the uppermost Sespe red bed. The upper contact of this member sometimes is difficult to locate due to a middle member facies change from silt to sand in an easterly direction. Generally, the contact is placed at the top of the highest fossiliferous sandstone bed, which usually occurs below a major interval of siltstone. *Turritella inezana* or *Anomia vaquerosensis* are the most common fossils occurring in this bed. This contact has been chosen because, although it is gradational, it represents a major change in lithology between the predominantly sandy lower member and the silty middle member. In some areas the contact is covered by brush.

LITHOSOME A

### Lithology

Lithosome A is composed of approximately 80 percent siltstone and 20 percent sandstone. Outcrops of this interbedded siltstone and sandstone commonly are covered. Fresh color of the siltstone is olive green (5GY3/2), whereas the sandstone usually is very light gray (N8). Weathered surfaces of siltstone are pale olive (1GY3/2) and of sandstone, medium light gray (N6). The siltstone and sandstone are interbedded in composite bedsets with interval thickness averaging between .3 and 1.5 m. Bedding within intervals ranges from 1 to 35 cm. Bed shape is variable ranging from tabular to lens shaped. Contacts between the siltstone and sandstone usually are sharp with some beds exhibiting a wavy bedding contact. Thin laminations composed of alternating layers of dark and light minerals occur in both siltstone and sandstone beds. Sedimentary structures are rare, although some sandstone beds contain faint, small-scale crossbedding. Biogenic structures include rare rhizomorphs and moderate bioturbation with both horizontal and vertical burrows present in some beds.

The siltstone contains mostly silt grains, although some sand is present. The sandstone is fine to medium grained. Most individual grains are subrounded to rounded, although some well rounded grains are present. Pore space is filled with calcite spar. Composition is summarized in Table 3. Both the siltstone and sandstone are unfossiliferous.

## Salt Marsh Interpretation

The interbedded siltstone and sandstone of Lithosome A are interpreted as salt marsh deposits because of their stratigraphic position between overlying and underlying backshore deposits and the presence of rhizomorphs. Modern marsh sediments primarily are composed of silt and clay; however, interbeds of fine-grained sandstone may be present (Frey and Basan, 1978, p. 124; Reineck and Singh, 1975, p. 354). No plant debris and only a few rhizomorphs are present in Vaqueros marsh deposits. Although modern marshes contain an abundant and varied flora, in some salt marshes there are areas that remain relatively unvegetated (Bird, 1968, p. 159; Reineck and

| | MB150 (Lithosome A) | MB151 (Lithosome C) | MB153 (Lithosome F) |
|---|---|---|---|
| Percent terr. framework | 60 | 71 | 63 |
| Percent matrix | -- | 29 | 37 |
| Percent cement | 40 | -- | -- |
| Framework elements: | | | |
| quartz | 43 | 31 | 46 |
| orthoclase | 22 | 20 | 24 |
| plagioclase | 22 | 8 | 13 |
| biotite | 1.5 | 27 | 10 |
| muscovite | -- | 3 | -- |
| heavy minerals* | 1.5 | 4 | 7 |
| opaque minerals | -- | 3 | -- |
| rock fragments | 10 | 4 | -- |

*zircon, amphibole, epidote

Table 3. Composition of lower member thin sections.

Singh, 1975, p. 354). According to Frey and Basan (1978, p. 123), although plant debris is abundant in some Pacific coast marshes, relatively little of the debris is incorporated into the substrate. The scarcity of sedimentary structures in the siltstone and the presence of burrows in some beds suggest moderate to dense reworking of the sediments by plants and animals. Bioturbation by plant roots implies a slow to moderate rate of deposition, and because vertical burrows predominate over horizontal burrows, it is suggested that a moderate rate of deposition occurred in the Vaqueros salt marsh environment.

The thin, fine-grained sandstone beds that are interbedded with the unfossiliferous siltstone are interpreted as washover fan deposits; Reineck and Singh (1975, p. 298-299) report that sand layers that are interbedded with the silty and muddy sediments of a marsh commonly represent such deposits. They further note that these layers commonly exhibit thin laminations and low-angle crossbedding. Bioturbate structures, including root mottles, may also be present. Similar sedimentary structures occur in numerous sandstone interbeds present in Vaqueros marsh deposits.

In their study of salt marshes, Frey and Basan (1978, p. 105-106) report that marshes on a tectonically active coast, such as the coast of California, typically are restricted to narrow fringes around protected bays. It is postulated that Vaqueros marsh deposits may have been deposited in a similar protected environment.

LITHOSOME B

## Lithology

Lithosome B is usually the first lithosome above the contact with the Sespe Formation and commonly interfingers with the Sespe. Outcrops of this medium to coarse sandstone are well exposed along canyon walls and are best observed near measured section I. Rock color on fresh surfaces is in the gray hues, yellowish gray (5Y7/2) to grayish orange (10YR7/4), whereas weathered surfaces are dusky yellow (5Y6/4). The sandstone is present in simple bedsets which average 3 m in thickness, although some bedsets are as thick as 10 m. Individual beds rarely are thicker than 2 m. Stratification is indicated by a change in color or grain size. At measured section I is an erosional surface within this lithosome that is indicated by a change from medium to coarse sand, an irregular bedding contact, and greater resistance of the lower bed. Laminations are present in some beds, and in a few beds are subjacent to small-scale cross-bedding. Sedimentary structures consist of faint, small-scale cross-bedding, small siltstone rip-up clasts, and heavy mineral concentrations. Locally common bioturbation by vertical burrowing is found in some beds.

The average sandstone contains subangular to subrounded grains that are moderately sorted. Composition is similar to that of the sandstone in Lithosome A with the major terrigenous components of the rock being quartz and feldspar. Lithosome B is unfossiliferous.

## Backshore Interpretation

The medium- to coarse-grained, unfossiliferous sandstone beds of Lithosome B are interpreted as backshore deposits as defined by Komar (1976, p. 12-13). At the base of the Vaqueros, these beds overlie floodplain deposits of the Sespe Formation; higher in the section, they are interbedded with Vaqueros marsh or foreshore deposits. It should be noted that these backshore deposits are overlain by Vaqueros marsh deposits only in those sequences representing a regression of the sea.

Lower Vaqueros backshore deposits are composed of rocks which texturally are very similar to modern analogs examined by Davis (1978, p. 252-272), Komar (1976, p. 342), and Shepard (1973, p. 127). Sedimentary structures observed in these lower Vaqueros beds are reported by the above writers to occur in modern backshore environments, as well. The stratigraphic position of these lower Vaqueros beds and their similarities in lithology and sedimentary structures to modern backshore deposits suggest a similar environment of deposition.

The coarse-grained sandstone bed at measured section I which is separated from underlying beds by an erosional surface is interpreted as a beach ridge deposit. According to Reineck and Singh (1975, p. 291-292), a beach ridge, which is deposited near the high-water line, is composed of the coarsest material on a beach. According to Psuty (1966), horizontal laminations with superjacent low-angle crossbeds occur near the base of a beach ridge and, as in this Vaqueros deposit, these are separated from underlying sediments by an erosional surface. The coarseness and similarity of this Vaqueros deposit to the beach ridge deposits described by Psuty (1966) and Reineck and Singh (1975, p. 291-295) implies a similar environment of deposition. The fact that the Vaqueros beach ridge deposit overlies foreshore deposits and is overlain by marsh deposits also supports this interpretation.

## LITHOSOME C

### Lithology

The rocks of Lithosome C are composed of fine- to medium-grained, moderately-sorted sandstone. Outcrops are best observed in canyon areas and along some slopes which contain fair to good exposures. Color on fresh surfaces ranges from very light gray (N8) to moderate olive brown (5Y4/4), whereas weathered surfaces vary from grayish orange (10YR7/4) to grayish yellow (5Y8/4). The sandstone beds of Lithosome C are present in simple bedsets. Interval thickness averages between 1.5 and 3 m. Individual beds range from .6 to 3 m in thickness, but rarely are thicker than 2 m. Contacts between beds generally are sharp, with a few beds exhibiting wavy bedding contacts. Stratification is shown by changes in color. Laminations are common and consist of alternating layers of dark and light minerals. These laminations usually are parallel to the bedding planes and rarely have a dip angle greater than 4°. Sedimentary structures present in this lithosome include faint, small-scale crossbedding. The crossbedding most commonly is found in resistant, tabular- to lenticular-shaped coarse sandstone units which are best observed near measured section II. These units are 15-30 cm thick and have a wavy, erosional contact with subjacent sediments. Within the units are eastward-dipping, high-angle crossbeds which are overlain by westward-dipping (10-20°) crossbeds. The sandstone beds bounding these units are faintly laminated or moderately bioturbated. Vertical burrows are common within some beds in Lithosome C with the amount of bioturbation ranging from sparse to moderate.

Individual sand grains predominantly are subrounded. Composition is summarized in Table 3. Biotite is an important component of these rocks and it constitutes in some layers up to 20 percent of the minerals present. An average rock of Lithosome C seems to be moderately compacted with the pore space being filled with matrix material, non-calcareous cement, or no cement.

## Fossils

Fossil content is very minor and in some rocks is totally absent (Table 4). The CSUN localities are shown on Plate I and the stratigraphic position of the fossil localities is shown on Plate II.

*Kewia fairbanksi* is present in a few beds in moderate abundance in the central and eastern portions of the study area. The species always occurs as fragmented individuals associated with broken and fragmented *Balanus* sp. The fragmented condition of these fossils and the lack of any whole individuals suggest that they were transported a moderate distance and/or were deposited in a moderate- to high-energy environment.

*Anomia* sp. and *Turritella inezana* are rare and are found in the

| | CSUN 566 | CSUN 567 |
| --- | --- | --- |
| Echinodermata | | |
| *Kewia fairbanksi* | c | |
| Gastropoda | | |
| *Turritella inezana* | | r |
| Bivalvia | | |
| *Anomia* sp. | x | |
| Unident. bivalve | | x |
| Arthropoda | | |
| *Balanus* sp. | c | c |
| Vertebrata | | |
| mammal bones | | r |

r = rare    c = common    x = identified in the field

Table 4. Fossils in Lithosome C

same areas as *Kewia fairbanksi*. These fossils also are highly fragmented and abraded, which indicates a moderate amount of transport.

*Balanus* sp. is the most common fossil found in Lithosome C. It usually is associated with the previously mentioned species, but in a few beds it is the only fossil present. Individuals usually are broken; however, whole *Balanus* are present in a few beds. All of the fossils are abraded and show signs of transport.

Mammal bones are rare and occur as single, isolated bones rather than as parts of a whole fossil. The only two specimens found are abraded, which suggests a moderate degree of transport.

## Foreshore Interpretation

The sandstone beds of Lithosome C are interpreted as foreshore deposits as defined by Komar (1976, p. 12-13). Studies of modern foreshore deposits indicate that grain size and sorting are variable; however, when a foreshore deposit is composed of sand, it is commonly fine-grained and well-sorted (Davis, 1978, p. 242; Spearing, 1974, Sheet 4; Komar, 1976, p. 342-343). The coarsest material in this environment is located near the beach scarp (plunge step) and is composed of poorly sorted, medium- to coarse-grained sandstone and shell debris (Davis, 1978, p. 242; Reineck and Singh, 1975, p. 302). According to Elliott (1979, p. 147), Reineck and Singh (1975, p. 301), and Shepard (1973, p. 156-157), the main bedding type in foreshore deposits consists of parallel laminations that dip seaward at angles of 2° to 3°. These laminations usually are composed of alternating layers of dark, heavy minerals and light minerals (Elliott, 1979, p. 147; Komar, 1976, p. 371). Because the rocks of Lithosome C contain the above characteristics, it is suggested that they were deposited in a similar environment. Other sedimentary structures present in Lithosome C that are common in modern foreshore environments include small-scale ripplebedding produced by backwash and moderate bioturbation (Komar, 1976, p. 368; Shepard, 1973, p. 158; Reineck and Singh, 1975, p. 301-302).

The resistant, tabular and lenticular, coarse sandstone units containing crossbedding in Lithosome C are interpreted as ridge and runnel deposits similar to those described by Davis and others (1972, p. 413-421) and Hays and Boothroyd (1969, p. 245-265). According to these writers, a ridge and runnel system occurs in the "swash zone", the transitional area between the foreshore and shoreface environments. This system is comprised of a series of asymmetrical ridges separated by troughs which result from swash-backwash processes present along a beach during fair weather (Elliott, 1979, p. 147). Davis and others (1972, p. 418-419) report that ridges contain high-angle, landward-dipping laminations which are overlain by near-horizontal, seaward-dipping laminations of the beach face and that runnels commonly exhibit seaward-dipping laminations which are subjacent to ripple-laminated sands. The similarities between the sedimentary structures present in the coarse sandstone units of Lithosome C and the ridge and runnel deposits described by the above writers implies a similar mode of origin.

The average energy in a coastal system can be interpreted from the beach sediment grain size and the sedimentary structures present in these deposits. According to Komar (1976, p. 342), there are three main factors controlling grain size: (1) the source of the sediment, (2) the wave energy level, and (3) the offshore slope angle. Assuming the sediments necessary for the development of a sandy beach were provided (see sections on Provenance and Paleogeography), there remains the relationship between the wave energy and the offshore slope. In general, the higher the wave energy along a coast, the coarser the sediments will be in the beach deposit (Komar, 1976, p. 342; Spearing, 1974, Sheet 4; Russell and McIntire, 1965, p. 314-315). Komar (1976, p. 303) and Russell and McIntire (1965, p. 314-315) report that the slope of a beach is most affected by sediment grain size. They state that the coarser the sediment present, the higher the angle of the beach slope; hence, the higher the angle of dip of beds of laminated sand. However, Komar (1976, p. 308) further notes that for a given grain size on a beach, higher wave energies will produce lower beach slopes. Because lower Vaqueros foreshore deposits primarily are composed of fine to medium sand with minor amounts of coarse sand and exhibit laminations that rarely exceed a dip angle of 4°, it is suggested that deposition occurred in a moderate-energy environment. The presence of a ridge and runnel system in some of these Vaqueros deposits also supports this interpretation. Ridge and runnel development most commonly occurs along beaches with moderate wave energy, an abundant sand supply, and a relatively flat, fine-grained beach face (Elliott, 1979, p. 147). This proposed moderate-energy environment for the Vaqueros at Big Mountain contrasts with the low-energy coasts postulated by Eastes and Fritsche (1979) and Reid (1978) for the Vaqueros Formation in the Ojai and Sespe Creek areas, respectively.

A modern analog to the Vaqueros foreshore environment is found at Kouchibouguac Bay, Canada. This area is a microtidal, low- to moderate-energy coastline with waves ranging from 1 to 2 m in height with 4 to 5 second periods (Davidson-Arnott and Greenwood, 1976, p. 149-168; Davidson-Arnott and Greenwood, 1974, p. 698-704). The sediment grain size and sedimentary structures described by the above writers in the nearshore bar, trough, and beach face are similar to those found in Lithosome C. Because of these similarities, it is postulated that wave characteristics present during deposition of

Lithosome C were similar to those occurring along the modern Kouchibouguac Bay.

## LITHOSOME D

### Lithology

Lithosome D is composed of approximately 60 percent fine- to medium-grained, unfossiliferous sandstone, 35 percent fine- to medium-grained fossiliferous sandstone, and 5 percent medium- to coarse-grained fossiliferous sandstone. Fair to good exposures are present along some slopes. The best outcrops, however, are along canyon walls. Fresh color ranges from very light gray (N8) to moderate olive brown (5Y4/4), whereas weathered surfaces predominantly are grayish orange (10YR7/4) or grayish yellow (5Y8/4). The fine to medium sandstone and coarse sandstone that comprise this lithosome are interbedded in composite bedsets that average 4 m in thickness. Individual beds range from .3 to 4 m in thickness and vary in shape from tabular to lens shaped. Bedding contacts within bedsets are sharp and usually are planar, although wavy contacts are present in a few intervals. Stratification is shown by changes in grain size or color. Laminations are common in some beds and frequently are associated with small-scale crossbedding. A few beds contain large-scale ripplebedding (wavelength averaging .9 m). Sparse to moderate bioturbation is present in some beds.

At measured section I (CSUN 555) is a channel feature (approximately 10 m - width, 3 m - height) that is composed of fine- to coarse-grained sandstone with abundant fossils which are oriented along high-angle foresets. It should be noted that the stratigraphic sequence in which this channel feature is found contains rocks of Lithosomes D, E, and F. The following rocks and their corresponding sedimentary structures are present in ascending order: laminated fine sandstone -- medium to coarse sandstone with trough crossbedding (lunate megaripples) -- fossiliferous medium to coarse sandstone with tabular crossbeds -- bioturbated fine sand to siltstone. The laminated fine sandstone and superjacent crossbedded sandstone are rocks of Lithosome D. The fossiliferous sandstone containing tabular crossbeds exhibits characteristics of both Lithosomes D and E. It is interpreted as being Lithosome E because (1) it contains fossils that most commonly occur in rocks of Lithosome E and are rare or absent in Lithosome D, and (2) there is a high faunal density which also is characteristic of Lithosome E. The bioturbated fine sandstone and siltstone are interpreted as rocks of Lithosome F. The basal sandstone unit of Lithosome D is thinly laminated. The overlying sets of trough crossbedding are 10-cm-high sets with an erosive, trough-shaped base and high-angle cross lamination. The fossiliferous sandstone unit is approximately 2 m thick and contains high-angle tabular crossbedding in which the foresets are dipping to the west.

Another stratigraphic sequence of particular interest is present near measured section IIA. The rock units in this sequence are, in ascending order: bioturbated, coarse sandstone with rare planar crossbeds -- thinly laminated fine to medium sandstone containing small siltstone rip-ups -- coarse sandstone containing small-scale trough crossbedding bounded by thin laminations -- bioturbated fine sandstone with rare, faint laminations/crossbedding (?). All of these beds are interpreted as rocks of Lithosome D. The trough crossbeds occur in a set which is approximately 6 cm high and which contains low-angle cross laminations. The crossbeds also show transitions to the laminations which bound these sedimentary structures.

All of the sandstone is moderately to poorly sorted with individual grains being subangular to subrounded. Composition is similar to Lithosome C, except for a lesser percentage of biotite and muscovite. Rocks of this lithosome usually contain calcareous cement.

## Fossils

Fossil content varies from 0 to approximately 15 percent (Table 5). Fossils are either whole or moderately fragmented and broken. CSUN fossil localities are shown on Plate I and their stratigraphic position on Plate II.

*Kewia fairbanksi* is common in the fossiliferous beds of Lithosome D. This species commonly occurs as complete, well-preserved individuals; shell fragments of the species are also identifiable in shell debris. When present as shell debris, it is usually associated with broken *Balanus* and *Anomia* shells. Less commonly it is associated with *Turritella inezana*. Whole individuals usually occur alone with the flat side of the echinoid down, parallel to the bedding plane, although in rare instances the base of the fossil is observed to be laying almost perpendicular to bedding, possibly indicating *in situ* burial.

| | CSUN 551 | CSUN 568 | CSUN 569 | CSUN 571 |
|---|---|---|---|---|
| Echinodermata | | | | |
| *Kewia fairbanksi* | c | c | x | c |
| Gastropoda | | | | |
| *Turritella* sp. | | | r | |
| Bivalvia | | | | |
| *Anomia* sp. | | | | r |
| *Anadara* sp. | | c | | |
| Unident. bivalve | | | c | x |
| Arthropoda | | | | |
| *Balanus* sp. | | c | r | c |

r = rare c = common x = identified in the field

Table 5. Fossils in Lithosome D of the lower member.

*Balanus* sp. normally occurs in those beds containing *Kewia fairbanksi*. It usually is fragmented, although in the rare cases where it is attached to another fossil, it is present as a whole individual. This fossil also is present in beds containing shell debris.

*Turritella inezana* is present in minor to moderate amounts in this lithosome and is usually associated with shell debris or poorly preserved unidentified bivalves. However, in a few beds this gastropod occurs in monospecific assemblages. It is commonly broken and abraded suggesting a moderate degree of transport. Individuals show no orientation.

*Anomia* sp. and *Anadara* sp. are present in only a few beds. *Anomia* is always disarticulated, abraded, and usually broken. It most commonly occurs as shell debris, although rare whole individuals are present in a few beds. *Anadara* is always articulated but poorly preserved. It is commonly associated with *Kewia fairbanksi,* although in a few beds it is the only fossil present. In rare cases numerous fossils of this species are perpendicular to the bedding plane suggesting *in situ* burial.

Unidentified bivalves are common in many of the fossiliferous beds of Lithosome D. They usually are articulated but poorly preserved. These fossils usually are found in association with one or more of the above species.

## Shoreface Interpretation

The composite sandstone bedsets of Lithosome D represent a shoreface environment as defined by Elliott (1979, p. 148). The similarities in lithology and sedimentary structures of these Vaqueros beds to modern shoreface deposits, the depth ranges of the fauna in these deposits, and their stratigraphic position between Vaqueros foreshore and transition zone deposits all support this interpretation.

In modern shoreface environments, sediments most commonly are fine grained and become progressively finer as they near the shelf environment (Reineck and Singh, 1975, p. 304-305; Swift, 1976a, p. 268; Spearing, 1974, Sheet 4). However, Swift (1976a, p. 268) reports that along retrograding coasts, such as the present-day coast of the Netherlands, shoreface sediments generally are coarser than along other coasts. The coarsest material in this environment most commonly is concentrated under the breaker zone and is subsequently transported on to the beach (Swift, 1976a, p. 268; Harms, 1975, p. 82). It is postulated that the medium to coarse sandstone beds in Lithosome D were deposited near the breaker zone, whereas the fine to medium sandstone beds were deposited seaward of this zone.

The channel feature at measured section I which contains trough crossbedding overlain by planar crossbedding is interpreted to be a rip-channel deposit similar to those described off the coast of Oregon by Hunter and others (1979, p. 715-721). The following vertical sequence is reported by the above writers to occur in a progradational nearshore rip-channel deposit; in ascending order: bioturbated, fine-grained sand -- medium to coarse sand with seaward-dipping, tabular crossbeds -- coarse or pebbly sand with trough crossbedding -- fine to medium sand with parallel laminations. The sequence at measured section I is similar to that described above, however, it is inverted suggesting deposition during a transgression rather than a regression.

The close association of parallel-laminated sand and crossbedded sand, transitional structures between these two sands, and the occurrence of siltstone rip-ups in the sequence described from measured section IIA imply deposition by wave action. This sequence in Lithosome D exhibits characteristics similar to those described by Davidson-Arnott and Greenwood (1974, 1976) for low- to moderate-energy bar systems off the eastern coast of Canada. The succession of subenvironments these writers found on the seaward side of their bar systems was: small-scale ripples interbedded with parallel laminations followed landward by small- to medium-scale trough crossbedding produced by lunate megaripples interbedded with parallel laminations. In Messinian Age rocks in Spain, Roep and others (1979, p. 146-149) describe similar sedimentary structures from a rock unit they interpret as representing lower shoreface deposits. This unit is characterized by wave-rippled sandstone containing small- to medium-scale trough crossbedding and interbedded parallel-laminated sandstone. Because of the similarities between the sequence at measured section IIA and the shoreface bar deposits described by the above writers, it is postulated that these rocks of Lithosome D represent a shoreface bar system.

According to Elliott (1979, p. 148-152), Swift (1976a, p. 268-271), and Reineck and Singh (1975, p. 304-305), the upper shoreface commonly contains small-scale ripplemarks, crossbedded rip-current channels, and longshore bars, whereas the lower shoreface is characterized by horizontal laminations, rare low-angle crossbedding, and moderate to abundant bioturbation. The presence of similar groupings of sedimentary structures in the rocks of Lithosome D combined with their stratigraphic position imply deposition in a shoreface environment.

Reineck and Singh (1975, p. 340-341) report that the shoreface environment usually contains a sparse macrofauna. They further note that shells and shell debris often are transported from the transition zone to the shoreface. In Monterey Bay, scattered empty or broken shells of the sand dollar *Dendraster excentricus* have been transported from the transition zone to the shoreface zone (Clifton and others, 1971, p. 660). Scattered whole and broken shells of the Vaqueros sand dollar *Kewia fairbanksi* are present in some beds of Lithosome D. The occurrence of *Kewia fairbanksi*, *Anadara* sp., *Turritella inezana*, and *Balanus* sp. in a few beds of Lithosome D suggests that these beds were deposited near the transition zone, which contains an abundant fauna (Reineck and Singh, 1975, p. 308). Ingle (1975, p. 2-4) and Swift (1976a, p. 255) report that the shoreface environment rarely is deeper than 20 m. Many of the megafossil genera that occur in the Vaqueros Formation still are living in modern Pacific Coast environments. The depth ranges of the living genera are shown in Table 6. Because 20 m is within the depth ranges of the fossils present in this lithosome, and because of the stratigraphic position of these beds, it is suggested that the rocks of Lithosome D were deposited in water no deeper than 20 m.

## LITHOSOME E

### Lithology

The composition of Lithosome E is variable, with sandstone constituting 30 to 50 percent of the lithosome, siltstone varying from 30 to 40 percent, and limestone ranging from 10 to 20 percent. Exposures are fair to poor along slopes; however, excellent exposures are present along canyon walls. Although most slopes are covered by brush, some resistant beds may be traced for several kilometers. Rock color on fresh surfaces ranges from very light gray (N8) to moderate olive brown (5Y4/4), whereas weathered surfaces are yellowish gray (5Y8/2) or grayish orange (10YR7/4). The sandstone, siltstone, and limestone of this lithosome are interbedded in composite bedsets

| Genera | Depth Range | Lithosome C | D | E | F |
|---|---|---|---|---|---|
| *Anadara* | Intertidal - 140 m | | X | X | X |
| *Anomia* | 2 - 183 m | X | X | X | X |
| *Balanus* | Intertidal - 311 m | X | X | X | X |
| *Calyptraea* | Intertidal - 150 m | | | X | |
| *Chione* | Intertidal - 70 m | | | X | X |
| *Crassatellites* | Intertidal - 80 m | | | X | |
| *Diplodonta* | Intertidal - 240 m | | | X | |
| *Dosinia* | 2 - 12 m | | | X | |
| *Macoma* | Intertidal - 600 m | | | X | X |
| *Mytilus* | Intertidal | | X | | |
| *Panopea* | Intertidal | | | X | |
| *Pecten* | 10 - 580 m | | X | X | X |
| *Phacoides* | 4 - 849 m | | | X | X |
| *Polinices* | Intertidal - 538 m | | | X | |
| *Saxidomus* | Intertidal - 40 m | | | X | |
| *Spisula* | Intertidal - 31 m | | | X | |
| *Tagelus* | Intertidal - 30 m | | | X | |
| *Tellina* | Intertidal - 150 m | | | X | |
| *Terebra* | Intertidal - 60 m | | | X | |
| *Trachycardium* | Intertidal - 150 m | | X | X | |
| *Turritella* | 4 - 200 m | X | X | X | X |

Table 6. Depth ranges of modern genera present in the Vaqueros Formation (from Keen, 1963; Gosner, 1971; Ricketts and Calvin, 1968; and Yonge and Thompson, 1976)

which average 3 m in thickness. Bedding contacts within the bedsets commonly are sharp with some beds exhibiting wavy bedding contacts. Although sandstone and siltstone beds usually are tabular, limestone beds commonly are lens shaped. Individual bed thickness varies from .2 to 1 m. Stratification in sandstone and siltstone beds is shown by a change in grain size or resistance; in limestone beds stratification is absent. Laminations rarely are present in this lithosome and predominantly occur in the sandstone beds. Sedimentary structures usually are found in sandstone beds and rarely in siltstone beds. The structures consist of rare, small-scale ripplebedding and rare, wave-ripple flasers. Bioturbation is moderate to abundant in most sandstone and siltstone beds and absent in limestone beds.

The sandstone is fine to medium grained and moderately sorted. Individual grains are subangular to subrounded. The average sandstone in this lithosome is an arkose, the composition being similar to other sandstones in this member of the Vaqueros. Fossil content ranges from 0 to 30 percent and consists of whole individuals, slightly broken individuals, or shell debris.

Siltstone in Lithosome E consists of moderately sorted, silt- to sand-sized particles in a clay matrix. Foraminifers and/or shell debris may be present, but never constitute more than 25 percent of the rock.

Limestone beds consist of shell fragments and identifiable whole fossils in a sand or silt matrix. The terrigenous material is moderately to poorly sorted and has subangular to subrounded grains. Shell debris is angular to subrounded and consists of fragments of bivalves, echinoids, gastropods, and barnacles. A few beds primarily are composed of the shells of *Terebra santana* and unidentified pelecypods in a sandy calcitic matrix. Thin section analysis reveals that an average limestone is composed of millimeter-sized fossil fragments in a matrix of very fine-grained sand cemented with spar. Also present are silt intraclasts and micrite intraclasts. There is no fabric.

## Fossils

The megafossils occurring in Lithosome E are listed in Table 7. Microfossils present in this lithosome are shown in Table 8. CSUN and MB fossil localities and their stratigraphic positions are shown on Plates I and II, respectively.

*Anomia vaquerosensis* is the most common megafossil in this lithosome and occurs in sandstone, siltstone, and limestone beds. In some limestone beds, *Anomia* comprises 75 percent of the faunal content. This fossil normally is present in fragments scattered throughout individual beds. Shell fragments are variable in size and shape, although most range in size from 1 cm to 8 cm. Unbroken *Anomia* shells are disarticulated and usually 10 to 12 cm in length. Although whole individuals are present throughout individual beds, they most commonly occur along the upper surface of a bed. *Anomia vaquerosensis* usually is associated with both whole and broken specimens of *Turritella inezana, Pecten sespeensis, Balanus* sp., *Macoma sespeensis,* and *Rapana vaquerosensis.*

*Turritella inezana* most commonly occurs in the sandstone and

| | CSUN 550 | CSUN 553 | CSUN 555 | CSUN 559 | CSUN 560 | CSUN 561 | CSUN 570 | CSUN 572 | CSUN 573 | CSUN 574 | CSUN 575 | CSUN 576 | CSUN 579 | CSUN 581 | CSUN 586 | CSUN 590 | CSUN 591 | CSUN 621 | CSUN 623 | CSUN 624 | CSUN 628 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Echinodermata | | | | | | | | | | | | | | | | | | | | | |
| *Kewia fairbanksi* | | | | | | | | x | x | | | | | | | | x | | | | |
| Gastropoda | | | | | | | | | | | | | | | | | | | | | |
| *Calyptraea* sp. | | | | | | | | | | | | r | | | | | | | | | |
| *Nerita beali* | | | c | | | | | | | | | | | | | | | | | | |
| *Polinices recluzianus* | | | a | | | | | | | | c | | | | | | | | | | |
| *Purpura* sp. | | | | | | r | | | | | | | | | | | | | | | |
| *Rapana vaquerosensis* | c | | r | | r | | r | | | | | | | | | r | r | | | | |
| *Solenosteira merriami* | | | a | | | | | | | | | | | | | | | | | | |
| *Terebra santana* | | | va | | | | | | | a | | | | | va | | | c | x | | |
| *Turritella inezana* | | | r | c | a | | r | x | | | r | c | | | | c | r | | | x | a |
| unidentified gastropod | | | | | | | | | | | | | | | | | | c | c | c | r |
| Bivalvia | | | | | | | | | | | | | | | | | | | | | |
| *Anadara santana* | | | | | c | | | | | | | | | | | | | | | | |
| *Anadara* sp. | | | | | | | | | | | | | | | | c | | | | | |
| *Anomia vaquerosensis* | r | | | | | | a | a | | c | c | a | a | | | c | c | x | c | c | |
| *Cardium woodringi* | | | | | r | | | | | | | | | | | | | | | | |
| *Chione* sp. | | | | | c | | | | | c | | | | | | | | | | | |
| *Clementia pertenuis* | | | c | c | | | | | | | | c | | c | | | c | | | | c |
| *Clementia* sp. | | | | | | | | | | | | | x | | | | | | | | |
| *Crassatellites granti* | | | | | c | | | | | | | | | | | | | | | | |
| *Diplodonta (?)* sp. | c | | | | | | | | | | | | | | | | | | | | |
| *Dosinia* sp. | | | | | | | | | | | | | | | | | | | | | |
| *Macoma arctata* | | | | | c | | | | | | | | | | | c | | | | | |
| *Macoma sespeensis* | c | | | | a | | c | | | | | c | | | | | | | | | |
| *Panope* cf. *P. generosa* | | | | | | | | | | | | | | | | | | | | | c |
| *Pecten andersoni* | | | | | | | | | | | | | | | | c | c | | | c | |
| *Pecten sespeensis* | | r | | | | | | | r | x | | c | | | | | | | a | a | |
| *Pecten* sp. | | | | | | | | c | | | | | | | | x | | | | c | |
| *Phacoides santacrucis* | | | | | c | | | | | | | | | | | | | | | | |
| *Pinna stocktoni* | | | | | | | | | | | | | | | | | | | | | r |
| *Saxidomus vaquerosensis* | a | c | | | | | | | | | | | | c | | | | c | | | |
| *Spisula* aff. *S. hemphilli* | | | | | | | | | | | | | | | | c | | | | | |
| *Tellina* sp. | | | | | | | | | | | | | | | | | | | | | c |
| unidentified bivalve | | | | c | | | | | c | | a | | c | x | | | x | c | c | | |
| Arthropoda | | | | | | | | | | | | | | | | | | | | | |
| *Balanus* sp. | c | | c | | | x | x | x | | c | | c | c | | r | | | c | | | c |
| Vertebrata | | | | | | | | | | | | | | | | | | | | | |
| fish tooth | x | | | | | | | | | | | | r | | | x | r | | | | |
| mammal bones | | | | | | | | | | | | | | | | | r | | | | |

r = rare c = common a = abundant va = very abundant x = identified in the field

Table 7. Megafossils in Lithosome E of the lower member.

| | MB-79-57 | MB-79-66 |
|---|---|---|
| *Ammobaculities strathernensis* | r | r |
| *Globigerina* sp. | r | |
| *Virgulina bramletti* | r | |

r = 2-20 individuals

Table 8. Microfossils in Lithosome E of the lower member.

siltstone beds of Lithosome E. *Turritella* fossils are unsorted and unoriented. Individuals rarely are broken but commonly are abraded indicating a small degree of transport. When present, *Turritella* usually is common to abundant. This gastropod most commonly occurs with *Anomia vaquerosensis*, *Rapana vaquerosensis*, and *Clementia pertenuis*, although in some sandstone beds it is present in monospecific assemblages.

*Terebra santana* usually occurs in series of 30- to 80-cm thick beds of sandstone and/or limestone separated by siltstone beds. This fossil is most abundant in limestone beds located near measured sections I, II, and IIA. Shells usually are whole, unoriented, and show signs of transport. Although usually associated with other species, *Terebra* is very dominant in assemblages occurring in a few limestone beds, comprising up to 90 percent of the fauna. It should be noted that the presence of *Terebra santana* in this lithosome is much more common than Table 7 indicates. When present in an outcrop, this fossil usually is associated with *Anomia vaquerosensis*, *Pecten sespeensis*, and *Balanus* sp. It is less commonly found with *Polinices* *recluzianus, Nerita beali,* and *Solenosteira merriami.*

*Pecten sespeensis* is most abundant in limestone beds, although it does occur in some siltstone beds. Shells generally are broken and fragmented; however, whole individuals are common in several beds and are particularly abundant near measured section IV. *Pecten* usually occurs in limestone beds containing a greater percentage of sand than silt. It is associated with *Turritella inezana, Anomia vaquerosensis,* and *Balanus* sp.

*Clementia pertenuis, Saxidomus vaquerosensis,* and *Macoma sespeensis* commonly co-occur and commonly are found in living positions. These fossils usually occur as whole individuals. Most valves are articulated and retain some of their original ornamentation. These pelecypods most commonly are associated with *Turritella inezana, Balanus* sp., and *Anomia vaquerosensis.*

*Rapana vaquerosensis* most commonly occurs in the siltstone beds of this lithosome. It rarely is present in limestone or sandstone beds. Specimens usually are whole or slightly fragmented; solitary fragments are uncommon. Rarely are more than three individuals present at any one locality. This fossil usually is associated with whole *Turritella inezana* and *Anomia vaquerosensis.* Shell debris composed of broken *Anomia* and unidentified bivalve shells also occurs with *Rapana* individuals.

The remaining megafossils in Table 7 usually are found in association with the more commonly occurring species discussed above. Most occur as whole or slightly broken individuals showing little sign of transport. Unidentified gastropods and bivalves commonly are whole. They lack any definitive ornamentation, however, making species identification impossible. The shell debris that occurs in this lithosome is composed primarily of broken and fragmented *Pecten*, *Anomia*, and unidentified bivalve shells. Fragments of *Balanus* shells also are present.

Calcareous foraminifera present in this lithosome are moderately to poorly preserved. The large majority consist of internal casts of the original that have been replaced by silica. Arenaceous foraminifera rarely are present in this lithosome. Ostracods occur in some beds and also have been replaced by silica.

## Transition Zone Interpretation

The sandstone, siltstone, and limestone beds of Lithosome E represent transition zone deposits as defined by Reineck and Singh (1975, p. 307). The presence of predominantly fine-grained sediments, scarcity of sedimentary structures, abundant fauna, moderate to dense bioturbation, and stratigraphic position between shoreface and offshore deposits taken together suggest deposition in a transition zone environment.

According to Reineck and Singh (1975, p. 307-308), transition zone sediments primarily are composed of sandy silt and silty sand with interbedded layers of sand and shells. The small grain size, the occurrence of rare laminations and wave-ripple flasers, and the presence of moderate to dense bioturbation indicate deposition below wave base (Clifton and others, 1971, p. 660; Kumar and Sanders, 1976, p. 149). The rocks of Lithosome E contain all these criteria.

Similar grain sizes and sedimentary structures have been described in rocks of the Turre Formation in southeastern Spain by Roep and others (1979, p. 143-145) and in the modern day Gulf of Gaeta by Reineck and Singh (1975, p. 311-313). These writers have identified these sequences as representing a transition zone environment. The similarity of the rocks of Lithosome E to these sequences implies a similar environment of deposition.

The limestone beds in Lithosome E which predominantly contain whole shells of *Anomia, Pecten, Turritella, Terebra* and/or other species represent shoal deposits. The concentration of shells in these beds may have resulted from short-term environmental changes. The occurrence of relatively whole shells in this lithosome as well as the presence of micrite intraclasts and the dominance of spar over microcrystalline calcite implies deposition in a relatively moderate to high energy environment. Similar Vaqueros shoal deposits have been described by Fritsche and Eastes (1979, p. 33-34) and by Stanley (1973).

The limestone beds predominantly composed of shell debris are interpreted as storm-lag deposits similar to those described by Brenner and Davies (1973, p. 1690-1692) in Upper Jurassic rocks in Wyoming and Montana. According to these writers, these deposits are caused by sudden short-term changes from low- to high-energy conditions that may occur during a storm. Such conditions result in the transportation, fragmentation, and reorganization of shells and shell debris with disturbed bottom sediments. Similar lag deposits have been described in modern environments by Kumar and Sanders (1976) and Powers and Kinsman (1953, p. 229-234). The similarity of the coquina beds in lower Vaqueros rocks to those deposits described by the above writers implies a similar environment of deposition. These coquina beds in Lithosome E are interpreted as storm-lag deposits which were deposited in a transition zone environment because: (1) these beds usually are bounded by fossiliferous sandy siltstone or fine sandstone beds, (2) the relatively fine grain size of the matrix material implies deposition in a low-energy environment, and (3) these beds lack the three-part sequence described by Kumar and Sanders (1976, p. 145-149) as being characteristic of shoreface storm-lag deposits. However, it should be noted that those coquina beds with a sandy matrix and which overlie or are subjacent to rocks of Lithosome D may have been deposited in or near shoreface environment.

According to Reineck and Singh (1975, p. 308), the transition zone is characterized by a maximum diversity of species and high faunal densities. The presence of Lithosome E of many beds containing numerous relatively unbroken fossils suggests minimal post-mortem transport of these shells. Although living genera of many of the fossils in this lithosome may exist in an intertidal environment, the presence of *Pecten* indicates water depths greater than 10 m (Table 6). Depth ranges for some Vaqueros microfossils are listed in Table 9. The occurrence of *Ammobaculites* sp. in Lithosome E deposits suggests water depths ranging from intertidal to 20 m (Table 9). Because Reineck and Singh (1975, p. 308) report that the lower limit of the transition zone rarely exceeds 30 m, it is postulated that lower Vaqueros transition zone sediments were deposited in water

| Genera | Depth Range | Lithosome E | F | G |
|---|---|---|---|---|
| *Ammobaculites* | Intertidal - 20 m | X | X | X |
| *Bolivina advena* | 150 - 500 m | | | X |
| *Buliminella curta* | 50 - 180 m | | | X |
| *Globobulimina pacifica* | 150 - 500 m | | | X |
| *Globobulimina pyrula* | 150 - 500 m | | | X |
| *Nonion incisum* | Intertidal - 50 m | | X | |
| *Nonionella miocenica* | Intertidal - 60 m | | X | |
| *Quinqueloculina* | Intertidal - 60 m | | X | |
| *Trochammina* | Intertidal - 60 m | | X | |

Table 9. Depth ranges of microfossils present in the Vaqueros Formation (from Arnal and Vedder, 1976, and Ingle, 1972).

ranging from 10 to 30 m in depth.

LITHOSOME F

## Lithology

Lithosome F is composed of approximately 80 to 90 percent siltstone and 10 to 20 percent fine-grained sandstone. Exposures are poor except for those outcrops located along steep canyon walls. Rock color on fresh exposures is olive green (5GY3/2), grayish yellow green (5GY7/2), or light greenish gray (5GY8/1). Weathered surfaces are pale greenish yellow (10Y8/2) and grayish yellow green (5GY7/2). The siltstone and fine sandstone that comprise this lithosome are interbedded in composite bedsets ranging from .4 to 10 m in thickness. Individual beds of siltstone range from .3 to 7 m in thickness; beds of sandstone rarely are thicker than .5 m. Bedding contacts within bedsets usually are sharp and are planar or wavy.

Rare, thin laminations are present in some sandstone interbeds. Sedimentary structures generally are absent in this lithosome, except for rare, small-scale crossbedding in a few sandstone beds. The amount of bioturbation varies from moderate to abundant.

The siltstone is similar in composition to the siltstone in Lithosome E. However, the siltstone of Lithosome F is well sorted and rarely contains shell debris. Foraminifers may be present, but never comprise more than 25 percent of the rock.

The sandstone is fine to very fine grained and is poorly sorted. The texture is heterogeneous with minor local concentrations of coarser and finer sand. Most individual grains are subangular to subrounded. Composition is summarized in Table 3. The sandstone contains rare whole fossils and common local concentrations of shell debris.

## Fossils

The megafossils in Lithosome F were identified in the field. Microfossils present in this lithosome are listed in Table 10, the MB localities are shown on Plate I, and the stratigraphic position of the fossil localities is shown on Plate II.

Megafossils rarely are present in this lithosome. Recognizable whole fossils include *Anomia* sp., *Chione* sp., *Pecten* sp., and *Turritella inezana*. Whole paired unidentified bivalves are also present in some beds. These fossils rarely occur together and always are poorly preserved. Fossil debris is more common than whole fossils, but is found almost exclusively in the sandstone interbeds. The

| | MB-79-58 | MB-79-67 | MB-79-75 |
|---|---|---|---|
| *Ammobaculites strathernensis* | r | r | |
| *Cyclammina* cf. *C. incisa* | r | | |
| *Nonionella miocenica* | | | r |
| *Virgulina bramletti* | r | | |

r = 2-20 individuals

Table 10. Microfossils in Lithosome F of the lower member.

debris is composed of small (less than 6 cm) shell fragments of *Anomia, Turritella, Balanus,* and unidentified shells.

Calcareous foraminifera are present in some beds. They consist of moderately to poorly preserved internal casts that have been replaced by silica. A few foraminiferal tests are filled with hematite. Arenaceous foraminifera rarely occur in this lithosome. Ostracods are present in some beds and also are replaced by silica.

## Shallow Offshore Shelf Interpretation

The siltstone and fine sandstone of Lithosome F are interpreted as deposits which formed in a shallow shelf as defined by Johnson (1979, p. 207). The rocks in this lithosome are composed of sediments similar in grain size and texture to those described in modern off-shore (shelf) deposits (Swift, 1976b, p. 311-345; Reineck and Singh, 1975, p. 308-310; Shepard, 1973, p. 222-225). Although not diagnostic of offshore deposits by themselves, the sedimentary structures in Lithosome F also have been reported as occurring in modern offshore deposits (Ingle, 1975, p. 204; Reineck and Singh, 1975, p. 341, 345;

Curray, 1960, p. 249-250). Similar grain sizes, sedimentary structures, and stratigraphic sequences have been reported in ancient sediments which have been interpreted as offshore deposits by Roep and others (1979, p. 143-145) and Brenner and Davies (1973, p. 1686-1689).

The fine sandstone interbeds present in Lithosome F are interpreted as storm-sand layers (Hayes, 1967, p. 937-938; Powers and Kinsman, 1953; Reineck and Singh, 1975, p. 308). These deposits are similar to the swell-lag deposits of Brenner and Davies (1973, p. 736-747). According to these writers, storm-sand layers are composed of fine sand, whole shells, and shell debris which were deposited as the result of high-amplitude marine swells transporting and depositing material along the substrate. The sedimentary structures in these deposits include graded bedding, thin laminations, and ripplemarks, all of which have been discussed in detail by Campbell (1966, p. 825-828) and Goldring and Bridges (1973, p. 736-747).

Megafossils in Lithosome F suggest deposition in water not shallower than 10 m (Table 6). The occurrence of the foraminifera *Nonionella miocenica* indicates a water depth ranging from intertidal to 60 m (Table 9). Based on the above information and because the lower limit of the transition zone is 30 m, it is suggested that the beds of Lithosome F were deposited in water ranging from 30 to 60 m in depth.

## SUMMARY

At the end of Sespe Formation deposition, a broad, relatively flat floodplain existed in the Big Mountain area. The major Vaqueros transgression that covered these deposits began with a number of minor transgressions and regressions. These fluctuations in sea level resulted in the deposition of a series of beach and salt marsh deposits along a protected coastline similar to present-day Monterey Bay. As the transgression continued, the uppermost low- to moderate-energy, sandy beach deposit was covered by the sand and silt of the shoreface and transition zone environments. Although minor fluctuations in sea level continued, conditions were stable enough to allow the existence of a wide variety of invertebrates. These environments existed along the southern Ventura Bay of Loel and Corey (1932, opp. p. 50). These writers report (p. 164-165) that during deposition of the Vaqueros, tropical to subtropical temperatures and relatively normal marine salinity existed in the bay. Storms over the bay may have been responsible for the accumulations of shells and shell debris in lag deposits. As the water deepened, a shallow-water shelf environment formed.

## MIDDLE MEMBER

### INTRODUCTION

Three lithosomes are present in the middle member; two are a repetition of lithosomes in the lower member, whereas one is new. In generally ascending order, Lithosome F is composed of siltstone with minor interbeds of fine to medium sandstone, Lithosome G is composed of siltstone and minor amounts of mudstone, and Lithosome E is composed of interbedded siltstone and fine to medium sandstone

(Fig. 5). The member is present in all measured sections, but thins to the east due to a basal facies change from siltstone to sandstone in an easterly direction. The zero edge of this thinning trend is not visible due to truncation by the overlying Calabasas Formation. Although stratigraphic evidence suggests that the member increases in thickness to the west, no surface measurements are obtainable due to overlapping by the Saugus Formation, which has covered the lower and middle members. This member forms nonresistant grass- and brush-covered slopes throughout most of the study area. Exposures generally are poor except along steep cliff faces and a few road cuts where fair to good outcrops may be observed.

The contact between the lower and middle members was discussed previously. The contact with the upper member occurs at the top of the stratigraphically highest siltstone bed which occurs below a massive, fine to medium sandstone bed. This contact is easily recognizable due to an abrupt change in texture of the rocks and an increase in the slope.

Distinctive characteristics of this member include its brownish-gray color, relatively uniform texture, and poor relief. Bedding composition is difficult to determine but seems to be somewhat uniform. Lithosome F occurs across the entire study area and is present in the lower and upper thirds of the member (Fig. 5). The distribution of Lithosome G is limited to the western half of the study area where it is present in the middle third of the member, bounded by rocks of Lithosome F. Lithosome E is found across the entire study area. Rocks of this lithosome are present in the upper

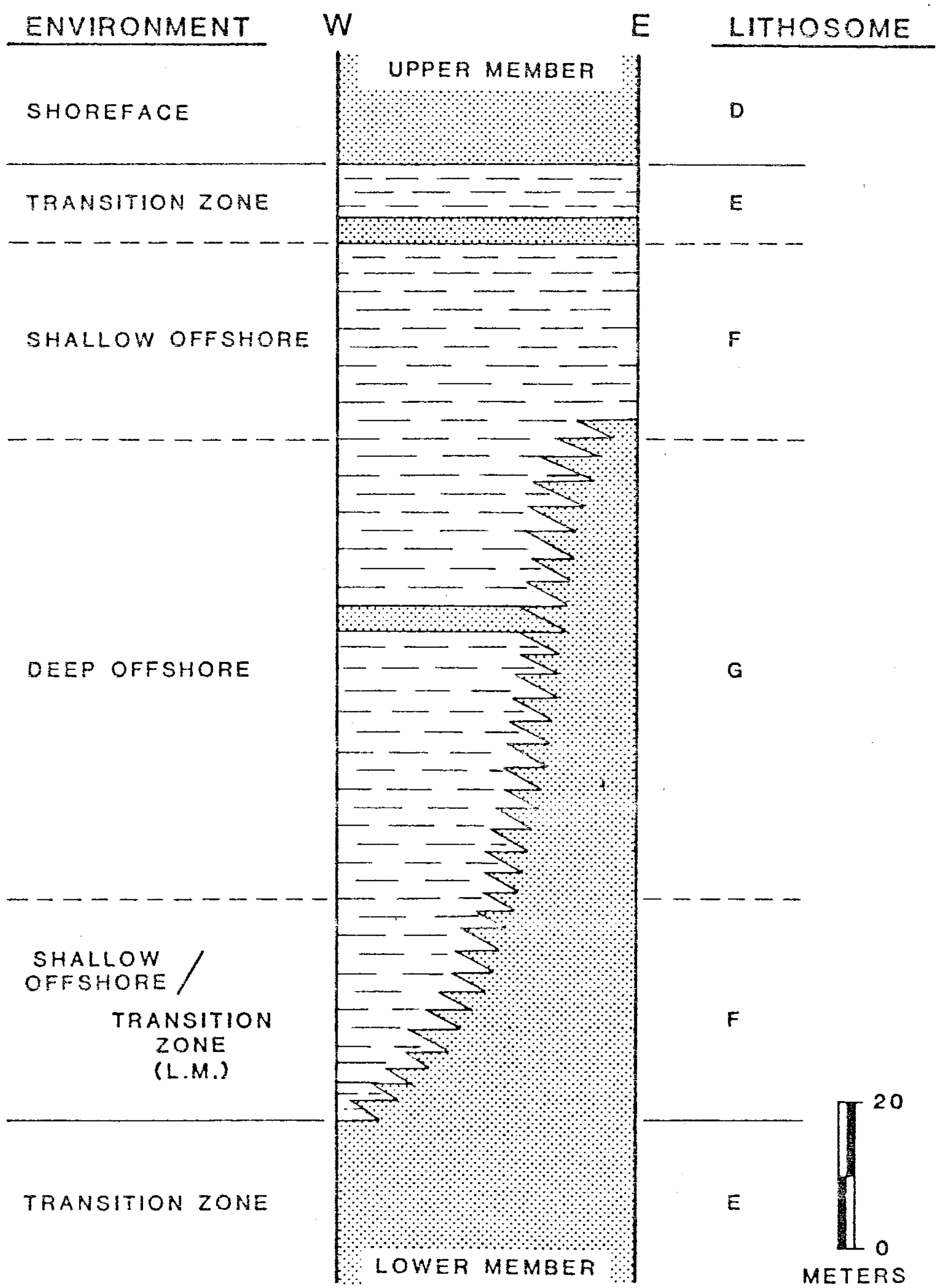


Figure 5. Generalized lithology and sedimentary environments of the middle member.

fifth of the middle member, where it is interbedded with rocks of Lithosome F. The upper portions of Lithosome E are on the contact between the middle and upper members of the Vaqueros.

LITHOSOME F

### Lithology

Lithosome F in the middle member is lithologically similar to Lithosome F in the lower member.

### Fossils

The megafossils in Lithosome F are listed in Table 11 and the microfossils in Table 12. CSUN and MB fossil localities and their stratigraphic position are shown on Plates I and II, respectively.

*Anadara santana* is a relatively common megafossil in this lithosome, although specimens were collected from only one location. This fossil usually is found as whole individuals and specimens exhibit excellent preservation. *Anadara* is found almost exclusively in the siltstone of this lithosome and normally is associated with *Macoma* sp., *Turritella inezana*, and unidentified bivalves.

*Anomia vaquerosensis* is found in the sandstone interbeds of Lithosome F. This fossil is present as broken shell debris or rarely as whole individuals. Shell fragments are variable in size and shape; most range in size from 1 to 6 cm. Whole shells are disarticulated and average approximately 10 cm in length. These individuals most commonly occur at the top of a sandstone bed. *Anomia* is found either in monospecific assemblages or associated with unidentified fossils.

| | CSUN 606 | CSUN 608 | CSUN 609 | CSUN 610 | CSUN 629 | CSUN 630 |
|---|---|---|---|---|---|---|
| Gastropoda | | | | | | |
| *Conus* sp. | x | | | | | |
| *Turritella inezana* | | | | | | r |
| unidentified gastropod | | | r | | | |
| Bivalvia | | | | | | |
| *Anadara santana* | | c | | | | |
| *Anomia vaquerosensis* | | | | c | | |
| *Chione* sp. | | | r | | | |
| *Macoma sespeensis* | | | c | | | |
| *Macoma* sp. | | r | | | | r |
| *Phacoides santacrucis* | | x | | | x | |
| unidentified bivalve | r | c | x | r | r | |
| Vertebrate | | | | | | |
| fish tooth | r | r | | | | |

r = rare c = common a = abundant x = identified in field

Table 11. Megafossils in Lithosome F of the middle member.

*Macoma sespensis* and *Chione* sp. also are present in the sandstone interbeds of this lithosome. These fossils normally are articulated. However, they are poorly preserved and exhibit no preferred orientation suggesting some degree of post-mortem transport. *Macoma* and *Chione* occur with each other as well as with unidentified bivalves and gastropods.

The remaining megafossils most commonly are associated with the species discussed above. Most occur as relatively whole individuals and exhibit varying degrees of preservation. The unidentified gastropods and bivalves are found in the sandstone beds and are badly

| | MB-79-34 | MB-79-37 | MB-79-38 | MB-79-44 | MB-79-52 | MB-79-53 | MB-79-79 | MB-79-84 | MB-79-85 | MB-79-86 | MB-79-90 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| *Ammobaculites strathernensis* | c | r | | r | r | | r | | c | r | r |
| *Globigerina praebulloides* | | | | | | | | | r | r | |
| *Globigerina* sp. | | | | | | | | | | p | |
| Misc. arenaceous foraminifera | | | | | | | | | r | | |
| *Nonion costiferum* | c | | | r | r | | r | | | | r |
| *Nonion incisum* | | | | | r | | | | | | r |
| *Nonionella* cf. *N. miocenica* | | | | | c | | | r | | | c |
| *Nonionella miocenica* | | | | | r | | | | p | p | r |
| *Quinqueloculina* spp. | | | | | r | | p | | | | r |
| *Spiroplectamina coreyi* | | | | | | | | | r | | |
| *Spiroplectamina kewi* | | | | | | | | | r | | |
| *Textularia inflata* | p | | | | | | | | p | | |
| *Textularia shivelyi* | | | | | | | | | r | | |
| *Trochammina parva* | r | | | | | | | | p | | |
| *Trochammina pilea* | | | | r | | | | | | | |
| *Virgulina bramletti* | | | p | | r | r | | | | | r |

p = 1 individual    r = 2-20 individuals    c = 21-40 individuals

Table 12. Microfossils in Lithosome F of the middle member.

badly abraded which makes species identification impossible.

The microfossils listed in Table 12 predominantly are calcareous; however, arenaceous foraminifera are common to abundant in a few beds. Most of the calcareous species have been replaced by silica and consist of an internal cast of the original. A few have been replaced by pyrite. Ostracods are present in numerous beds and have undergone similar replacement.

### Shallow Offshore Shelf Interpretation

The physical and biogenic characteristics of offshore deposits were discussed for rocks of Lithosome F in the lower member. The microfossils in Lithosome F indicate that water depth was relatively shallow during deposition of this lithosome. The presence of various shallow water foraminifera, including *Nonion incisum, Nonionella miocenica, Trochammina* sp., *Ammobaculites* sp., and *Quinqueloculina* sp., and the lack of deeper water species suggests deposition in water no deeper than 60 m (Table 9). This lower depth limit also is within the depth ranges of the relatively whole megafossils found in this lithosome (Table 6). Because the lower limit of the transition zone is 30 m, it is suggested that the siltstone and sandstone beds of Lithosome F were deposited in waters ranging from 30 to 60 m in depth.

## LITHOSOME G

### Lithology

Lithosome G is lithologically similar to Lithosome F except in the fossil content and a general decrease in grain size to approximately 90 percent siltstone, 5 percent mudstone, and 5 percent sandstone.

## Fossils

Megafossils are rare in rocks of Lithosome G. The megafossils observed are unidentifiable except for one *Turritella inezana* and one *Anomia vaquerosensis*. Both of these specimens are broken and abraded suggesting post-mortem transport. Because most of the fossils are unidentifiable, no specimens were collected.

Microfossils are common in this lithosome and are listed in Table 13. MB fossil collecting localities and their stratigraphic position are shown on Plates I and II, respectively. Like the microfossils present in Lithosome F, those in Lithosome G predominantly are calcareous although common arenaceous foraminifera occur in some beds. Most of the foraminifera have been replaced by silica and a few by pyrite. Ostracods are present in a few beds and also have been replaced by silica.

## Deep Offshore Shelf Interpretation

The siltstone and mudstone beds of Lithosome G are interpreted as deep offshore shelf deposits similar to those described by Johnson (1979, p. 221-229) and Reineck and Singh (1975, p. 306-310). This interpretation primarily is based on the microfossils present in this lithosome as well as the lithology and stratigraphic position of the rocks.

The physical and biogenic characteristics of the sediment of Lithosome G correspond to those described from modern shelf environments by Kulm and others (1975, p. 145-176) and Curray (1960, p. 221-

| | MB-79-35 | MB-79-36 | MB-79-45 | MB-79-51 | MB-79-54 | MB-79-87 |
|---|---|---|---|---|---|---|
| *Ammobaculites strathernensis* | r | r | r | | | |
| *Bolivina advena* | | | | | | r |
| *Buliminella curta* | r | | p | | | r |
| *Globigerina praebulloides* | r | r | p | | | |
| *Globigerina* spp. | r | r | | | | va |
| *Globobulimina pacifica* | r | | | r | p | c |
| *Globobulimina pyrula* | | | | | | r |
| *Haplophragmoides* spp. | | | | | | r |
| Misc. arenaceous foraminifera | r | r | | | | |
| *Nonion costiferum* | | c | | | | |
| *Nonionella* cf. *N. miocenica* | r | p | p | | | c |
| *Nonionella miocenica* | r | r | | | | va |
| *Quinqueloculina* spp. | | | | | | r |
| *Siphogenerina* sp. | | p | | | | |
| *Trochammina parva* | r | r | | | | |
| *Trochammina pilea* | r | r | r | | | |
| *Virgulina bramletti* | r | c | | | | c |

p = 1 individual  r = 2-20 individuals  c = 21-40 individuals
a = 41-60 individuals  va = 61-100 individuals

Table 13. Microfossils in Lithosome G.

266). The fine grain size of the sediment indicates deposition by weak currents and the moderate to dense bioturbation suggests a low sedimentation rate. The foraminifera in Lithosome G, including *Globobulimina pacifica, Bolivina advena, Globobulimina pyrula,* and *Buliminella curta,* suggest that during deposition of these sediments, water depth was no shallower than 150 m (Table 9), a depth deeper than for Lithosome F. This evidence combined with the stratigraphic position of Lithosome G above shallow offshore shelf deposits suggests deposition in a deep offshore shelf environment.

## LITHOSOME E

### Lithology

Lithosome E is composed of 30 to 40 percent sandstone and 60 to 70 percent siltstone. This lithosome differs from Lithosome E in the lower member in that it lacks limestone beds. Color varies from olive green (5GY3/2) to medium light gray (N6) on fresh surfaces and from moderate brown (5YR3/4) to grayish yellow green (5GY7/2) on weathered surfaces. The sandstone and siltstone of this lithosome are interbedded in composite bedsets which average 4 m in thickness. Bedding contacts within bedsets generally are sharp. Individual bed thickness averages between .3 and 1 m. Stratification is shown by a change in grain size. Laminations rarely are present. No sedimentary structures were observed. Moderate to dense bioturbation is present in most beds.

The composition of the siltstone and sandstone in Lithosome E is similar to the siltstone and sandstone of Lithosome F in the lower member.

## Fossils

Megafossils from Lithosome E are listed in Table 14, the location of CSUN fossil localities is shown on Plate I, and the stratigraphic position of the fossil localities is shown on Plate II. No microfossils were found in the samples collected from this lithosome.

*Anadara divincta* and *Anadara santana* locally are common in this lithosome. Specimens exhibit excellent preservation and commonly occur together. These fossils usually are associated with unidentified bivalves and gastropods as well as *Phacoides santacrucis* and *Macoma* sp.

*Macoma* sp. and *Phacoides santacrucis* also are common in this lithosome. Individuals show fair to good preservation. *Macoma* occurs as articulated individuals that in some beds are found perpendicular to the bedding planes suggesting *in situ* burial. Both *Macoma* and *Phacoides* commonly are associated with unidentified bivalves and gastropods and the other species discussed in this section.

*Turritella inezana* generally are well preserved in Lithosome E. Individuals usually are whole, exhibit moderately well preserved ornamentation, and range from 2.5 to 7 cm in length. Specimens show no preferred orientation. Near the top of the middle member at measured section II are two zones of abundant individuals which are traceable to section III. *Turritella* usually are not associated with other fossils.

| | CSUN 593 | CSUN 594 | CSUN 595 |
|---|---|---|---|
| Gastropoda | | | |
| *Turritella inezana* | a | | |
| unidentified gastropod | | | x |
| Bivalvia | | | |
| *Anadara divincta* | | | c |
| *Anadara santana* | | c | |
| *Macoma* sp. | | | c |
| *Phacoides santacrucis* | | c | r |
| unidentified bivalve | | a | |

r = rare c = common a = abundant

x = identified in the field

Table 14. Megafossils in Lithosome E of the middle member.

## Transition Zone Interpretation

The characteristics of this environment were discussed in the section describing the transition zone sediments of the lower member. The poorly sorted, predominantly fine-grained sediments of Lithosome E indicate deposition by weak, nonwinnowing currents. The occurrence of moderate to dense bioturbation implies deposition below wave base and a slow sedimentation rate.

The presence of relatively numerous unbroken fossils in Lithosome E suggests minimal post-mortem transport of these specimens. Many of the living genera of these fossils exist in an intertidal environment, however the presence of *Turritella* and *Phacoides* suggests water depths greater than 4 m (Table 6). Because the lower depth limit of the transition zone, approximately 30 m, is within the depth ranges of the genera found in this lithosome, it is postulated that deposition occurred in water ranging in depth from 4 to 30 m.

## SUMMARY

As the sea further transgressed the low-lying coastal plain of the lower member, a shallow shelf environment formed in the Big Mountain area. Bottom sediment distribution is finer to the west suggesting that the deepest portion of the bay also was to the west. Foraminifera collected from the lower portion of the member indicate that the bay was no deeper than 60 m. Storms over the bay may have been responsible for thin, fossiliferous sandstone interbeds which have been interpreted as lag deposits. As basin subsidence continued and water deepened, a deeper shelf environment developed. The microfossils present in these deposits indicate that deposition occurred in water between 50 m and 500 m in depth. Following deposition of the deeper shelf deposits, a regression began. The deep water fauna was displaced by a shallow water fauna which indicates that water depth was again less than 60 m. As shoaling continued, a greater influx of sand occurred eventually resulting in the formation of a transition zone environment.

# UPPER MEMBER

## INTRODUCTION

Three lithosomes previously described in the lower member are recognized also in the upper member: Lithosome D, composed of fine to coarse sandstone; Lithosome E, composed of interbedded sandstone, siltstone, and limestone; and Lithosome F, composed of siltstone with fine sandstone interbeds. Lithosome D is present throughout the member and is found wherever rocks of the upper member crop out (Fig. 6). The sandstone of this lithosome which constitutes 47 percent of the member, most commonly is interbedded with rocks of Lithosome E. Lithosome E also is present throughout the member although it most commonly occurs in the lower two-thirds of the member. Rocks of this lithosome comprise 36 percent of the upper member and are interbedded with both Lithosome D and Lithosome F. Lithosome F is present throughout the member, constitutes about 17 percent of the member, and usually is interbedded with Lithosome E.

The upper member is tabular to broadly wedge shaped. The member is overlapped in the west by rocks of the Saugus Formation and is absent in the east due to erosion and subsequent truncation by rocks of the Calabasas Formation. The unit has a maximum thickness of 136 m at section IV. Exposures generally are good and are best observed along steep slopes, canyon walls, and road cuts.

The contact between the middle and upper members was discussed previously. The upper contact is placed either between the upper member and the easily identified basalts of the unconformably overlying Conejo Volcanics or, where the Conejo Volcanics are absent, at the boundary between the upper member and a basal conglomerate in the unconformably overlying Calabasas Formation.

## LITHOSOME D

### Lithology

Lithosome D is composed of approximately 70 percent unfossili-

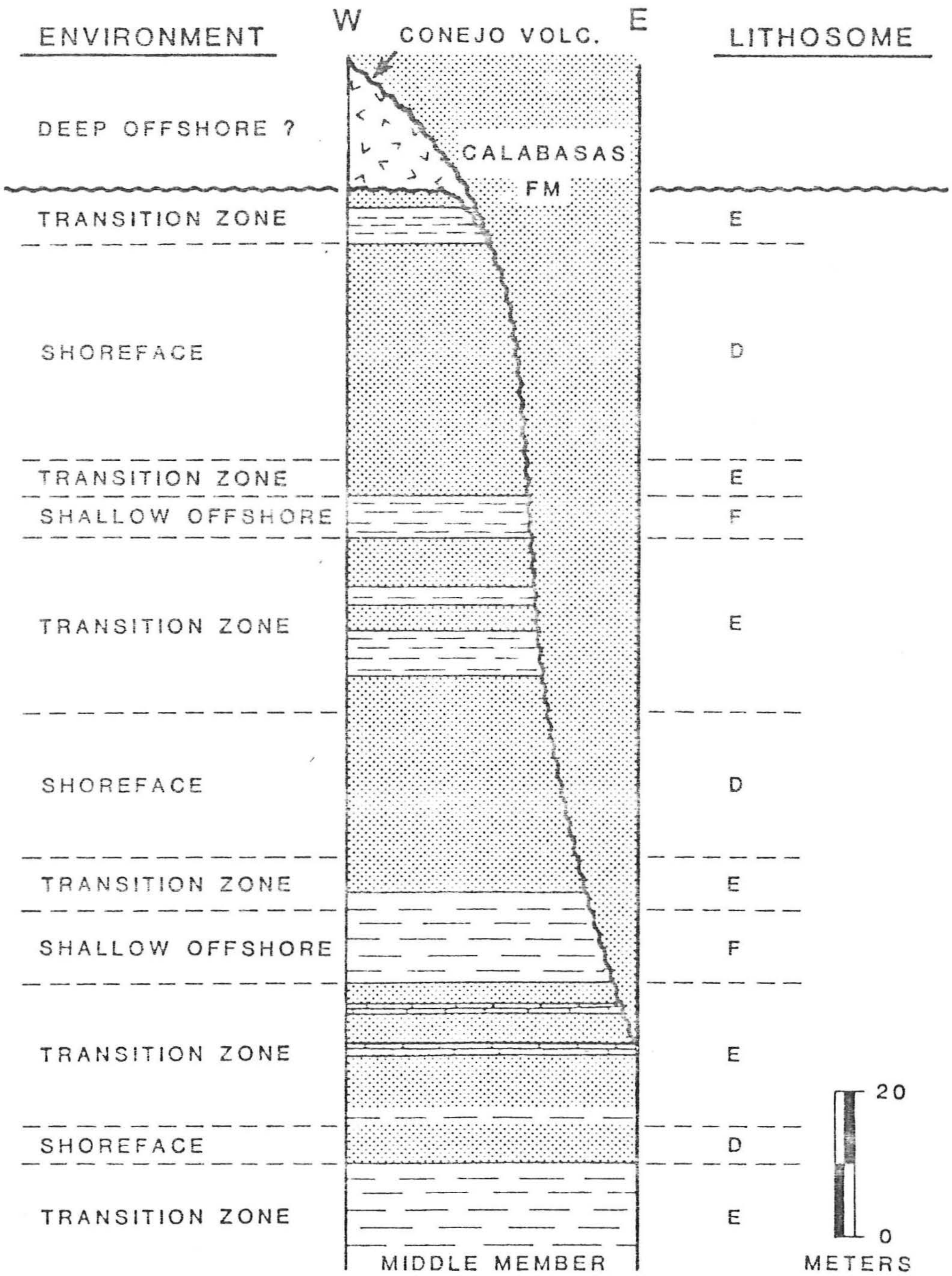


Figure 6. Generalized lithology and sedimentary environments of the upper member.

ferous fine to medium sandstone, 20 percent fossiliferous fine to medium sandstone, and 10 percent fossiliferous medium to coarse sandstone. Except for the differences discussed below, this lithosome is lithologically similar to Lithosome D in the lower member.

Rare pebble- to cobble-sized clasts are present at the bases of two intervals near the top of the member. The clasts are surrounded by a matrix composed of medium to coarse sand and rare shell debris. Superjacent to this unit is a fine sandstone bed containing rare laminations and small scale ripplebedding. This unit is sparsely to moderately bioturbated. The fine sandstone is overlain by a medium to coarse sandstone unit that contains moderate to dense bioturbation.

Near the top of the member at measured section II is an interval containing faint, small-scale ripplebedding with siltstone drapes over the crests of the ripples. This 15-cm interval is composed of fine sandstone which is superjacent to fine-grained, laminated sandstone and subjacent to medium-grained, crossbedded sandstone. All three units are sparsely to moderately bioturbated.

All of the sandstone in Lithosome D is poorly to moderately sorted with predominantly subangular individual grains. Composition is summarized in Table 15. Volcanic glass shards are abundant in some rocks of this lithosome. Rare, pebble- to cobble-sized clasts, which are discussed in more detail in the section on provenance, are present near the top of the member. Lithic fragments are volcanic (60%), quartzitic (20%), and granitic (20%). Thin section examination suggests that some rocks in Lithosome D in the upper member are moderately compacted with pore space being filled with calcareous

| | MB157 (Lithosome D) | MB158 (Lithosome E) | MB159 (Lithosome E) |
|---|---|---|---|
| Percent terr. framework | 65 | 71 | 55 |
| Percent matrix | -- | 29 | 45 |
| Percent cement | 35 | -- | -- |
| Framework elements: | | | |
| quartz | 32 | 24 | 44 |
| orthoclase | 21 | 14 | 8 |
| plagioclase | 30 | 21 | 21 |
| biotite | 2 | 28 | 20 |
| muscovite | -- | 4 | -- |
| chlorite | -- | 1 | -- |
| heavy minerals* | -- | 2 | -- |
| rock fragments | 15 | 6 | 7 |

*zircon, amphibole, epidote

Table 15. Composition of upper member thin sections.

cement.

## Fossils

Fossil content ranges from 0 to approximately 10 percent in some rocks (Table 16). CSUN localities are shown on Plate I and the stratigraphic position of these localities is shown on Plate II.

*Crassostrea vaquerosensis* is the most common fossil in this lithosome. Individuals generally are broken and abraded although a few whole specimens were observed. *Crassostrea* is found in the lower half of the member and usually is associated with *Turritella* sp., *Balanus* sp., and shell debris of other bivalves.

*Mytilus expansus* is present only in a few beds. More than one individual rarely is found at any one locality. Individuals are whole, articulated, and exhibit little abrasion suggesting minimal post-mortem transport. These fossils frequently are associated with *Trachycardium vaquerosensis*, *Balanus* sp., and unidentified gastropods and bivalves.

The other fossils in Lithosome D generally occur in the lower two-thirds of the member as broken and fragmented individuals. These specimens are poorly preserved and commonly are found together as shell debris. *Turritella* sp. and *Balanus* sp. rarely occur as whole individuals.

## Shoreface Interpretation

The physical and biogenic characteristics of the shoreface environment were discussed in the interpretation of Lithosome D in the lower member.

| | CSUN-563 | CSUN-602 | CSUN-604 | CSUN-605 | CSUN-619 | CSUN-633 | CSUN-634 |
|---|---|---|---|---|---|---|---|
| Echinodermata | | | | | | | |
| *Kewia* sp. | r | | | | | x | |
| Gastropoda | | | | | | | |
| *Solenosteira merriami* | | r | | | | | |
| *Turritella* sp. | | | | | c | | |
| unidentified gastropod | | r | | | | | x |
| Bivalvia | | | | | | | |
| *Crassostrea vaquerosensis* | c | c | c | | x | c | |
| *Mytilus expansus* | | | | r | | | x |
| *Trachycardium vaquerosensis* | | | | r | | | r |
| unidentified bivalve | r | c | r | | | r | r |
| Arthropoda | | | | | | | |
| *Balanus* sp. | r | c | | | r | r | x |
| Vertebrata | | | | | | | |
| mammal bones | r | | | | r | | |

r = rare c = common x = identified in the field

Table 16. Megafossils in Lithosome D of the upper member.

Those beds in this member that contain pebble and cobble clasts are interpreted as storm-lag deposits similar to those described by Powers and Kinsman (1953, p. 229-234) and Kumar and Sanders (1976, p. 145-162). According to these writers, a basal lag, composed of pebbles, cobbles and shell debris, and an overlying finely laminated sand are deposited as a storm wanes. During periods of fair weather a coarser sand, which may contain wave-ripple laminae or which later may become burrow mottled, is deposited over the finely laminated sand. The similarity of the pebbly sandstone beds in Lithosome D to those described by the above writers suggests a similar mode of origin.

The 15-cm interval in this member near the top of measured section II which contains small-scale ripplebedding with siltstone drapes represents the transition between Vaqueros shoreface and transition zone deposits. A similar sequence is described by Roep and others (1979, p. 145) in Messinian Age rocks in Spain. In their paper, these writers describe a transitional interval between shelf muds and shoreface sand which is characterized by the frequent presence of wave-rippled sand flasers with clay drapes. These fine-grained sand flasers are interbedded with laminated silty shelf deposits and crossbedded sandy shoreface deposits. Because of the similarities with the rocks discussed above it is suggested that the interval described in Lithosome D formed as a transitional deposit between upper member shoreface and transition zone sediments.

As in the lower member, the water probably was no deeper than 20 m. There are a few minor differences in the fossil content of this lithosome between the lower and upper members, but the reasons for this are not clear at this time.

## LITHOSOME E

### Lithology

The composition of Lithosome E is variable with sandstone constituting 50 to 60 percent of the lithosome, siltstone ranging from 39 to 48 percent, and limestone varying between 1 and 2 percent. Lithosome E in this member is lithologically similar to Lithosome E in the lower member except for the differences discussed below.

The sandstone in this lithosome is very fine to fine grained and moderately to poorly sorted. Individual grains are subangular to subrounded. Composition is summarized in Table 15. Analysis of two thin sections suggests that the sandstone in Lithosome E contains an appreciable amount of matrix material composed of altered feldspars and volcanic glass shards. Biotite and volcanic glass shards are common in most of the sandstones. Lithic fragments are volcanic (60%) and metamorphic (40%). Siltstone intraclasts rarely are present. Fossil content ranges from 5 to 30 percent.

Limestone beds in Lithosome D in the upper member are composed almost entirely of whole shells and shell fragments of *Crassostrea vaquerosensis* in a sand or silt matrix. The terrigenous material is poorly sorted and consists of subangular to subrounded grains, whereas the shell debris predominantly is subrounded. Stratification in the limestone beds is shown by layering of the *Crassostrea* shells.

## Fossils

Microfossils in Lithosome E are listed in Table 17; megafossils are shown in Table 18. CSUN and MB fossil localities and their stratigraphic positions are shown on Plates I and II, respectively.

*Anadara santana* and *A. santaclarana* are common to abundant throughout the study area in the lower half of the member. Both species usually occur as articulated, whole individuals that still exhibit much of their original ornamentation, which suggests *in situ* burial. These fossils most commonly occur with *Macoma* sp., *Dosinia* sp., *Phacoides santacrucis*, *Pecten* sp., and *Turritella* sp.

*Trachycardium vaquerosensis* is common in a few beds in the lower two-thirds of the member. Specimens always are whole and articulated and frequently are found in near vertical positions. Individuals usually are associated with whole specimens of *Pecten* sp., *Crassostrea vaquerosensis*, *Panopea* cf. *P. generosa*, and *Terebra santana*.

*Turritella* sp. occurs throughout the member in all portions of the study area. Individuals predominantly are whole, but frequently are abraded. Fossils of this species are unoriented and unsorted. *Turritella* frequently is found with *Anadara* spp., *Tagelus clarki*, and *Chione* sp. However, in a few beds they occur in monospecific assemblages.

*Lyropecten magnolia* occurs as articulated or disarticulated complete shells. This pelecypod is present in the upper two-thirds of the member and is found throughout the study area. More than one individual rarely occurs at any one locality. Specimens are found

| | MB-79-101 | MB-79-102 |
|---|---|---|
| *Nonionella miocenica* | r | p |
| *Quinqueloculina* sp. | p | |
| Misc. arenaceous foraminifera | | p |

p = 1 individual     r = 2-20 individuals

Table 17. Microfossils in Lithosome E of the upper member.

alone or are most commonly associated with *Crassostrea vaquerosensis*.

*Crassostrea vaquerosensis* is most common to abundant throughout the lower third of the member. These fossils most commonly occur in limestone beds which can be traced for many kilometers. Individuals generally are unbroken and are articulated or disarticulated. The large majority of the shells are flat-lying; no orientation is evident. Shells show minimal abrasion and exhibit much of their original ornamentation suggesting minimal post-mortem transport. Although some individuals are associated with other fossils such as *Lyropecten magnolia* the majority are found in monospecific assemblages.

The other species listed in Table 18 generally occur as whole or slightly broken individuals. Most of these species are found in the lower third of the member and are present in all portions of the study area containing outcrops of the upper member.

Calcareous foraminifera in this lithosome are poorly to moderately preserved and predominantly consist of internal casts that have been replaced by silica. Arenaceous foraminifers rarely are present

| | CSUN-596 | CSUN-597 | CSUN-598 | CSUN-599 | CSUN-601 | CSUN-603 | CSUN-611 | CSUN-613 | CSUN-615 | CSUN-617 | CSUN-618 | CSUN-632 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Gastropoda | | | | | | | | | | | | |
| *Calliostoma* sp. | | r | | | | | | | | | | |
| *Olivella* sp. | | | c | | | | c | | | | | |
| *Rapana vaquerosensis* | | r | | | | | | | | | | |
| *Solenosteira venturana* | | r | | | | | | | | | | |
| *Tegula* sp. | r | | | | | | | | | | | |
| *Terebra santana* | | | | c | | | | | | | | |
| *Thais* sp. | | a | | | | | | | | | | |
| *Thais carrizoensis* | | | r | | | | | | | | | |
| *Tritonalia* sp. | | | c | | | | c | | | | | |
| *Turritella* sp. | | r | | r | | | c | | | x | | |
| *Turritella inezana* | | | | | | | | | | | | c |
| unidentified gastropod | c | r | | | | c | | | r | | | |
| Bivalvia | | | | | | | | | | | | |
| *Anadara santana* | a | | c | | | | | | | c | | |
| *Anadara santaclarana* | a | | | | | | | | | | | |
| *Chione* sp. | | c | | | | | | | | | | |
| *Crassostrea vaquerosensis* | | x | | x | a | x | | a | | | x | x |
| *Diplodonta* cf. *D. arbella* | | c | | | | | | | | | | |
| *Dosinia* sp. | c | | | | | | | | | | | |
| *Dosinia margaritana* | | c | | | | | | | | | x | |
| *Lyropecten magnolia* | | | | | | | | r | | | c | |
| *Macoma arctata* | a | | | | | | | | | | | |
| *Macoma sespeensis* | | | | | | | | | a | | | |
| *Macoma* sp. | | | c | | | | | | | | | |
| *Panope* cf. *P. generosa* | | | | c | | | | | | | | |
| *Pecten* sp. | x | | | | | x | | | | | | |
| *Phacoides santacrucis* | c | | c | | | | c | | | | | |
| *Saxidomus vaquerosensis* | | | c | | | | | | | | | |
| *Tagelus clarki* | | | | | | | | | | a | | |
| *Trachycardium vaquerosensis* | | | | c | | c | | | | | | |
| unidentified bivalve | c | | c | r | x | | r | x | r | r | c | |
| Arthropoda | | | | | | | | | | | | |
| *Balanus* sp. | | c | | | | | | | | | | |
| Vertebrata | | | | | | | | | | | | |
| fish tooth | | x | | | | | | | | | | |
| mammal bones | | | | | | | | | | | r | |

r = rare c = common a = abundant x = identified in the field

Table 18. Megafossils in Lithosome E of the upper member.

in this lithosome.

## Transition Zone Interpretation

The characteristics of the transition zone already were discussed for rocks in the lower member, but the limestone beds of Lithosome E in the upper member differ from those of Lithosome E in the lower member and therefore require additional interpretation. The upper member limestone beds composed almost entirely of shells and shell debris of *Crassostrea vaquerosensis* represent reefs. Similar reefs have been reported in the northern Gulf of Mexico by Parker (1959, p. 2100-2166), Shepard and Moore (1960, p. 117-152, and Hopkins (1957, p. 1129-1134). These modern reefs are composed of the shells of *Crassostrea virginica* which accumulate perpendicular to water circulation patterns. Although *Crassostrea* reefs may be present in an open shelf environment, they most commonly occur in enclosed bays (Hopkins, 1957, 1129; Shepard and Moore, 1960, p. 128).

The ideal ecology for modern *Crassostrea* is a firm substrate, salinities ranging from 12 to 25 parts per thousand and water temperatures that drop below 15°C to reduce reproductive activities thereby allowing more energy for individual growth (Parker, 1959, p. 2129). It should be noted that whereas the ideal habitat for these oysters is in low-salinity areas, they commonly occur in water of normal marine salinity. According to Parker (1959, p. 2122), the shape of *Crassostrea* generally is diagnostic of certain environmental conditions. Thick, slightly curved shells that are almost as wide as they are long are most common on a hard substrate and in uncrowded conditions. Specimens collected from the Big Mountain area have similar shell morphology. The limestone beds in Lithosome E most commonly are interbedded with fossiliferous silty sandstone that provided the hard substrate upon which the *Crassostrea* shells accumulated. These factors suggest that the Vaqueros oysters probably lived on a firm sandy bottom in relatively uncrowded conditions. Based on similar morphologies and substrate associations, the ecology of *C. vaquerosensis* seems to closely approach that of *C. virginica.*

Some of the fauna collected from Lithosome E resembles the fauna collected by Parker (1960) from protected bay margins in the Rockport area of Texas. He reports that whereas *Crassostrea, Trachycardium Macoma, Chione,* and *Tagelus* may be present in an open nearshore shelf environment, they most commonly occur in a bay margin environment. However, the presence of *Thais, Anadara, Diplodonta,* and *Terebra* in beds of Lithosome E implies open ocean conditions (Gosner, 1971; Keen, 1963). In the Rockport area, semi-permanent circulation of open ocean water through the bays results in salinities ranging up to 42 parts per thousand, thereby allowing open ocean species to inhabit bay margins (Parker, 1959, p. 2112). Although some of the fauna in Lithosome E suggests that deposition may have occurred in a bay margin environment, there is no evidence to indicate the existence of barrier islands during deposition of the upper Vaqueros. This suggests that the area was protected from open-ocean conditions. It is therefore postulated that the southern portion of Ventura Bay may have been protected by a peninsula to the south (see Paleogeography) and that normal marine salinity and other open ocean conditions existed during deposition of Lithosome E. As in the lower member, the upper Vaqueros transition zone sediments were deposited in water ranging in depth from 10 to 30 m.

## LITHOSOME F

### Lithology

Lithosome F is composed of approximately 90 percent siltstone and 10 percent fine to very fine sandstone and lithologically is similar to Lithosome F in the lower member.

### Fossils

The fossils in Lithosome F are listed in Table 19, the MB localities are shown on Plate I, and the stratigraphic position of these localities is shown on Plate II.

Megafossils are scarce in Lithosome F. *Macoma arctata,* the only identifiable fossil found in the siltstone beds, occurs as whole, articulated individuals which are moderately to poorly preserved. The disarticulated, fragmented shells of *Crassostrea vaquerosensis,* which are present in a few sandstone beds, suggest post-mortem transport.

The majority of the calcareous foraminifera in this lithosome consist of internal casts that have been replaced by silica. Ostracods are present in a few beds and also have been replaced by silica.

| | MB-79-97 | MB-79-98 | MB-79-99 | MB-79-104 |
|---|---|---|---|---|
| *Ammobaculites strathernensis* | r | | r | r |
| *Cyclammina* cf. *C. incisa* | | | | p |
| *Nonion incisum* | | | | p |
| *Nonionella* cf. *N. miocenica* | | | r | r |
| *Nonionella miocenica* | r | | r | r |
| *Quinqueloculina* spp. | | | r | p |
| *Trochammina pilea* | | | r | |
| Misc. arenaceous foraminifera | | r | r | |

p = 1 individual     r = 2-20 individuals

Table 19. Microfossils in Lithosome F of the upper member.

## Shallow Offshore Shelf Interpretation

The interbedded siltstone and fine sandstone of Lithosome F represent offshore shelf deposits. The physical and biogenic parameters characteristic of shallow offshore deposits were discussed previously. The sandstone interbeds in this lithosome are interpreted as storm-sand layers, the composition and genesis of which are discussed in more detail in the section describing shallow offshore deposits in the lower member.

The microfaunal assemblage collected from Lithosome F in the upper member indicates that water depth was relatively shallow during deposition of this lithosome. The presence of *Ammobaculities*, *Nonionella miocenica*, *Nonion incisum*, *Quinqueloculina*, and *Trochammina* combined with a lack of deeper water species suggests deposition in water no deeper than 60 m (Table 9). Because the lower limit of the transition zone is 30 m, it is suggested that the rocks of Lithosome F were deposited in water ranging in depth from 30 to 60 m.

## SUMMARY

The regression that began during deposition of the middle member continued throughout deposition of the upper member. The thickness of the member indicates that the regression was slow and of long duration and the presence of alternating sequences of shoreface and shallow offshore deposits suggests that the regression in this area was not a continuous event but rather a series of fluctuations in sea level. The mechanism responsible for these fluctuations is discussed in the section on Paleogeography. As the sea became shallower and sediment influx increased, environments developed which supported a wide variety of invertebrate life. Oyster reefs were present in various parts of southern Ventura Bay. Although faunal assemblages in the upper member are similar to those found in modern protected bays along the coast of Texas, the lack of any evidence supporting the existence of a barrier island in southern Ventura Bay suggests that deposition of the upper member occurred under normal marine conditions. Evidence of shallowing to depths of less than the shoreface environment is missing due to post-depositional erosion. The erosion event itself, however, indicates that the area eventually became subaerial.

## PALEOCURRENT AND PROVENANCE ANALYSIS

### PALEOCURRENTS

Sedimentary structures that may be used as current indicators are found both in the lower and upper members of the Vaqueros at Big Mountain. However, the majority of these structures are too poorly preserved to obtain reliable measurements. The six measurements diagrammed in Fig. 7 were taken from crossbedding in the rip channel in Lithosome D of the lower member (CSUN locality 555). The predominant current direction is toward the west-northwest, perpendicular to the proposed shoreline (see Paleogeography). It is suggested that the crossbeds are present as the result of the migration of lunate megaripples which formed from rip currents. Because of the moderate size of the previously mentioned channel and frequent occurrence of current indicators in the lower and upper members, it is postulated that energy in the Vaqueros littoral system was low to moderate strength.

### PROVENANCE

Composition of the arkosic Vaqueros sandstones of the Big Mountain area includes, in addition to quartz, orthoclase, microcline, and perthite, rock fragments of schist, granitic and volcanic rocks, and muscovite-bearing quartzite; grains of brown tourmaline and epidote; and volcanic glass shards and pumice fragments. The few, rounded to well rounded conglomerate clasts that occur in the upper member include 18 quartzites, 1 gneiss, 3 granitic rocks, and 1 tuff.

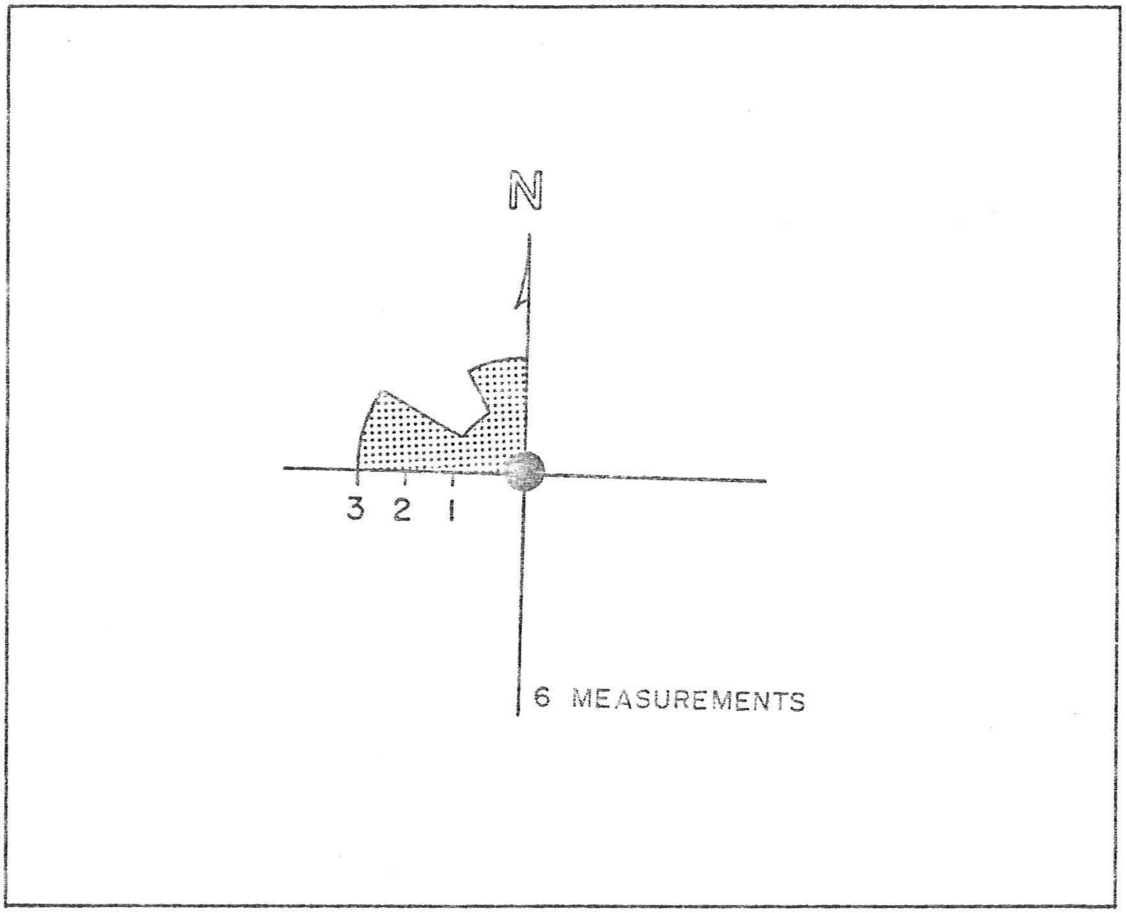


Figure 7. Distribution of current data from the Vaqueros Formation.

The predominance of quartzite clasts indicates that the primary source was from reworked sedimentary rocks, although the arkosic nature of the sandstone implies that the reworking was of short duration. Nearby highland areas from which pre-Oligocene sedimentary rocks could have been eroded include the San Rafael uplift to the north (Fischer, 1976; Reid, 1978) and the areas now occupied by the Santa Susana Mountains to the west and the Santa Monica Mountains to the southeast. If any of the sediments were from primary igneous or metamorphic terranes, they probably came from igneous and metamorphic outcrops in the areas now occupied by Frazier Mountain to the north, the San Gabriel Mountains south of the San Gabriel Fault to the west, or the eastern Santa Monica Mountains. Paleocurrent and compositional data are insufficient to determine which of the above areas were the primary source of sediment. The glass shards and pumice fragments indicate the presence of contemporaneous volcanism, but as above, the distance and direction to the source are unknown.

# PALEOGEOGRAPHY

## INTRODUCTION

A discussion of Vaqueros paleogeography must take into consideration the relative absence of any terrigenous clastic material larger than coarse sand. If the Vaqueros unconformably overlies the Sespe Formation as Canter (1974) reports, then the Sespe would have been a possible source for Vaqueros sediment. However, if this were true there should be a basal conglomerate in the Vaqueros because the Sespe Formation contains an appreciable amount of conglomerate clasts. The alternative to the reworking of Sespe sediment is that Vaqueros sediment was transported a moderate distance from the source area by intermittant, low-energy streams. Additional transport resulted from longshore currents moving the sediment along the paleo-coastline.

The location of the shoreline during Vaqueros deposition has been debated. Early writers such as Loel and Corey (1932) believed that the Vaqueros was deposited in embayments having east-west-trending shorelines. Later workers, however, suggested that in the eastern Ventura Basin the shoreline was north-south (Yeats, 1979; Campbell and Yerkes, 1976). Stratigraphic evidence in the Big Mountain area suggests the presence of a Vaqueros shoreline to the east. The siltstone of the Vaqueros middle member at Big Mountain pinches out toward the east. A similar thinning is reported along Oak Ridge by Yeats (1979, p. 196), indicating that the eastern edge of the middle member trends almost north-south. In a section of the Santa Susana Mountains east of the study area, Yeats (1979, p. 202) reports that Eocene beds are overlain by a non-marine sequence unlike the Sespe in that it contains bentonite interbeds. He suggests that because some Vaqueros beds at Big Mountain also contain tuffaceous material, the nonmarine beds may be of the same age. Taken together, these lines of evidence suggest that a north-south trending paleoshoreline was present in the eastern portion of the Simi Valley.

Yeats (1976, Fig. 9) and Campbell and Yerkes (1976, p. 545-546) report that during deposition of the Vaqueros, a north-northwesterly shoreline existed from the Santa Monica Mountains to Oak Ridge. They note that both in the Santa Monica Mountains and at Oak Ridge, shallow-water marine sediments change facies to nonmarine sediments in an easterly direction. Based on this similarity between the two areas, they infer the presence of a north-south trending shoreline during Vaqueros deposition.

Ehrenspeck (1972, p. 22-25) reports the presence of the Vaqueros Formation approximately 6 km south of the Big Mountain area. Approximately 700 m southeast of the easternmost Vaqueros outcrops, the Vaqueros Formation is absent and a nearly planar, concordant contact exists between the Sespe Formation and the overlying Conejo Volcanics. The absence of the Vaqueros in this area is the result of either 1) erosion that occurred after deposition of the Vaqueros which was more active or of longer duration than that which occurred to the north, or 2) nondeposition of Vaqueros sediment. Subsequent investigations in the area by the writer and A. E. Fritsche have resulted in the interpretation of these Vaqueros outcrops as beach and shallow nearshore deposits. Unfortunately, there is no way presently to determine the relationship of these rocks to the Vaqueros Formation at Big Mountain. If these outcrops are correlative to rocks of the lower member at Big Mountain, it cannot be determined if and where a shoreline existed to the south. However, if the shallow Vaqueros deposits in Ehrenspeck's area are correlative to the middle member at Big Mountain, then the uppermost Sespe deposits would be correlative to the lower member, thereby indicating the presence of an east-west trending paleoshoreline through the central portion of the Simi Valley.

All paleogeographic reconstructions are plotted on reproductions of Figure 8. These maps are slightly shortened in a north-south direction because folding has not been removed.

## PRE-VAQUEROS PALEOGEOGRAPHY

Prior to deposition of the Vaqueros in the Big Mountain area, there existed a relatively flat plain throughout most of the southern Ventura Basin. According to Flemal (1966, p. 184), this broad coastal plain was bordered by highlands near the present eastern Santa Monica Mountains, San Gabriel Mountains, and Mount Pinos-Frazier Mountain region. Traversing this area were many small rivers and intermittant streams. Basin drainage into local topographically low areas formed small playa-lakes.

## LOWER MEMBER PALEOGEOGRAPHY

The transgression represented by the lower member seems to have begun in the west. The initial period of transgression was marked by minor fluctuations in sea level. During this time, moderate-energy,

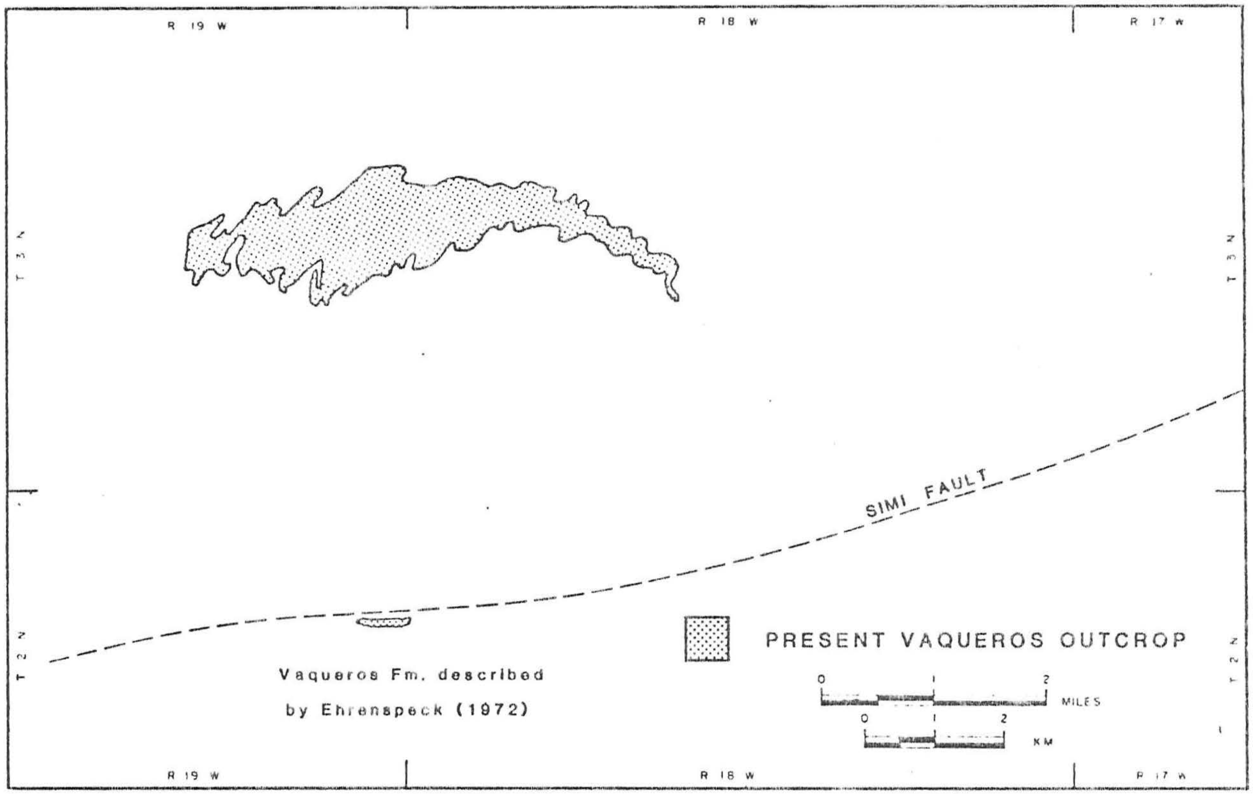


Figure 8. Base map for paleogeographic reconstructions.

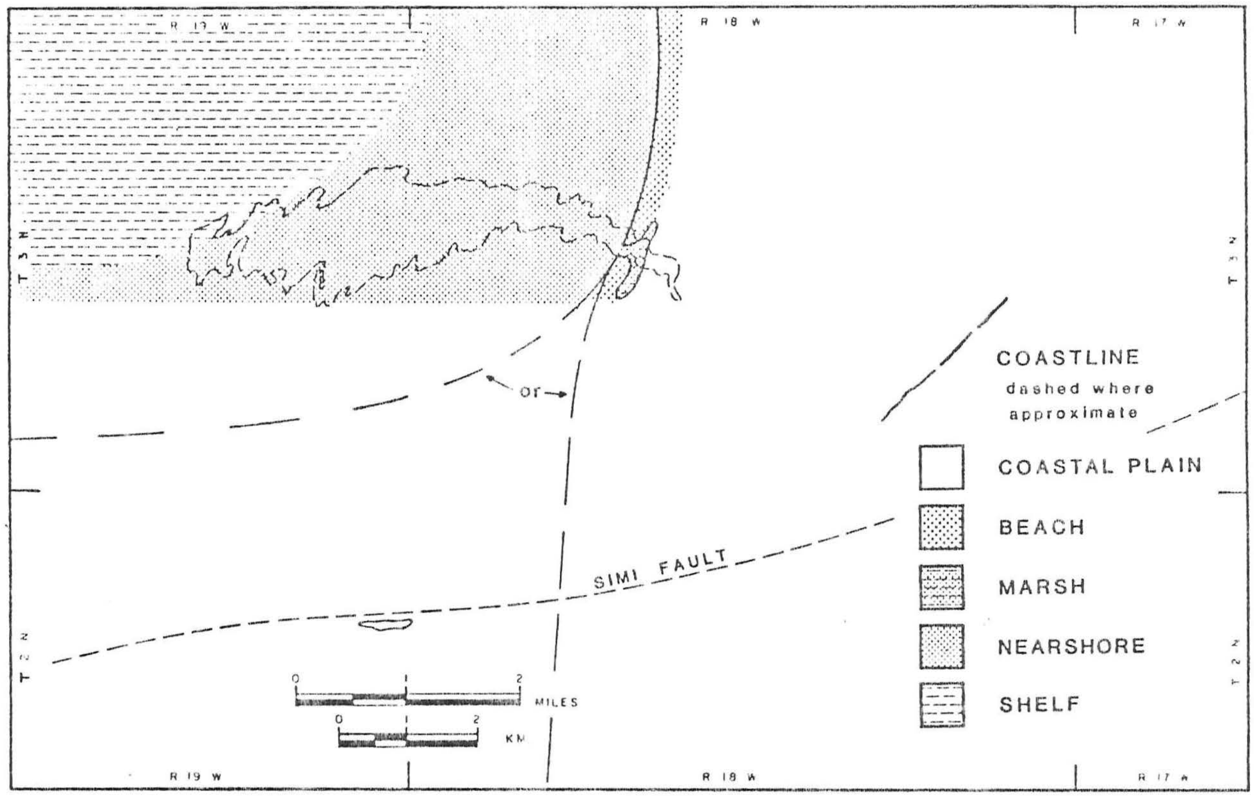


Figure 9. Lower member paleogeography.

wave-dominated sandy beaches and coastal salt marshes slowly transgressed eastward over the low-lying coastal plain (Fig. 9). In terms of size and overall shape, as well as its degree of protection from open marine conditions, the bay may have had some similarity to the geometry of present-day Monterey Bay. In the area of Big Mountain the water depth eventually reached 60 m.

## MIDDLE MEMBER PALEOGEOGRAPHY

Lithologic and paleontologic data in the lower and middle portions of the middle member indicate a continuation of the transgression that was coincident with deposition of the lower member. Subsidence of the area continued during deposition of these portions of the middle member, however, the bay probably retained the same general shape present during deposition of the lower member (Fig. 10). The bay was deeper to the northwest with water depths no shallower than 150 m and bottom sediment distribution becoming finer in the same general direction.

In the upper portion of the middle member, the presence of a shallow-water microfauna and corresponding increase in the percentage of sand to silt implies that a regression began during deposition of this portion of the member. The maximum thickness of the middle member is 103 m. About half of this thickness, 51 m, would represent the thickness of sediment deposited during the regression. This thickness by itself, if deposited with no change in sea level, would have shallowed the basin from the minimum depth of 150 m to a minimum of 99 m. Transition zone deposits in the upper portion of the member

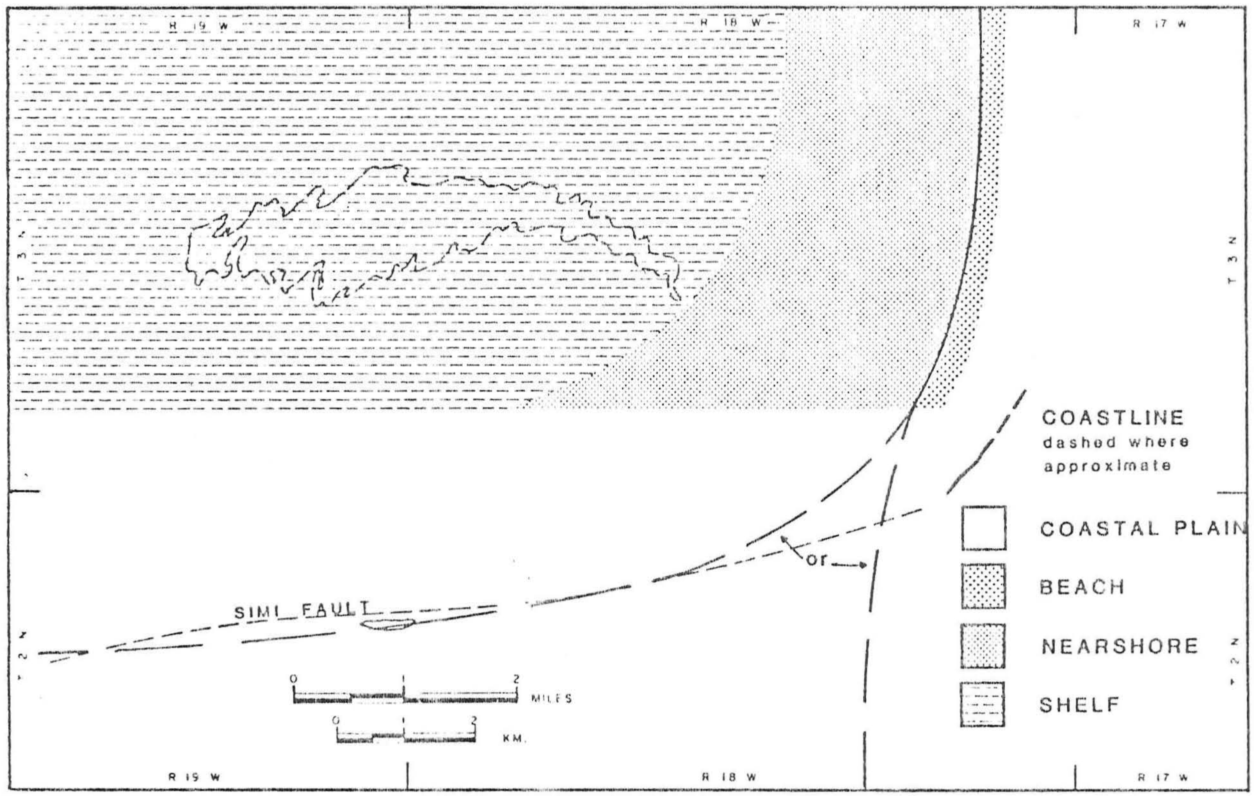


Figure 10. Middle member paleogeography.

were deposited in water not deeper than 30 m. Therefore, uplift of at least 69 m must have occurred during deposition of the upper portion of the middle member. Uplift most likely was the result of tectonic events, because a eustatic change in sea level would have affected both sides of the Ventura Basin and, in the northern Ventura Basin, stratigraphic and paleoenvironmental data indicate a continuation of the transgression initiated in late Oligocene/early Miocene time (Edwards, 1971; Fischer, 1976; Reid, 1978).

To date, no major tectonic activity has been reported to have occurred near the Big Mountain area during deposition of the Vaqueros Formation. In his report on the Santa Susana Fault System, Yeats (1979, p. 196) dates the inception of movement along this system as late early Miocene, post-Vaqueros, or early middle Miocene, pre-Topanga. Movement along the Simi Fault, south of the study area, has been dated as post-Vaqueros and pre-Conejo Volcanics (Ehrenspeck, 1972, p. 114). It is postulated that the tectonic uplift which began during deposition of the middle member of the Vaqueros at Big Mountain eventually resulted in the beginning of movement on the Simi Fault and/or Santa Susana Fault System.

## UPPER MEMBER PALEOGEOGRAPHY

The slow regression of the sea, initiated during deposition of the upper portion of the middle member, continued during deposition of the upper member. The presence of alternating sequences of shoreface and shallow offshore deposits suggests that uplift of the area occurred in cycles rather than as a continuous movement.

Water depth ranged from subtidal to 60 m. As uplift of the area continued, the seas retreated further north and west until deposition of the Vaqueros in the Big Mountain area ceased.

POST-VAQUEROS PALEOGEOGRAPHY

The truncation of Vaqueros rocks in an easterly direction by rocks of the Calabasas Formation indicates upwarping of the Vaqueros Formation in the east. This upwarping perhaps initiated movement along the Santa Susana Fault System. This period of upwarping was followed by erosion which occurred prior to subsidence and subsequent deposition of the Conejo Volcanics and Calabasas Formation. The shoreline moved perhaps as far north as the Santa Clara Valley because the Miocene sequence north of the valley is continuous. If the Miocene sequence on Oak Ridge is continuous, then the shoreline moved no farther north than Oak Ridge. Lack of extensive Miocene exposures to the west precludes determination of the westward extent of the shoreline. Perhaps this problem can be resolved with future subsurface studies.

## REFERENCES CITED


Addicott, W. O., 1972, Provincial middle late Tertiary molluscan stages, Temblor Range, California, *in* Stinemeyer, E. H., ed., The proceedings of the Pacific Coast Miocene biostratigraphic symposium: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 1-22.

Arnal, R. E., and Vedder, J. G., 1976, Late Miocene paleobathymetry of the California continental borderland north of 32° *in* Fritsche, A. E., Ter Best, H., and Wornardt, W. W., eds., The Neogene symposium: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 1-8.

Bandy, O. L., 1972, Neogene planktonic foraminiferal zones, California, and some geologic implications: Paleogeography, Paleoclimatology, Paleoecology, v. 11, p. 131-150.

Bird, E. C. F., 1968, Coasts: Canberra, Australia, The Australian National University Press, 246 p.

Brenner, R. L., and Davies, D. K., 1963, Storm-generated coquinoid sandstone: genesis of high-energy marine sediments from the Upper Jurassic of Wyoming and Montana: Geological Society of America Bulletin, v. 84, no. 5, p. 1685-1698.

Campbell, C. V., 1966, Truncated wave-ripple laminae: Journal of Sedimentary Petrology, v. 36, p. 825-838.

Campbell, R. H., and Yerkes, R. F., 1976, Cenozoic evolution of the Los Angeles basin area--relation to plate tectonics, *in* Howell, D. G., ed., Aspects of the geologic history of the California continental borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 541-560.

Canter, N. W., 1974, Paleogeology and paleogeography of the Big Mountain area, Santa Susana, Moorpark, and Simi Quadrangles, Ventura County, California: Ohio University, M.S. thesis, 58 p.

Clifton, H. E., Hunter, R. E., and Phillips, R. L., 1971, Depositional structures and processes in the non-barred high-energy nearshore: Journal of Sedimentary Petrology, v. 41, no. 3, p. 651-670.

Corey, W. H., 1927, Paleontology and stratigraphy of the Vaqueros Formation (lower Miocene) of Oak Ridge and South Mountain, Ventura County, California: California University, Berkeley, M.A. thesis, 64 p.

Curray, J. R., 1960, Sediments and history of Holocene transgression, continental shelf, northwest Gulf of Mexico *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 221-266.

Cushman, J. A., and Le Roy, L. W., 1938, A microfauna from the Vaqueros Formation, lower Miocene, Simi Valley, Ventura County, California: Journal of Paleontology, v. 12, no. 2, p. 117-126.

Davidson-Arnott, R. G. D., and Greenwood, B., 1974, Bedforms and structures associated with bar topography in the shallow-water wave environment, Kouchibouguac Bay, New Brunswick, Canada: Journal of Sedimentary Petrology, v. 44, no. 3, p. 698-704.

Davidson-Arnott, R. G. D., and Greenwood, B., 1976, Facies relationships on a barred coast, Kouchibouguac Bay, New Brunswick, Canada, *in* Davis, R. A., Jr., and Ethington, R. L. eds., Beach and nearshore sedimentation: Society of Economic Paleontologists and Mineralogists Special Publication 24, p. 149-168.

Davis, R. A., Jr., 1978, Beach and nearshore zone *in* Davis, R. A., Jr., ed., Coastal sedimentary environments: New York, Springer-Verlag, p. 101-169.

Davis, R. A., Jr., Fox, W. T., Hayes, M. O., and Boothroyd, J. C., 1972, Comparison of ridge and runnel systems in tidal and non-tidal environments: Journal of Sedimentary Petrology, v. 2, p. 413-421.

Eastes, J. L., and Fritsche, A. E., 1979, Stratigraphy and depositional environments of the Vaqueros Formation near Lake Casitas, Ventura County, California, *in* Bell, G., and Berger, D., eds., Geology of the Lake Casitas area, Ventura County, California: American Association of Petroleum Geologists, Pacific Section, Spring Field Trip Guidebook, p. 30-37.

Edwards, L. N., 1971, Geology of the Vaqueros and Rincon Formations, Santa Barbara embayment, California: California University, Santa Barbara, Ph.D. dissertation, 240 p.

Ehrenspeck, H. E., 1972, Geology and Miocene volcanism of the eastern Conejo Hills area, Ventura County, California: California University, Santa Barbara, M.S. thesis, 135 p.

Eldridge, G. H., and Arnold, R., 1907, The Santa Clara Valley Puente Hills, and Los Angeles oil districts, southern California: U.S. Geological Survey Bulletin 309, p. 15-21.

Elliott, T., 1979, Clastic shorelines, *in* Reading, H. G., ed., Sedimentary environments and facies: New York, Elsevier, p. 143-177.

Fischer, P. J., 1976, Late Neogene - Quaternary tectonics and depositional environments of the Santa Barbara basin, California, *in* Fritsche, A. E., Ter Best, H., Jr., and Wornardt, W. W., eds., The Neogene symposium: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 33-52.

Flemal, R. C., 1966, Sedimentology of the Sespe Formation, southwestern California: Princeton University, Ph.D. dissertation, 224 p.

Folk, R. L., 1974, Petrology of sedimentary rocks: Austin, Texas, Hemphill Publishing Company, 182 p.

Frey, R. W., and Basan, P. B., 1978, Coastal salt marshes, *in* Davis, R. A., Jr., ed., Coastal sedimentary environments: New York, Springer-Verlag, p. 101-169.

Goddard, E. N., chairman, 1970, Rockcolor chart: Boulder, Colorado, Geological Society of America.

Goldring, R., and Bridges, P., 1973, Sublittoral sheet sandstones: Journal of Sedimentary Petrology, v. 43, no. 3, p. 736-747.

Gosner, K. L., 1971, Guide to identification of marine and estuarine invertebrates: New York, John Wiley and Sons, Inc., 693 p.

Hall, E. A., Durrie, J. W., and Saunders, J. M., 1967, Geology of the Big Mountain oil field and the nearby area, including notes on the trip from Piru to Big Mountain: American Association of Petroleum Geologists, Pacific Section, Spring Field Trip, Morning Section, p. 1-11.

Hamlin, H., 1904, Water resources of the Salinas Valley, California: U.S. Geological Survey Water Supply Paper 89, 91 p.

Harms, J. C., 1975, Stratification and sequence in prograding shoreline deposits, *in* Harms, J. C., Southard, J. B., Spearing, D. R., and Walker, R. G., eds., Depositional environments as interpreted from primary sedimentary structures and stratification sequences: Society of Economic Paleontologists and Mineralogists Short Course No. 2, p. 81-102.

Hayes, M. O., 1967, Hurricanes as geological agents, south Texas coast: American Association of Petroleum Geologists Bulletin, v. 51, no. 6, p. 937-956.

Hays, M. O., and Boothroyd, J. C., 1969, Storms as modifying agents in the coastal environment, *in* Coastal Research Group, University of Massachusetts, eds., Coastal environments of northeastern Massachusetts and New Hampshire: Society of Economic Paleontologists and Mineralogists, Eastern Section, Field Trip Guidebook, p. 245-265.

Hopkins, S. W., 1957, Oysters, *in* Hedgpeth, J. W., ed., Treatise on marine ecology and paleocology: Geological Society of America Memoir 67, v. 1, p. 1129-1134.

Hunter, R. E., Clifton, H. E., and Phillips, R. L., 1979, Depositional processes, sedimentary structures, and predicted vertical sequences in barred nearshore systems, Southern Oregon coast: Journal of Sedimentary Petrology, v. 49, no. 3, p. 711-726.

Ingle, J. C., Jr., 1972, Biostratigraphy and paleocology of early Miocene through early Pleistocene benthonic and planktonic foraminifera, San Joaquin Hills-Newport Bay, Orange County, California, *in* Stinmeyer, E. H., ed., The proceedings of the Pacific coast Miocene biostratigraphic symposium: Society of Economic Paleontologists and Mineralogists, Pacific Section, p. 255-283.

Ingle, J. C., Jr., 1975, Nearshore processes and beach deposits, *in* Dickinson, W. R., ed., Current concepts of depositional systems with applications for petroleum geology: San Joaquin Geological Society, Short Course, p. 2-1 to 2-11.

Jennings, C. W., and Strand, R. G., 1972, Geologic map of California, Los Angeles sheet: California Division of Mines and Geology, scale 1:250,000.

Johnson, H. D., 1979, Shallow siliciclastic seas, *in* Reading, H. G., ed., Sedimentary environments and facies: New York, Elsevier, p. 207-258.

Keen, A. M., 1963, Marine molluscan genera of Western North America: Stanford, California, Stanford University Press, 126 p.

Kew, W. S. W., 1919, Structure and oil resources of the Simi Valley, southern California: U.S. Geological Survey Bulletin 691, p. 330-333.

Kew, W. S. W., 1923, Geologic formations of a part of southern California and their correlation: American Association of Petroleum Geologists Bulletin, v. 7, p. 411-420.

Kew, W. S. W., 1924, Geology and oil resources of a part of Los Angeles and Ventura counties, California: U.S. Geological Survey Bulletin 753, 202 p.

Kleinpell, R. M., 1938, Miocene stratigraphy of California: Tulsa, Oklahoma, American Association of Petroleum Geologists, 450 p.

Komar, P. D., 1976, Beach processes and sedimentation: Englewood Cliffs, New Jersey, Prentice-Hall, Inc., 429 p.

Krumbein, W. C., and Sloss, L. L., 1963, Stratigraphy and sedimentation: San Francisco, California, W. H. Freeman and Company, 660 p.

Kulm, L. D., Rousch, R. C., Harlett, J. C., Neudeck, R. H., Chambers, D. M., and Runge, E. J., 1975, Oregon continental shelf sedimentation: interrelationships of facies distribution and sedimentary processes: Journal of Geology, v. 83, p. 145-176.

Kumar, N., and Sanders, J. E., 1976, Characteristics of shoreface storm deposits: modern and ancient examples: Journal of Sedimentary Petrology, v. 46, no. 1, p. 145-162.

Loel, W., and Corey., W. H., 1932, The Vaqueros Formation, lower Miocene of California, I, paleontology: University of California Publications in the Geological Sciences, v. 22, 411 p.

Louderback, G., 1913, The Monterey series in California: University of California, Berkeley, Geological Bulletin, v. 7, no. 10, p. 177-241.

Parker, R. H., 1959, Macro-invertebrate assemblages of central Texas coastal bays and Laguna Madre: American Association of Petroleum Geologists Bulletin, v. 43, no. 9, p. 2100-2166.

Parker, R. H., 1960, Ecology and distributional patterns of marine macro-invertebrates, northern Gulf of Mexico, *in* Sheppard, F. P., Phleger, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 302-337.

Powers, M. C., 1953, A new roundness scale for sedimentary particles: Journal of Sedimentary Petrology, v. 23, no. 2, p. 117-119.

Powers, M. C., and Kinsman, B., 1953, Shell accumulations in underwater sediments and their relation to the thickness of the traction zone: Journal of Sedimentary Petrology, v. 23, no. 4, p. 229-234.

Psuty, N. P., 1966, The geomorphology of beach ridges in Tabasco, Mexico: Louisiana State University, Baton Rouge, Coastal Studies Institute Technical Report 30, 51 p.

Ragan, D. M., 1973, Structural geology, an introduction to geometrical techniques: New York, John Wiley and Sons, 208 p.

Redin, T. W., 1962, Geology of the Big Mountain, Simi, west Tapo area, Ventura County, California: Unpublished Union Oil Company Field Report, p. 13-16.

Reid, S. A., 1978, Mid-Tertiary depositional environments and paleogeography along upper Sespe Creek, Ventura County, California, *in* Fritsche, A. E., ed., Depositional environments of Tertiary rocks along Sespe Creek, Ventura County, California: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Field Guide 3, p. 27-41.

Reineck, H. E., and Singh, I. B., 1975, Depositional sedimentary environments: New York, Springer-Verlag, 439 p.

Ricketts, E. F., and Calvin, J., 1968, Between Pacific tides: Stanford, California, Stanford University Press, 614 p.

Roep, T. B., Beets, D. J., Dronkert, H., and Pagnier, H., 1979, A prograding coastal sequence of wave-built structures of Messinian age, Sorbas, Almeria, Spain: Sedimentary Geology, v. 22, p. 135-163.

Russell, R. J., and McIntire, W. G., 1965, Beach cusps: Geological Society of America Bulletin, v. 76, no. 3, p. 307-320.

Shepard, F. P., 1973, Submarine geology: San Francisco, California, Harper and Row, 517 p.

Shepard, F. P., and Moore, D. G., 1960, Bays of central Texas coast, *in* Shepard, F. P., Phleger, F. B., and van Andel, T. H., Recent sediments, northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 117-152.

Spearing, D. R., 1974, Regressive shoreline sand deposits, *in* Summary sheets of sedimentary deposits with bibliographies: Geological Society of America, v. MC-8, sheet 4.

Stanley, R. G., 1973, Paleoecology of a shell bank in the Vaqueros sandstone (lower Miocene) near Zayante, Santa Cruz County, California: California University, Santa Cruz, Senior thesis, 49 p.

Swift, D. J. P., 1976a, Coastal sedimentation, *in* Stanley, J. S., and Swift, D. J. P., eds., Marine sediment transport and environmental management: New York, John Wiley and Sons, p. 255-310.

Swift, D. J. P., 1976b, Continental shelf sedimentation, *in* Stanley, J. S., and Swift, D. J. P., eds., Marine sediment transport and environmental management: New York, John Wiley and Sons, p. 311-350.

Taliaferro, N. L., Hudson, F. S., and Craddock, W. M., 1924, Oil fields of Ventura County, California: American Association of Petroleum Geologists Bulletin, v. 8, p. 789-829.

Thorup, R. R., 1942, The stratigraphy of the Vaqueros Formation at its type locality, Monterey County, California: Stanford University, M.A. thesis, 70 p.

Vail, P. R., Mitchum, R. M., Todd, R. G., Widmier, J. M., Thompson, S., Sangree, J. B., Bubb, J. N., and Hatlelid, W. G., 1977, Seismic stratigraphy and global changes in sea level, part 4 - global cycles of relative changes of sea level, *in* Seismic stratigraphy - applications to hydrocarbon exploration: American Association of Petroleum Geologists Memoir 26, p. 83-97.

van Andel, T. H., and Curray, J. R., 1960, Regional aspects of modern sedimentation in northern Gulf of Mexico and similar basins, and paleogeographic significance, *in* Shepard, F. B., and van Andel, T. H., eds., Recent sediments, northwest Gulf of Mexico: Tulsa, Oklahoma, American Association of Petroleum Geologists, p. 345-364.

Van Camp, Q. W., 1959, Geology of the Big Mountain area, Santa Susana and Simi Quadrangles, Ventura County, California: California University, Los Angeles, M.A. thesis, 98 p.

Wilson, E. J., 1954, Foraminifera from the Gaviota Formation east of Gaviota Creek, California: California University Publications in Geology, v. 30, no. 2, p. 103-170.

Woodford, A. O., Schoelhamer, J. E., Vedder, J. G., and Yerkes, R. F., 1954, Geology of the Los Angeles basin: California Division of Mines and Geology Bulletin 170, chap. 2 p. 65-82.

Wright, L. D., 1978, River deltas, *in* Davis, R. A., ed., Coastal sedimentary environments: New York, Springer-Verlag, p. 5-68.

Yeats, R. S., 1976, Extension *versus* strikeslip origin of the southern California borderland, *in* Howell, D. G., ed., Aspects of the geologic history of the California continental borderland: American Association of Petroleum Geologists, Pacific Section, Miscellaneous Publication 24, p. 455-485.

Yeats, R. S., 1979, Stratigraphy and paleogeography of the Santa Susana Fault zone, Transverse Ranges, California *in* Armentrout, J. M., Cole, M. R., and Ter Best, H., eds., Cenozoic paleogeography of the western United States: Society of Economic Paleontologists and Mineralogists, Pacific Section, Pacific Coast Paleogeography Symposium 3, p. 191-204.

Yerkes, R. F., and Campbell, R. H., 1979, Stratigraphic nomenclature of the central Santa Monica mountains, Los Angeles County, California: U.S. Geological Survey Bulletin 1457-E, p. E13-E23.

Yonge, C. M., and Thompson, T. E., 1976, Living marine molluscs: London, William Collins Sons and Company, Ltd., 228 p.