CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

DEPOSITIONAL ENVIRONMENTS OF THE VAQUEROS FORMATION ALONG UPPER SESPE CREEK, 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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Frontispiece. Air view of Piedra Blanca, looking northwest. Piedra Blanca consists of outcrops of the Vaqueros upper member exposed in the core of Tule Creek syncline.

Frontispiece

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ABSTRACT

DEPOSITIONAL ENVIRONMENTS OF THE VAQUEROS FORMATION

ALONG UPPER SESPE CREEK, VENTURA COUNTY, CALIFORNIA

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The Vaqueros Formation (Oligocene-lower Miocene) along upper Sespe Creek in Ventura County, California, is a transgressive marine sequence overlying the Sespe Formation and underlying the Rincon and Monterey Formations. The Vaqueros is exposed in a narrow graben between the Pine Mountain and Santa Ynez faults on the northern edge of the Ventura basin. Three members are distinguished: a lower limestone, sandstone, and mudstone, which averages 65 m thick; a middle mudstone, which averages 110 m thick; and an upper sandstone, which averages 75 m thick.

Rocks of the lower and middle members represent deposits in bay and inner shelf environments. The lowest mudstone and sandstone beds are muddy beach and bay margin deposits. Fossiliferous mudstone represents deposition in an open bay environment characterized by water depth of 1 to 10 m. Fossiliferous limestone containing abundant shell

debris interbedded with mudstone is storm-lag or swell-lag deposits. *Potamides*-bearing limestone indicates a grassy bay environment with water depth of 1 to 3 m. Limestone beds near the top of the lower member which contain *Anadara*, *Anomia*, *Chione*, *Macoma*, and *Ostrea* represent an inlet influenced bay environment and near normal oceanic circulation. Mudstone of the middle member represents deposition in a shallow inner shelf environment with few mollusks and water depth less than 10 m.

Rocks of the upper member represent environments of a shelf-depth sand sheet. Cross-bedded sandstone represents dune field deposits which accumulated from the southward migration of megaripples in water 15 to 30 m deep. Plane-bedded and massive sandstone are interdune deposits which collected sand at lower current velocities than that in the dune fields. Muddy conglomerate beds near the top of the Vaqueros represent debris flows and indicate a deepening of the shelf to 100 m or more. Glauconitic sandstone at the top of the formation indicates slackened deposition and outer shelf water depths.

Pebbles from the upper member indicate a sedimentary source terrane near the Pine Mountain area north of Sespe Creek and a granitic source terrane near the Alamo Mountain area northeast of Sespe Creek. These source terranes define the San Rafael uplift, which was an east-west trending highland separating Vaqueros exposures in the Sespe Creek and Cuyama Valley areas.

Paleogeographic features which controlled Vaqueros deposition were established before the end of Sespe Formation deposition. Alluvial fans on the edges of a large floodplain sloped upward to a highland to the west and upward to the San Rafael uplift to the north. With the beginning of the Vaqueros transgression, the flat floodplain was rapidly covered by the water of Sespe Bay, a sheltered area between the western highland and the San Rafael uplift. Low energy beaches formed north and west of the Sespe Creek area. At the beginning of upper member deposition, the rising water of the transgression separated the western highland from the San Rafael uplift, forming Ynez Island and San Rafael Strait. Oceanic circulation moved through the strait and created the dune fields in the Vaqueros Formation.

INTRODUCTION

PURPOSE

The goals of this thesis are to determine the sedimentary environments and paleogeography represented by the Vaqueros Formation along upper Sespe Creek, Ventura County, California, through a detailed study of lithology, paleontology, and sedimentary structures. This is the first detailed environmental study of the Vaqueros in the upper Sespe Creek area and is the first to compare detailed paleogeography there with that in the Cuyama and Sierra Madre areas.

LOCATION AND GEOGRAPHY

Outcrops of the Vaqueros studied are 100 to 120 km northwest of Los Angeles, in the Los Padres National Forest (Fig. 1). Exposures are in linear outcrops that generally parallel Sespe Creek. Access from Ojai is provided by State Highway 33 and Rose Valley Road, both of which are paved but may wash out in heavy storms. Further access to the east is along Hot Springs Road, an unmaintained jeep trail which is closed by the United States Forest Service from November 1 to April 1. Flooding in February and March of 1978 severely damaged the Hot Springs Road and the road may not be reopened to vehicles. Useful access trails into remote regions include Piedra Blanca, Chorro Grande, and Potrero John. Visiting all eastern exposures requires crossing Sespe Creek, a perennial stream which may be impassable for several winter and spring months.

Sespe Creek is in a 5 to 10 km wide east-west trending valley south

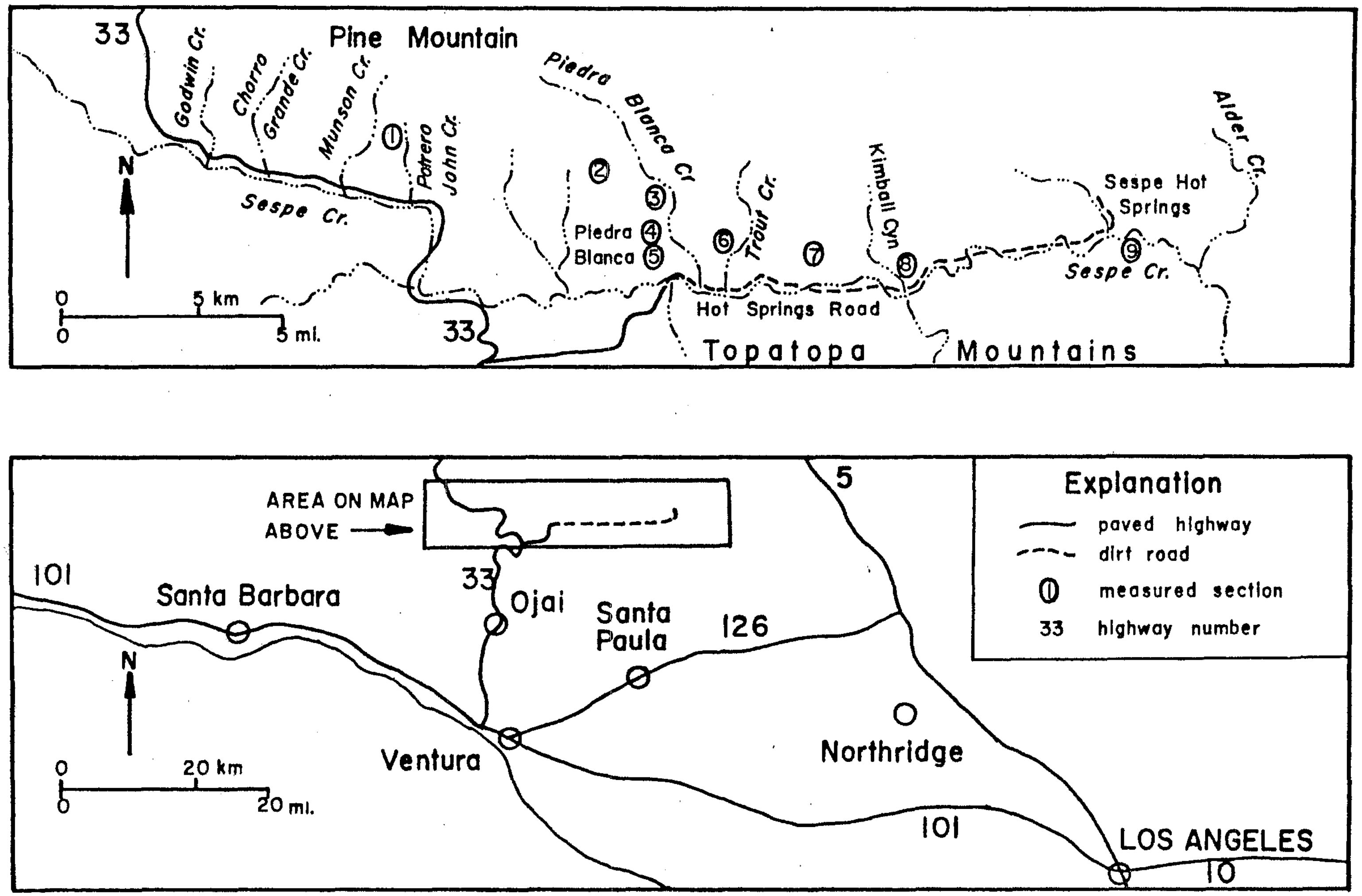


Figure 1. Index map showing location of the upper Sespe Creek area. Numbers show location of measured sections.

of Pine Mountain and north of the Topatopa Mountains, in the north-central Transverse Ranges. Sespe Creek drains east, and is fed by many smaller streams from the mountainous areas to the north and south.

The upper Sespe Creek area has a Mediterranean climate with an average 40 to 50 cm of rain per year. Summers are hot and dry. Winters are cool and wet, with freezing temperatures common at night. Snow occurs about once a winter. Canyons are steep and narrow, with rocky slopes and wooded bottoms. Chaparral covers the rugged foothills and terraces.

GEOLOGIC SETTING AND PREVIOUS WORK

The Vaqueros Formation in the upper Sespe Creek area is on the north edge of the Ventura basin, a Tertiary depression containing nonmarine conglomerate and sandstone and marine sandstone, shale, and limestone. The Vaqueros is stratigraphically above the nonmarine sandstone and conglomerate of the Sespe Formation and below the deep-marine mudstone and shale of the Rincon and Monterey Formations.

Geology of the upper Sespe Creek area is shown in Figure 2. Eocene and Oligocene rocks are predominant, whereas Vaqueros exposures are restricted to three areas south of the Pine Mountain fault. The 12-km-long western section, from State Highway 33 to Derrydale Creek, is homoclinal and dips steeply north. Outcrops of the central section are along upper Piedra Blanca Creek and follow 5 km of a southeast-trending syncline. The eastern section crops out in a 22 km band of gently eastward-plunging folds from Piedra Blanca to Sespe Hot Springs. Many small faults interrupt the sections so that few areas contain complete stratigraphic sequences. Vaqueros outcrops are bounded by portions of

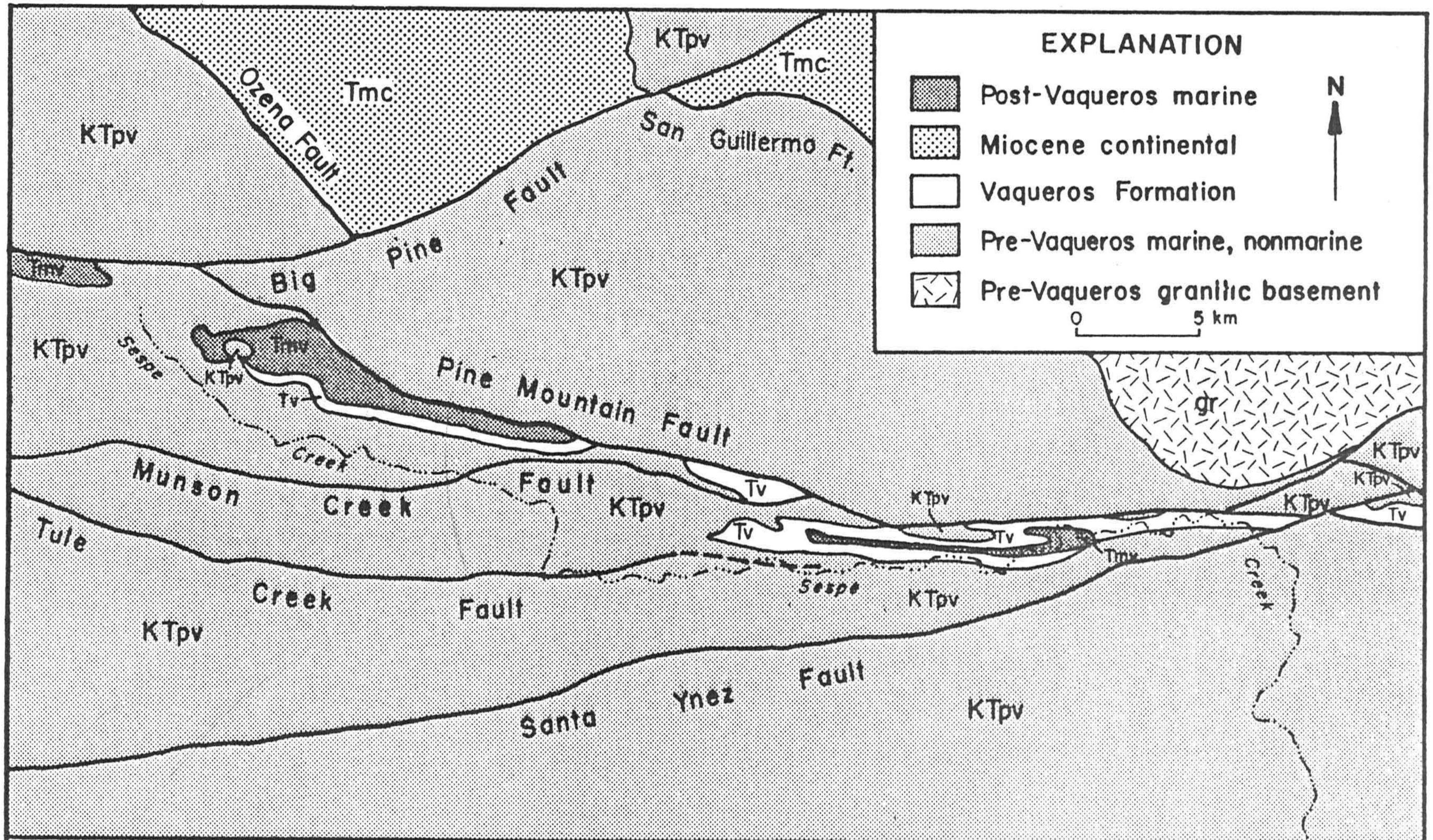


Figure 2. Regional geology of the Sespe Creek area showing major faults and gross rock unit distribution (adapted from Jennings and Strand, 1972).

the Pine Mountain, Munson Creek, Tule Creek, and Santa Ynez faults.

The first published description of the lithology and fossils in this area was by Loel and Corey (1932, p. 72-82). Geologists in published reports through 1954 identified the Vaqueros as Rincon and Monterey Formations or as younger rocks (Reed, 1933, Fig. 35; Merrill, 1954). More recent geologic maps of the area include those by Dickinson and Lowe (1966, p. 2466), Dibblee (Jennings and Strand, 1972), and Vedder and others (1973). Fritsche (1975) studied a glauconite bed used here for correlation of sections. Squires and Fritsche (1978) have compiled the most accurate and complete faunal list of the Vaqueros yet published for the Sespe Creek area. Unpublished master's theses of the upper Sespe Creek area include Dreyer (1935), Badger (1957), Hagen (1957), Gross (1958), Larson (1958), and Shmitka (1970). Edwards (1971, p. 98-119) studied the environment of deposition and paleogeography of the Vaqueros in the Sespe Creek area. Recent publications based on research from this thesis are by Reid and Fritsche (1978) on the environmental interpretation of upper Vaqueros cross bedding, and by Reid (1978) on the environment of deposition and paleogeography of the Vaqueros Formation.

PROCEDURES

About 40 days were spent in the field from Summer, 1977, to early Spring, 1978. Six stratigraphic sections were measured using the tape and brunton method (Compton, 1962, p. 239-240) at locations chosen for completeness and maximum exposure (Plate I). True stratigraphic thicknesses were determined orthographically, using the procedures of Ragan (1973, p. 15-21). Other fieldwork consisted of collecting paleocurrent data, collecting fossils, and following outcrops between measured sections. Several days were spent comparing Vaqueros exposures in the upper Sespe Creek area with Vaqueros outcrops at Piru Creek, the Cuyama Valley area, the type locality in Monterey County, California, and equivalent-aged rocks in the Lockwood Valley area.

Laboratory work consisted of examination of 110 hand samples, microscopic petrographic analysis of 39 thin sections, restoration to horizontal of 160 cross-bedding attitudes by rotation on a Wulff stereonet (Ragan, 1973, p. 100-101), measurement of aligned fossils on 3 acetate peels, and preparation and identification of fossil material. Further laboratory work on conglomerate samples consisted of binocular microscopic inspection of 10 slabbed samples and identification of 1,188 pebbles from 20 locations.

This thesis is a continuation of the investigations of the Advanced Stratigraphic Analysis course jointly taught at California State University, Northridge, by Professors Fritsche, Squires, and Colburn. Three stratigraphic sections and paleocurrent data from the above course, which were prepared by students and faculty, are used herein.

Additional data were obtained from Dr. A. E. Fritsche and from the Paleontology Collection of the Geoscience Department at California State University, Northridge.

ACKNOWLEDGEMENTS

I would like to thank my thesis committee for their help and cooperation in the research and writing of this thesis: Dr. I. P. Colburn of California State University, Los Angeles, for assistance with the provenance and cross bedding interpretations; Dr. R. L. Squires of California State University, Northridge, for stratigraphical and paleontological assistance; and Dr. A. E. Fritsche, thesis charirman, of California State University, Northridge, for helpful discussions on the environments of deposition. I am also grateful to Jim Mathews, Mik Cladis, and Sue Carter for their assistance in the field; to Donna Bridges for assistance at the Vaqueros type area; to Diane Evans for the micropaleontology analysis; to John Hardin for assistance with acetate peels; to Tom Blake for discussions on Vaqueros paleogeography in the Cuyama Valley area; to Jaris for assistance with the photographs; to the United States Forest Service for special permits into fire closure areas; and to the students, faculty, and staff of California State University, Northridge, for their patience and cooperation during completion of my thesis.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

INTRODUCTION

The goal of this section of the thesis is to provide enough basic information on rock texture, composition, paleontology, sedimentary structures, and vertical sequence to allow a detailed analysis of the environment of deposition.

Hand sample textural properties are classified according to Compton (1962, p. 214-215). Rock color and codes are from Goddard (1970). Cement, matrix, and major mineral compositions are visually estimated through petrographic analysis. Sorting and textural maturity are estimated according to Folk (1974, p. 102-105). Rounding classification is from Powers (1953). Sandstone, mudstone, and carbonate rocks are named with the Folk system (Folk, 1974, p. 147-148, 156-167). Genetic conglomerate names are from Pettijohn (1975, p. 165).

Plutonic rock fragments are classified according to the compositional limits used by the International Union of Geological Sciences (Streckeisen, 1973, p. 26). Volcanic rock fragments are classified according to Hyndman (1972, p. 35).

Sedimentary structures were identified and interpreted with comparisons from Reineck and Singh (1975). Cross bedding terminology and classification is from Reineck and Singh (1975, p. 14-46, 84-95).

Provenance interpretations of thin sections are from Folk (1974).

Fossils were collected from 35 localities in the upper Sespe Creek area (Plate I). Each locality is referred to by its California State

University, Northridge (CSUN) fossil locality number.

PRE-VAQUEROS ROCKS

SESPE FORMATION

STRATIGRAPHY AND LITHOLOGY

Stratigraphically below the Vaqueros Formation at all locations is the Sespe Formation. Exposures are varied in color from red to yellowish orange and in grain size from fine to medium sandstone and occasionally conglomerate. Bedding is tabular and lenticular, with larger lenses containing cobbles to the west. Pebbles consist mostly of sandstone clasts with some granitic, volcanic, and metamorphic clasts.

The contact with the Vaqueros lower member is usually covered and is difficult to follow between exposures in canyons, ridges, and road-cuts. In the eastern area, at Kimball Canyon and Piedra Blanca Creek, the contact is gradational over a 5 to 10 m interval. Near upper Piedra Blanca Creek, the contact may be unconformable, with the top 400 m of the Sespe Formation missing (Badger, 1957, p. 49).

The contact in the western area seems to be different because the Vaqueros units pinch out. Dickinson and Lowe (1966, p. 2465-2467) interpret the contact as conformable and interfingering over a 3.3 to 16.5 m interval. Hagen (1957, p. 52), Larson (1958, p. 36), and Gross (1958, p. 36) regard the contact as a disconformity. Field investigations show very little if any change in bedding attitude between Sespe and Vaqueros rocks, with the contact at any one point seeming to be conformable.

ENVIRONMENT OF DEPOSITION

The environment of deposition of the Sespe Formation is summarized below from Dickinson and Lowe (1966, p. 2467) and McCracken (1969, p. 42-43).

The Sespe Formation was deposited in stream and alluvial fan environments. Lower Sespe sandstone and conglomerate were deposited as lens-shaped sand and gravel bars and channels on a braided-bar plain which contained streams flowing south or east. Stream patterns suggest fan distributary systems at 3.2 km intervals along an east-west trend. The finer grain size and regular bedding below the Vaqueros reflect decreased slopes and current velocities on an alluvial plain. The depositing surface was smooth and even in the eastern area, but in the west, between Potrero John and Munson Creeks, the surface was uneven (Hagen, 1957, p. 53). West of State Highway 33 all parts of the Sespe coarsen to poorly sorted boulder conglomerate, which suggests that the alluvial plain graded westward into a fan environment.

VAQUEROS FORMATION

NOMENCLATURE

The name Vaqueros was first used by Hamlin (1904, p. 14) for exposures of coarse and pebbly sandstone in Los Vaqueros Valley, Monterey County, California. This original description of the type location was brief and did not define the boundaries of the formation. Thorup (1943, p. 463-466) restricted the definition to those rocks overlying continental beds and underlying marine shales and consisting of six members: a bottom massive sandstone, a siltstone, a coarse and pebbly sandstone, another siltstone, another coarse to pebbly sandstone, and a topmost fine to medium sandstone. The formation contains characteristic fossils which include *Turritella inezana* (Loel and Corey, 1932, p. 139-140).

Six major lithosomes are present in Oligocene to middle Miocene rocks along upper Sespe Creek. The oldest lithosome, which is red sandstone and conglomerate, is the Sespe Formation (Vedder and others, 1973; Dickinson and Lowe, 1966, p. 2464-2467; and Merrill, 1954). The youngest lithosome, which is yellow shale, is the Monterey Formation (Vedder and others, 1973, Dickenson and Lowe, 1966, p. 2467; and Merrill, 1954). The remaining four lithosomes, which are, from oldest to youngest, fossiliferous limestone, brown mudstone, sandstone, and brown foraminiferal mudstone, have been named Vaqueros, Rincon, and Monterey Formations by different authors (Table 1).

The brown foraminiferal mudstone occurs below a widespread bentonite bed. In Los Sauces Creek, 20 km south of Sespe Creek, mudstone below a bentonite bed and the Monterey Formation and above the Vaqueros Formation is named Rincon Formation (Kerr, 1931, p. 156). Rincon Formation is used as the name for the foraminiferal mudstone at Sespe Creek by Badger (1957, p. 45-51) and by Edwards (1971, p. 98-119) and in this thesis.

The limestone lithosome contains *Turritella inezana* and other fauna characteristic of the Vaqueros Formation. Although the lithology of the lower fossiliferous limestone is not similar to the type area, Loel and Corey (1932, p. 72) and Dickinson and Lowe (1966, p. 2467) correlate this unit to the Vaqueros Formation because of its faunal assemblage.

Table 1. Identification of major stratigraphic units in the Sespe Creek area.

<table>
<tr><th>LITHOLOGY</th><th>THIS PAPER</th><th>SHMITKA (1970)</th><th>BADGER (1957)</th><th>VEDDER AND OTHERS (1973)</th><th>DICKINSON AND LOWE (1966)</th></tr>
<tr><td>shale above bentonite</td><td>Monterey</td><td>Monterey</td><td>Monterey</td><td rowspan="2">middle shale Monterey</td><td>muddy phase Monterey</td></tr>
<tr><td>brown mudstone with foraminifera</td><td>Rincon</td><td>Rincon</td><td>upper member Rincon</td><td>(hiatus)</td></tr>
<tr><td>cross-bedded sandstone</td><td rowspan="2">upper member Vaqueros</td><td>Piedra Blanca member Vaqueros</td><td>Piedra Blanca member Rincon</td><td rowspan="2">lower sandstone Monterey</td><td rowspan="4">Vaqueros</td></tr>
<tr><td>sandstone</td><td>upper sandstone member Vaqueros</td><td>lower sandstone member Rincon</td></tr>
<tr><td>brown mudstone</td><td>middle member Vaqueros</td><td>middle member Vaqueros</td><td rowspan="2">lower member Rincon</td><td>Rincon</td></tr>
<tr><td>fossiliferous mudstone and limestone</td><td>lower member Vaqueros</td><td>lower member Vaqueros</td><td>Vaqueros</td></tr>
<tr><td>red sandstone, conglomerate</td><td>Sespe</td><td>Sespe</td><td>Sespe</td><td>Sespe</td><td>Sespe</td></tr>
</table>

The brown mudstone and sandstone lithosomes have been called Vaqueros (Loel and Corey, 1932, p. 72) and Rincon (Badger, 1957, p. 45). Badger (1957, p. 51) argues that because there is no resemblance to the Vaqueros at the type locality and because there is little difference between the brown mudstone and the foraminiferal mudstone, these two lithosomes should be called Rincon. However, the description of the Rincon Formation by Kerr (1931, p. 156) does not include sizable sandstone bodies.

The Vaqueros is highly variable in lithologic composition and few areas resemble the type locality. Macrofossils from the brown mudstone and sandstone, in addition to the limestone, correlate with the Vaqueros Stage. Therefore, the limestone, mudstone, and sandstone are considered together as the Vaqueros Formation, with each major lithosome an informal member.

AGE

The characteristic *Turritella inezana* fauna is in the "Vaqueros" megafauna stage of California (Loel and Corey, 1932, correlation chart) which is suggestive of an early Miocene age. Vaqueros microfaunal age is Zemorrian to early Saucesian (Kleinpell, 1938, p. 161, and correlation chart). The Zemorrian Stage is recently considered Oligocene (Bandy, 1972, p. 145). Because determination of the exact epochal age of the Vaqueros is not a necessary part of this thesis, it is important to refer only to a convenient local time-stratigraphic sequence. The California microfaunal stages are the most useful in correlating to other Vaqueros outcrops and shall be used here.

Microfossils from the Vaqueros in the upper Sespe Creek area are scarce because of secondary alternations of foraminifera. Collections by Evans (pers. comm., 1978) and Badger (1957, p. 50-51) indicate the Zemorrian-Saucesian boundary to be within or just above the upper member of the Vaqueros. Microfaunal ages are younger to the west, with the Zemorrian-Saucesian boundary in the western outcrop area near the top of the middle member (Gross, 1958, p. 37).

GENERAL STRATIGRAPHIC STATEMENT

Primary units for the stratigraphic descriptions and environmental interpretations are the three members of the Vaqueros Formation. The lateral and vertical relationships between these units are shown in detail on Plate II and generalized on Figure 3. Datum for this figure is a glauconitic sandstone bed at the top of the upper member, which, as suggested by Fritsche (1975, p. 318-319), is a recognizable lithologic correlation surface. Thickness of the Vaqueros Formation reaches a maximum at Kimball Canyon, where it is 325 m thick. Average thickness is 225 to 250 m. The formation thins to the west, and finally pinches out just west of State Highway 33. Generally, the lower member is moderately well exposed, the middle member is poorly exposed and covered, and the upper member is well exposed and commonly forms cliffs.

The members may be characterized as follows:

Lower member: fossiliferous coarse sandstone and limestone in thin tabular beds, interbedded with calcitic siltstone and mudstone beds; limestone and mudstone grade eastward and westward into fine sandstone.

Middle member: noncalcitic brown claystone, mudstone, and siltstone; poorly bedded; becomes silty and sandy to the west before

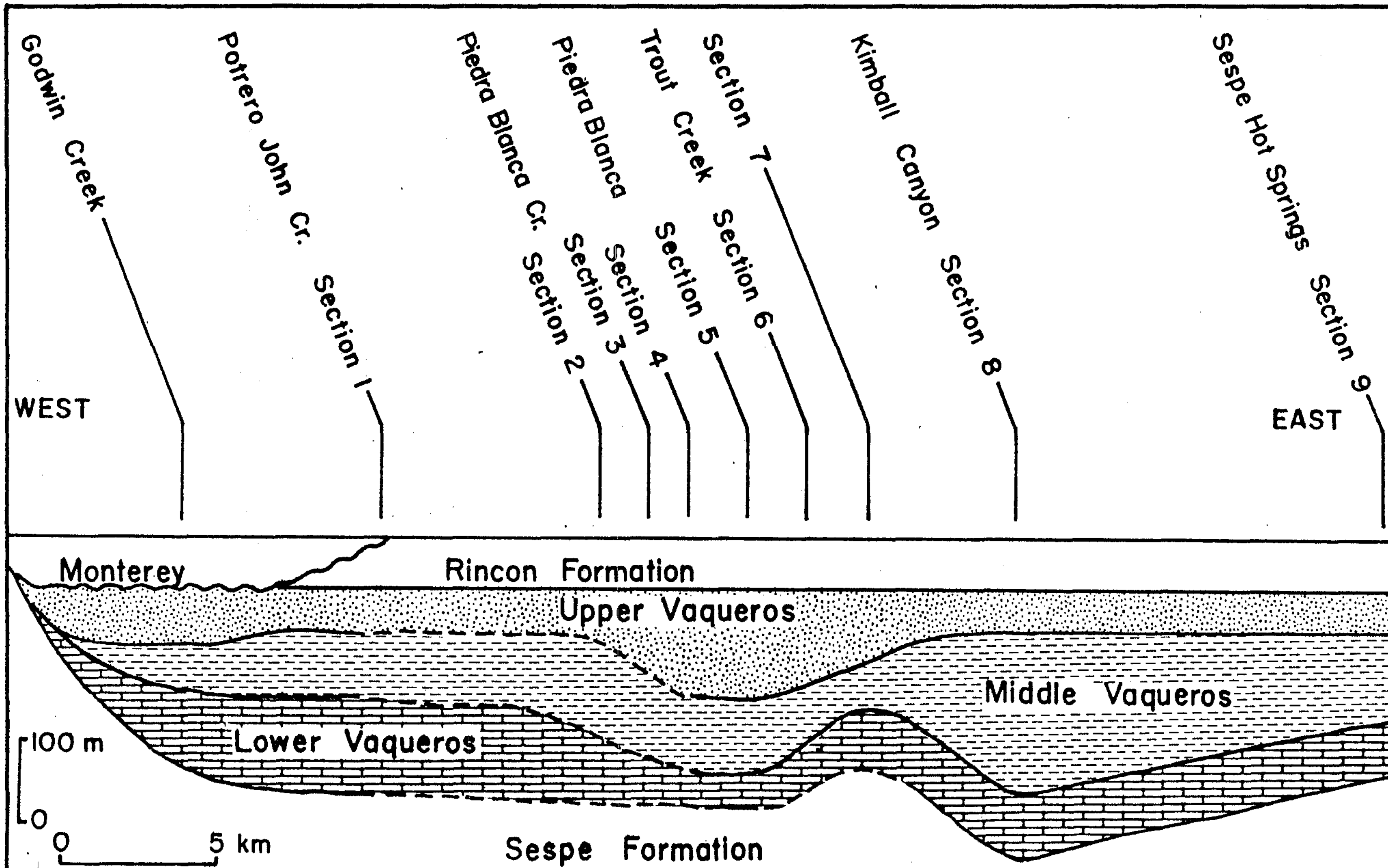


Figure 3. Lateral and vertical relationships of the three members of the Vaqueros Formation along upper Sespe Creek.

pinching out.

Upper member: resistant medium to coarse and pebbly sandstone, usually consisting of bedded fossil debris sandstone, massive and bioturbated medium sandstone, cross-bedded sandstone, pebbly mudstone and conglomerate, and massive glauconitic sandstone; grades westward into well sorted, cross-bedded, medium to coarse sandstone before pinching out.

DESCRIPTION OF LOWER MEMBER

GENERAL

The lower member, which consists of fossiliferous sandstone, mudstone, and limestone, is present at the base of all measured sections. Average thickness in the central and eastern areas is 65 m, with the thickest exposure at Kimball Canyon (section 9). The member is 60 to 115 m thick in the western area, but thins west of Munson Creek and pinches out entirely near the state highway. The shape of the member is variable and reflects possible irregularities on the top of the underlying Sespe Formation. Generally, it is tabular to broadly wedge shaped, thinning to the west and east and locally at section 7. Resistance of the unit is variable, with individual limestone and sandstone beds protruding through the brushy slopes (Fig. 4). The best exposures are on canyon floors.

The nature of the lower contact of the lower member has already been discussed. It is placed at the top of the last Sespe red bed, which is usually within a few meters of the first Vaqueros fossils.

The upper contact of the lower member is difficult to see because

Figure 4. Exposure of lower member in Trout Creek, showing outcrop of resistant *Turritella* limestone bed (center) and other fossiliferous limestone beds interbedded with mudstone.

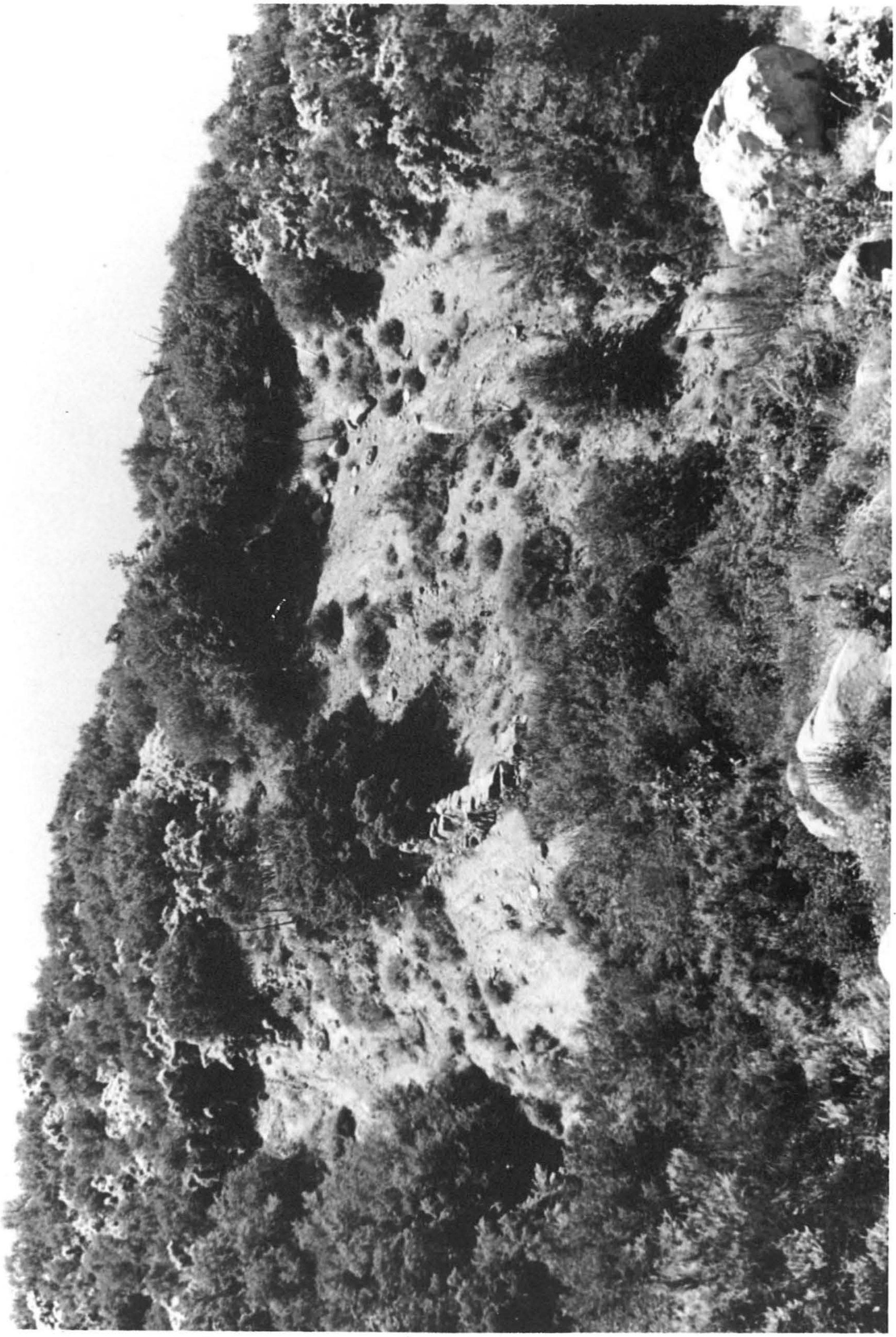


Figure 4

of brush. It is placed at the highest resistant fossil bed and usually is in the middle of a mudstone interval. The highest fossil bed commonly contains *Turritella inezana* or *Ostrea howelli*. The contact is difficult to recognize because the lithology on both sides is similar and the highest occurring fossil bed may easily be covered. However, it is an important place to divide the Vaqueros because it separates the highly fossiliferous lower mudstone, sandstone, and limestone from the overlying fossil-poor mudstone.

Bedding composition varies from east to west, although it is the most consistant in the eastern area. Average composition is 65 percent mudstone, 15 percent sandstone, present mostly near the base, and 20 percent limestone, present mostly in the middle and upper portions of the member. Variations in composition include 60 percent sandstone and 40 percent siltstone west of Munson Creek and up to 25 percent sandstone near Sespe Hot Springs. See Plate II for further details.

LOWER SANDSTONE

Lithology

Sandstone is usually the first lithosome above the contact with the Sespe Formation and commonly interfingers with the Sespe. Three types of sandstone are recognized in the lower member: a medium- to fine-grained calcitic sandstone, a medium- to fine-grained fossiliferous sandstone, and a resistant medium- to coarse-grained fossiliferous sandstone. The medium to fine sandstone beds are present at or near the Sespe contact. The medium to fine fossiliferous sandstone beds occur at all locations scattered throughout the lower member. The medium to coarse fossiliferous sandstone is limited to the lower third of the member west of Piedra Blanca Creek.

Bedding characteristics of the medium- to fine-grained sandstone are variable. Fresh color ranges from yellowish gray (5Y7/2) to pale reddish brown (10YR6/2) and greenish gray (5GY6/1). Exposures are poor and covered near the Sespe contact, but good higher in the member. Unit shapes are tabular or broadly wedge shaped. Stratification is shown by variations in color and grain size. The sandstone intervals average 3 m thick, but are 15 m thick in the western outcrop area. The intervals are entirely sandstone or interbedded with mudstone and limestone. The intervals may be internally structureless or bedded in 2 to 15 cm layers. Bedded sandstone may show interbedded mudstone partings every 40 to 70 cm. Interbedded mudstone is more common near the Sespe contact. Sedimentary structures are rare in the fine sandstone in the lower and upper thirds of the member. Greenish mudstone intraclasts 1 cm long are present near the Sespe contact at Potrero John Creek (section 1). Sedimentary structures of the middle third include locally moderate bioturbation by vertical burrowing and resistant fine sandstone lenses up to 40 cm thick. Ripple marks are present near Sespe Hot Springs (section 9). They are straight crested and lingoidal in shape with some crests bifurcating. Wavelength is about 6.5 cm. Interval boundaries are sharp.

An average fine sandstone tends to be bimodal, with 75 percent fine sand and 25 percent silt and clay. The rock is poorly sorted and immature. Individual grains are subrounded to angular, with several feldspar grains having an euhedral shape. There is no fabric. The rock is compact, and less than 5 percent of the volume is calcite cement. Composition is summarized in Table 2.

Variations from the average fine sandstone are common (Table 2). High in the member and in the western outcrop area, grain size increases and rocks are moderately sorted and submature. Larger grains are subrounded. Composition may include up to 35 percent fossil debris. This debris is 0.1 to 0.5 mm rounded and abraded fragments of barnacles, bivalves, and echinoids. The terrigenous composition and the calcitic cement remain uniform throughout the member.

Fossiliferous sandstone constitutes 3 percent of the total Vaqueros Formation and is scattered throughout the lower member. Color is in the gray hues: fresh surfaces light gray (N7), medium gray (N5), and yellowish gray (5Y8/1). Weathered surfaces are grayish orange pink (5YR7/2) to dark yellowish grown (10YR4/2). Fossiliferous sandstone is usually more resistant than the surrounding rock types and commonly protrudes through the slopes. Bed shape is tabular to broadly lenticular, with individual beds traceable for up to 0.5 km. The pinching out of the lower member in the western outcrop area results in wedge-shaped fossiliferous sandstone beds. Stratification is absent in many of the beds. Other sandstone beds show layering through their fossil components. *Kewia fairbanksi* and *Potamides sespeensis* are the two most common fossils that contribute to forming stratification. Fossil-laminated sandstone has layers 1 cm thick. Bed thickness varies from 0.1 to 1.5 m. Series of thinner fossiliferous sandstone beds commonly are interbedded with mudstone. Contacts of the fossiliferous sandstone beds are usually with mudstone and are shown by sharp changes in grain size and relief.

Table 2. Composition of lower sandstone thin sections.

	fine sandstone			with fossils		coarse ss	
	R3-1d	R5-1p	R3-2k	Pb-7	R4-5c	Pb-68	R4-1e
percent terr. framework	75	65	65	54	55	100	60
percent matrix	20	25	--	--	20	--	--
percent fossils	--	10	35	8	25	--	30
percent cement	5	--	--	38	--	--	10
framework elements:							
quartz	45	68	60	40	70	25	30
rock fragments	3	5	--	--	--	30	35
weathered feldspar	21	5	13	2	4	5	5
plagioclase	10	10	13	6	10	11	10
perthite	1	--	1	--	--	1	--
orthoclase	8	10	5	6	10	15	10
microcline	4	--	3	--	--	2	2
chert	5	--	4	1	--	10	3
opaques	2	2	1	11	3	--	--
glauconite	--	--	--	--	--	--	--
phosphate	--	--	--	32	2	--	--
other minerals	1	--	--	2	1	2	5

Characteristics of the fossiliferous fine sandstone lithosome may be summarized by R4-5c from Potrero John Creek (Fig. 5 and section 1). This rock shows well the relationship between sand and carbonate material that is common in the lower member fossiliferous sandstones. Just over half the rock is terrigenous material, with the rest being fossil debris and micrite (Table 2). Grain size ranges from 0.4 to .01 mm and averages very fine sandstone. No terrigenous clays are present, and the terrigenous material is moderately sorted and submature. Small grains have angular to subangular shapes, whereas the large sand grains are subrounded. Terrigenous composition is summarized in Table 2. The rock is an arkose. Unusual in the composition is the high amount of opaque material, which is pyrite, and the high amount of phosphate, which may be fish scales. Complete fossils may be present, but commonly fossil debris is a prime component of the framework. Fossil fragments are of angular gastropod, bivalve, and barnacle parts, and rounded echinoid fragments. Pore space is filled with micrite, which has been partially recrystallized. There is little variation amoung the fine fossiliferous sandstone beds.

Medium to coarse fossiliferous and unfossiliferous sandstone occurs in the central and western outcrop areas in the lower third of the member. It makes up one percent of the total Vaqueros Formation. Fresh color is light gray (N8) and weathered color is pinkish gray (5YR8/1). There are usually only two coarse sandstone beds per section. Thickness averages between 1 and 2 m, and the bed shape is tabular. The unit is very resistant and easily seen because of the resistant character. Stratification is variable and may be absent or shown by alternating

Figure 5. Photomicrograph of thin section R4-5c under normal polarized light showing distribution of fossils, sand, and micrite matrix. Gastropod at left is 5 mm in diameter. Angular sand grains average .15 mm in diameter.

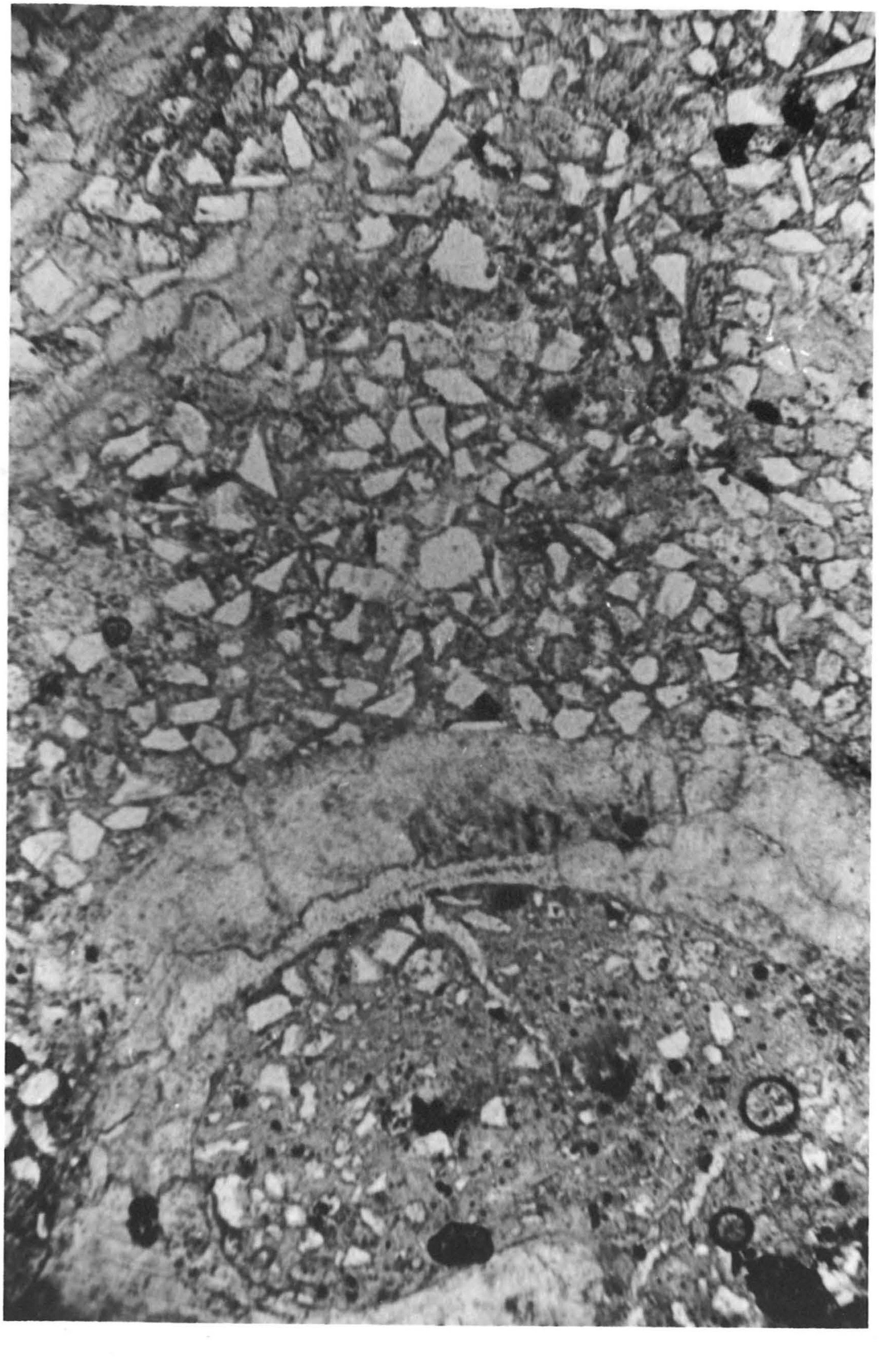


Figure 5

sandstone and *Potamides sespeensis* layers 1 cm thick. Sedimentary structures are rare and include cross bedding in wedge-shaped sets up to 0.4 m thick. Medium and coarse sandstone does not have other lithosomes interbedded. Contacts are sharp and usually with mudstone.

An average medium to coarse fossiliferous sandstone is 60 percent terrigenous framework, 30 percent fossils, and 10 percent calcite spar. Grain size ranges from 1 cm to .05 mm and averages medium sandstone. The coarser sand and granule grains are rounded, whereas the smaller grains are subrounded to angular. Terrigenous composition is summarized in Table 2. Rock fragments are a very important component of this rock and are 75 percent volcanic and 25 percent metamorphic and plutonic. The rock is a volcanic arkose. Fabric is shown by variations in grain size and the layering of fossil material. All fossil material is of individuals and fragments of *Potamides sespeensis*. This rock contained original pore space which has been filled with calcite spar.

Variations in the medium to coarse sandstone beds are concerned mostly with the fossil content. Fossil content varies from 0 to 40 percent. Those rocks with a higher percentage of fossil material approach being fossil hash. Fossils are either whole or extremely broken and rounded into 1 to 5 mm fragments. Fragments are of gastropods, bivalves, and barnacles. Other textural properties, such as grain size, sorting, maturity, and composition remain uniform.

Fossils

Fossils present in lower member sandstone beds are in Table 3, the position of CSUN fossil localities is shown on Plate I, and the stratigraphic position of the fossil localities is shown on Plate II.

Table 3. Lower sandstone fossils.

	CSUN 398	CSUN 410	CSUN 415	CSUN 416	CSUN 417	CSUN 419	CSUN 421	CSUN 424
Echinodermata								
Kewia fairbanksi	A							
Gastropoda								
Potamides sespeensis		A	A	A	A			
Turritella inezana						C	C	C
Bivalvia								
Anadara santana							C	
Anomia vaquerosensis							R	R
Chione sp.							C	
Macoma sp.							R	

A = abundant   C = common   R = rare

The characteristics of each species occurrence in the lower member sandstone are summarized below:

Kewia fairfanksi is present in one or two sandstone beds in locally large concentrations in the eastern, central, and western outcrop areas. This sand dollar is usually complete and well preserved, with the flat side down parallel to the bedding plane. When present in great numbers, the sand dollars are piled on top of each other, giving the rock a layered appearance. They are not usually associated with other fossils.

Potamides sespeensis is present in all areas except the extreme west. It is present in 0.1 to 1 m thick sandstone beds in the lower third of the member. Three to five beds are usually present. *Potamides* is usually whole and aligned and defines laminations in the sandstone. In other places *Potamides* occurs as debris in aligned and layered sandstone. This fossil is always abundant when present. Recrystallization of shell material is common.

Turritella inezana is a very common Vaqueros fossil and is present in several 10- to 50-cm-thick beds in the upper half of the lower member. The fossils are unoriented and unsorted in massive immature fine sandstone. *Turritella* is usually found in association with *Chione* sp., *Anomia vaquerosensis*, *Macoma* sp., and *Anadara santana*. These other fossils are present in minor amounts as angular fragments. They are thoroughly mixed with *Turritella*. This faunal assemblage commonly has a fossil debris matrix.

LOWER LIMESTONE

Lithology

Limestone is one of the most distinctive lithosomes in the lower member of the Vaqueros Formation. Three types are present: biomicrudite which contains an abundance of shell debris; biomicrite which lacks the shell debris; and a transitional group between the other two limestone types. The biomicrudite is present in the eastern outcrop area in the lower third of the member. The biomicrite and transitional limestone is present in all outcrop areas at all levels of the member. Fossils that mark the top of the member commonly occur in limestone beds. For a more complete description of limestone distribution see Plate II.

The biomicrudite is present only in 2 to 3 beds in the lower third of the member. Color is light gray (N7) to yellowish gray (5Y7/2). Exposures are very good because these beds usually protrude through soil and brushy slopes like a 1 to 2 m wall. The limestone beds are 0.5 to 4 m thick, have a tabular shape, and may be followed for several kilometers. Bedding is rare in the limestone and when present is shown by oriented *Potamides sespeensis*. No other sedimentary structures or lithosomes are present within the limestone. The biomicrudite beds have sharp boundaries with other units, which are usually sandstone and mudstone. The contacts are easily seen by the sharp change in relief of the limestone.

An average biomicrudite is R2-2f from section 8 at Kimball Canyon (Fig. 6 and Table 4). Terrigenous material is absent. Allochemical framework is 80 percent fossil debris and 20 percent pellets. The fossil material is 0.5 to 15 mm in size, averages 2 mm, and is poorly sorted. Fragments are angular to subrounded. There is no fabric. Fossil debris consists of fragments of bivalves, gastropods, and barnacles. Pellets are 0.1 mm in size, spherical in shape, and are locally concentrated into patches 2 to 5 mm in diameter.

Variations in the biomicrudite beds are common. Allochemical framework ranges from 24 to 90 percent of the rock. The shell component may be of one single fossil type or a mixture of bivalve, gastropod, barnacle, echinoid, and foraminifera parts. Pellets are usually rare, but they may be up to 37 percent of the allochems. Debris size and the lack of sorting remain constant.

Biomicrudite may contain up to 40 percent terrigenous material of well sorted fine sand and silt. Grains are subangular. Micrite supports the terrigenous material.

Transitional and biomicrite lithosomes consist of whole and large fragments of identifiable fossils in a matrix of sand, silt, clay, and micrite. Fresh color is pale brown (5YR5/2) to yellowish gray (5Y7/2); weathered is very pale orange (10YR8/2) to grayish orange (10YR7/4). Topographic exposure is moderate to poor, with these limestone beds

Figure 6. Photomicrograph of thin section R2-2f under normal polarized light showing 0.1-mm-diameter pellets (lower left) and angular 1- to 2-mm-diameter bivalve fragments.

Figure 6

Table 4. Composition of lower limestone thin sections.

	shelly					transition		normal
	R1-2d	R1-3d	R2-1a	R2-2f	Pb-8	R5-2i	Pb-38	R2-10c
percent terr. fmwk	6	40	35	--	--	60	--	12
percent allochems	24	25	30	60	40	10	35	30
percent micrite	70	35	30	40	60	30	65	48
percent cement	--	--	5	--	--	--	--	10
fmwk size (mm)	.25-.5	.01-.2	.05-.5	--	--	.05-.5	--	.05
fossil size (mm)	.25-8.	.2-5.	.3-10.	.5-15.	.2	--	5.-30.	.5-18.
allochem types:								
gastropod	*	90	15	12	--	100	--	60
bivalve	--	--	40	40	100	--	90	--
echinoid	--	5	15	--	--	--	10	--
barnacle	*	--	20	8	--	--	--	--
phosphate	--	1	--	--	--	--	--	--
pellets	--	3	--	20	--	--	--	37
other	--	1	10	20	--	--	--	3

* = present but precent not determined.

seen only in steep canyons with little soil and brush cover. Limestone may be unstratified or consist of oriented and layered fossil fragments. Beds are usually 20 to 30 cm thick and interbedded with mudstone. Two to three limestone beds containing *Turritella inezana* are present in 1 to 2 m intervals near the top of the lower member. Sedimentary structures are rare. Bed contacts are usually sharp, but may be gradational with mudstone.

Characteristic biomicrite composition is 12 percent terrigenous framework, 30 percent allochemical framework, 48 percent micrite and clay, and 10 percent spar cement. The terrigenous framework is angular silt-sized grains of quartz and feldspar. Carbonate framework consists of 0.5 mm fossil fragments, complete individual fossils, and pellets. Fossil fragments are angular and poorly sorted. Fossil composition is 90 percent gastropods, 4 percent foraminifera, 2 percent bryozoa, and 4 percent unidentified. No fabric is present. The framework is supported by a mixture of micrite and terrigenous clay.

Factors influencing variation in the limestone are the amount of terrigenous material and fossil debris. A complete series exists between silty biomicrudite and calcitic siltstone.

Fossils

The fossils present in lower member limestone beds are on Table 5, the CSUN fossil localities on Plate I, and the stratigraphic position of the fossil localities on Plate II. The characteristics of each species' occurrence in the lower member limestone are summarized below.

Potamides sespeensis is usually associated with the biomicrudite beds low in the member. It occurs in thin beds 10 to 30 cm thick.

Table 5. Lower limestone fossils.

	CSUN 400	CSUN 401	CSUN 402	CSUN 405	CSUN 406	CSUN 407	CSUN 408
Gastropoda							
Potamides sespeensis		A		A			
Turritella inezana			A			C	
Bivalvia							
Anadara santana							A
Anomia vaquerosensis	C				C		C
Chione sp.						C	
Macoma sp.						A	
Arthropoda							
crab claw	R						

A = abundant C = common R = rare

Shells are commonly oriented in two directions and layered. Over 75 percent of *Potamides* material is present as angular fragments. It is not associated with other fossils.

Turritella inezana limestone beds are very common in the eastern outcrop area. They are frequent in the middle and upper parts of the lower member in beds 20 to 40 cm thick. *Turritella* is seldom whole and most commonly found in fragments up to 5 cm long. They may be randomly oriented or, more commonly in the lower part of the member, have their apices aligned. *Turritella* is usually found by itself in the lower half of the member and with abundant *Macoma* and rare *Chione* higher in the section. The higher occurrences have larger, less fragmented individuals of *Turritella* and *Macoma* with paired valves.

Biomicrudite low in the section commonly contains fragments of *Anomia vaquerosensis*. Fragments of *Anomia* up to 5 cm are present. These limestone beds contain up to 90 percent fossil debris of *Anomia* debris plus other unidentifiable shell debris. One crab claw was found in association with the *Anomia* debris. The claw is preserved in a burrow.

Anadara santana is present in the upper third of the lower member in the western outcrop area. Present are 3-cm complete individuals and fragments up to 2 cm. The matrix contains 10 percent fossil debris of *Anomia*.

LOWER MUDSTONE

Lithology

Lower member mudstone and siltstone beds are present at all locations except to the extreme west. It is the major rock type of the lower member and all limestone and sandstone beds are interbedded with this lithosome. Mudstone occurs at the Sespe contact, interbedded with sandstone low in the member, and interbedded with fossiliferous limestone higher in the section. Mudstone is more common toward the top of the lower member. Two types of mudstone are distinguished: pure mudstone that lacks visible fossils and fossiliferous mudstone which contains large fragments and whole individuals. The fossiliferous mudstone is present only in the lower half of the member, whereas the pure mudstone is present throughout the member.

The pure mudstone is 50 percent of the lower member. Fresh color is medium dark gray (N4), grayish orange (10YR7/4), and grayish green (10GY5/2). Weathered surfaces are light olive gray (5Y6/1), grayish brown (5YR3/2), and moderate reddish brown (10R4/6). The mudstone forms nonresistant slopes and poor exposures. Mudstone is commonly covered with soil and brush (Plate II). Unit shape is difficult to determine because of the poor exposures. Thickness varies from 10 cm between sandstone beds to 20 m near to top of the member. Mudstone is commonly interbedded with sandstone and limestone in 1 to 2 m intervals. Internally, there are few sedimentary structures, although a conchoidal weathering pattern gives the impression of bedding. Moderate bioturbation is present in some areas in the lower third of the member. Mudstone boundaries with the more resistant bed types are sharp and with fossiliferous mudstone are gradational.

Lower pure mudstone is usually calcareous and contains up to one third micrite. Grain size is very small, with some sand present, but mostly silt and clay. Texturally the mudstone lithosomes are classified as siltstone, mudstone, and claystone. Claystone is most abundant near the top of the member. Siltstone is more common in the western outcrop area. An important heavy mineral component is pyrite, which may make up to 4 percent of the mudstone, and is commonly present as a secondary replacement of foraminifera. Pyrite later is replaced with hematite or limonite.

Fossiliferous mudstone is medium gray (N4) to yellowish gray (5Y7/2) on a fresh surface and very pale orange (10YR8/2) on a weathered surface. Exposures are poor because the nonresistant fossiliferous mudstone forms gentle slopes and bears a dense brush cover. Outcrops are limited to canyon bottoms. Beds vary in thickness from 10 cm when interbedded with sandstone to over 10 m. A crude layering is sometimes apparent by the alignment of fossils. Fossils are usually complete or in nearly complete fragments. They are seldom present in large concentrations, but usually are scattered throughout the mudstone. No sedimentary structures are present. Fossiliferous mudstone bed boundaries are commonly gradational with the pure mudstone and sharp with other rock types.

Texture and composition are similar to the pure mudstone beds. All fossiliferous mudstone beds are calcareous and contain micrite. Shell debris may be present, but is never more than 10 percent of the rock. Heavy minerals present include original pyrite and secondary hematite and limonite. Fossiliferous mudstone is usually siltier than the pure mudstone. Siltstone is most common in the western outcrop area, whereas the eastern area is predominantly fossiliferous claystone and mudstone.

Fossils

The fossils present, the location of the CSUN fossil localities, and the stratigraphic position of the fossil localities are shown on Table 6, Plate I, and Plate II. The characteristics of each species' occurrence in the lower member mudstone beds are summarized below.

Rapana vaquerosensis is present in the lower half of the member. Individuals are whole or slightly chipped. Fragments are uncommon. Size ranges from 4 to 10 cm. Only a few individuals are present at a location. Associated with *Rapana* are complete and oriented *Potamides*, complete *Mytilus*, fragments of *Anomia*, and complete paired molds of *Macoma*.

Ostrea howelli is present near the top of the member at every location except to the west of Munson Creek. *Ostrea* is found in 1 to 4 m beds of siltstone and mudstone that lack other fossil types. Valves are large and average 10 cm. Most valves show much of their original detail, and a few are articulated. It could not be determined if *Ostrea* was in its original growth position, but the condition of the fossils

Table 6. Lower mudstone fossils.

	CSUN 399	CSUN 400	CSUN 403	CSUN 408	CSUN 409	CSUN 411	CSUN 412	CSUN 413	CSUN 414	CSUN 417	CSUN 420	CSUN 422	CSUN 423	CSUN 426	CSUN 427	CSUN 429	CSUN 430	CSUN 435
Gastropoda																		
Potamides sespeensis		A																A
Rapana vaquerosensis		R				R	R											R
Ocenebra dorrancei ?			R															
Turritella inezana	C		C									C	C				C	
Bivalvia																		
Anadara santana												C	C				C	
Anomia vaquerosensis							R											
Chione sp.			C									C	C				C	
Clementia sp.			R															
Dosinia margaritana	R																	
Macoma sp.		R	C									C	C				C	
Mytilus sp.							R											
Ostrea howelli											C					C		
unidentified bivalves					R	R		R	R	R				R	R			
Vertebrata																		
fish tooth				R														

A = abundant C = common R = rare

suggests little transport.

Molds of several unidentified bivalves are common in the lower third of the member. They are 2 to 6 cm long, usually very thick, and are always articulated. *Macoma* is occasionally present with the unidentified bivalves.

Well preserved *Turritella inezana* fragments are common in the upper half of the member. Individuals are smaller than the turritellids found in the limestone beds. Fragments may be up to 5 cm long and unoriented in a muddy matrix. Many fossils are found in association with *Turritella*. *Macoma* is present as fragments and complete paired and unpaired shells. *Anadara santana* is complete but disarticulated. *Chione* is abundant and complete, but unpaired. Rare occurrences are of *Clementia* fragments, one complete *Ocenebra dorrancei*, and a fragment of *Dosinia margaritana*.

DEPOSITIONAL ENVIRONMENTS OF THE LOWER MEMBER

INTRODUCTION

The lower member of the Vaqueros Formation represents a transgressive sequence of environments from a distal floodplain to a bay or large lagoon. Several subenvironments of the bay exist: muddy beach, bay margin, shallow grassy hypersaline bay, open bay center, and inlet influenced hypersaline bay (Fig. 7). This bay will be referred to as Sespe Bay, which may have been part of the much larger Ventura Bay of Loel and Corey (1932, opp. p. 50).

This environmental interpretation of the lower member is modeled from modern protected bays behind barrier islands of the central and

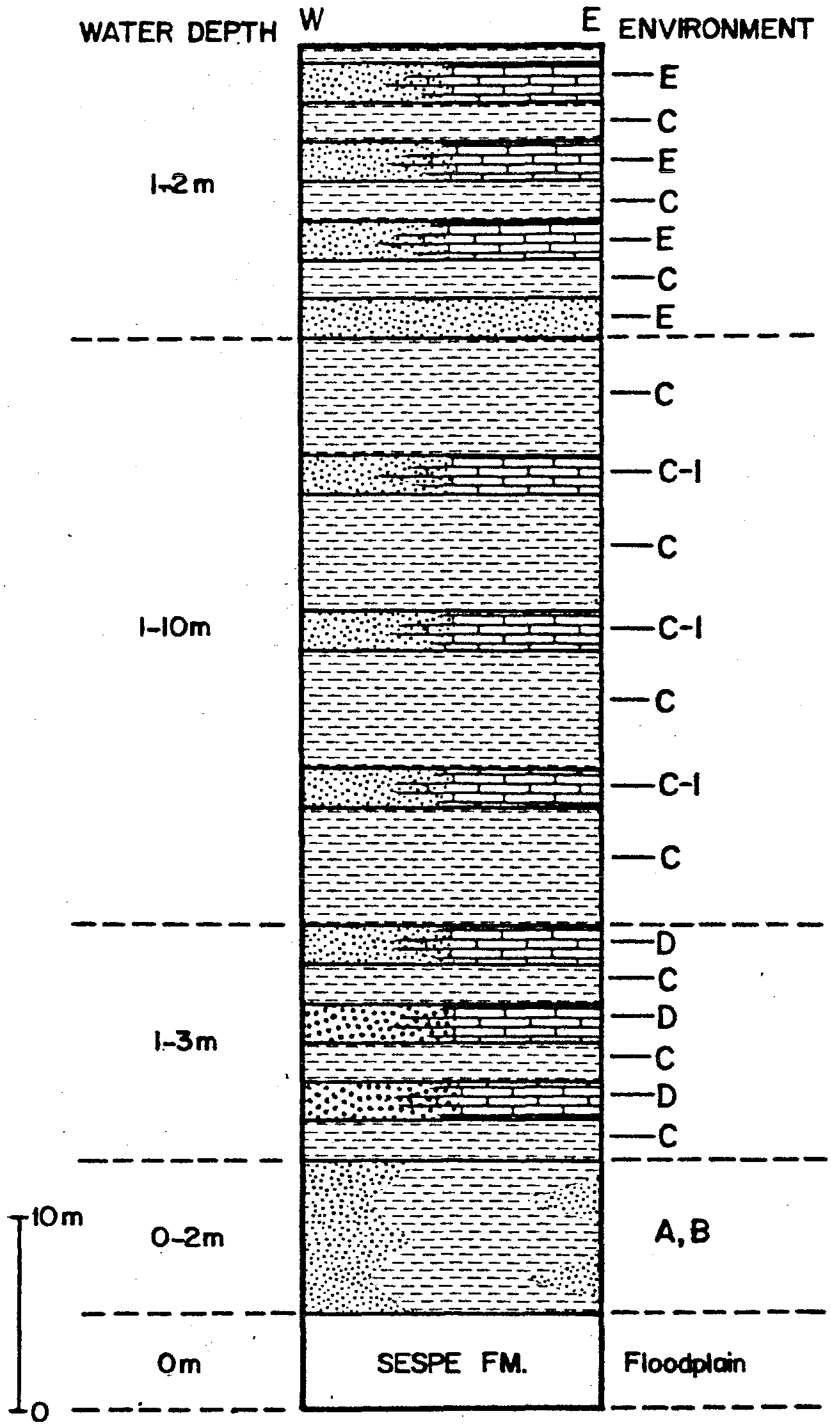


Figure 7. Generalized lithology and sedimentary environments of the lower member. Letters show stratigraphic position of environments: (A) muddy beach, (B) marginal bay, (C) open bay, (C-1) swell-lag deposits, (D) shallow grassy bay, (E) inlet influenced bay.

southern Texas coast. Detailed comparisons are with bays in the Rockport area (Shepard and Moore, 1955; Parker, 1959) and the Laguna Madre area (Parker, 1959). The bays are characterized by their restricted circulation, high salinity, and water depth of no more than 3 m. Variations in temperature and salinity are moderate to extreme. Climate is humid to semiarid and there is little fresh water influx. Sedimentation rates in the southern bays are slow.

The analogy to the Texas bays does not include the barrier islands. There is no evidence of their existence during Vaqueros time. Some other factor must be responsible for the restricted circulation in Sespe Bay.

Several Vaqueros genera are in a variety of ancient bay subenvironments. For this reason, the ecology of the fossils will be discussed before the subenvironment interpretations.

FOSSILS

Many of the fossil genera that occur in the lower member are still living today in Pacific Coast environments (Table 7). Many of the Vaqueros fossils, such as *Macoma*, *Potamides*, and *Rapana*, are complete, indicating little transport from their original living environment. Others, such as *Ostrea* and *Anadara*, are mostly disarticulated and no longer in the living positions, but the lack of shell damage again indicates little transportation following death. Therefore, the ecology of modern genera should correlate very closely to the environment of deposition of most of the Vaqueros fossils. Environmental conclusions for *Turritella* and *Anomia* are approximate because their fragmental nature indicates some port-mortem transport or abrasion.

Table 7. Ecology of modern genera present in the Vaqueros lower member (from Keen, 1963, p. 99-108; Parker, 1959; and Reid, 1967, p. 48).

GENERA	ENVIRONMENT
Potamides	Intertidal, on mudflats
Turritella	5 to 50 m
Anadara	Intertidal to 35 m, on sand
Anomia	Intertidal to 12 m, attached to rocks or shells
Chione	Intertidal to 12 m, on sand or mud
Dosinia	In tidal inlets
Macoma	Intertidal to 150 m, in sand or mud
Mytilus	Intertidal, attached to rocks by byssus
Panopea	Intertidal, buried about 1 m in sand or mud
Ostrea	Intertidal to 40 m, cemented to objects
Balanus	Intertidal, cemented to rocks

Analysis of Table 7 shows the overwhelming dominance of genera in the intertidal to 50 m depth range. *Dosinia*, *Mytilus*, *Potamides*, and *Balanus* indicate subtidal through intertidal environments. Bottom sediment type is variable. Further information on *Turritella*, *Potamides*, and *Ostrea* follows.

The ecology of *Turritella* is summarized by Merriam (1941, p. 10-17). *Turritella* is a bottom-dwelling, creeping gastropod found from below the intertidal zone to a depth of 150 m. In shallow areas it lives sheltered from strong currents. *Turritella* only lives in water with normal salinity and reaches maximum size and numbers in tropical water, although it may be present in cool water. The genus commonly occurs in communities of enormous numbers. The type of bottom sediment is unimportant to the *Turritella* life style.

The ecology of *Potamides* is summarized by Rogers (1951, p. 181). *Potamides* lives in the intertidal zone in tropical brackish waters. It is able to live for long periods above water suspended by threads attached to marine grasses. *Potamides sacrata* lives on the California coast in abundant numbers on muddy flats that are exposed at low tides.

The ecology of *Ostrea* is summarized by Hopkins (1957, p. 1129). Oysters are sedentary and live cemented to the substrate commonly on muddy bottoms. *Ostrea* lives in calm to moderately turbid water of near normal salinity in depths ranging between intertidal to 40 m (Keen, 1963, p. 106). It does not form massive reefs.

MUDDY BEACH

The lowest Vaqueros mudstone and poorly sorted fine sandstone represent an intertidal environment. This interval of rock is 5 to 20 m thick and is between the highest Sespe red beds and the lowest Vaqueros fossil beds. The poorly sorted fine sandstone and mudstone suggest weak, unwinnowing currents and the lack of laminations suggests a uniform current strength. The presence of pyrite indicates reducing conditions and suggests calm water. The stratigraphic position of the fine sandstone and mudstone between continental red beds and marine fossil beds indicates a beach environment, but normal beach features, such as winnowed sands, flaser and lenticular bedding, scouring, and channeling, are absent.

Walker and Harms (1975) have found a similar stratigraphic sequence in the Catskill Formation of central Pennsylvania and have identified the environment as a shoreline of weak tidal activity. They identify three criteria for the recognition of a low tidal range: the absence of channels, which would form from the runoff of a moderate tidal influence; the close vertical association of marine and nonmarine environments; and the absence of winnowed sands. The lowest Vaqueros deposits contain all these criteria.

A modern example of a muddy shoreline similar to that represented by the lowest Vaqueros deposits is along the southwestern Louisiana coast (Morgan and others, 1953, p. 15). Tidal and wave action on this section of the Gulf Coast is minimal because of the very broad, flat shelf off the Louisiana coast. Incoming clastic material is limited to silt and clay. As a result, only mud is available to be deposited on the shore.

BAY MARGIN

Closely associated with the muddy beach environment is the marginal bay environment. Marginal bay deposits are the lowest rocks of the Vaqueros Formation in the western outcrop area where they were deposited in place of the muddy beach deposits found further east. The deposit that formed in this environment is medium- to fine-grained, moderately to poorly sorted sandstone. Similar ranges in grain size and sorting are reported by Parker (1959, p. 2126) for the bay margins in the Rockport area of Texas. The bay margin environment includes deposits of the shoreline down to the base of the beach slope, which is usually within 0.5 km of the shoreline (Shepard and Moore, 1955, p. 1529).

The moderately to poorly sorted, medium to fine sandstone indicates moderate to weak currents in a slightly winnowing environment. The lack of laminations suggests constant current strength. The stratigraphic sequence above continental beds suggests a beach environment and the lack of sedimentary structures and well sorted sandstone indicates a low tidal range (Walker and Harms, 1975). The presence of *Anomia*, *Anadara*, and *Chione* suggests water depths of less than 12 m and a sandy sea floor (Keen, 1963, p. 99-108).

Other characteristics of the Vaqueros marginal bay environment are inferred from the modern Texas bays described by Parker (1959, p. 2108, 2161-2164). Water depth ranges from the shoreline down to the beach slope base of up to 1.5 m below sea level. Salinities range from 3 to 69 parts per thousand and average higher than normal open oceanic.

OPEN BAY CENTER

Most of the sandstone and mudstone above the muddy beach and marginal bay deposits formed in an open bay center. This includes all fossiliferous mudstone and sandstone except those beds with abundant fossils of diverse types. The open bay center environment is one of the most difficult to determine because of its similarities to the open shelf environment (Parker, 1959, p. 2124-2125), but the close stratigraphic association of this Vaqueros environment to the muddy beach and marginal bay environments indicates a bay, rather than an open shelf.

The fine sandstone and mudstone of the lower member represents slow, constant deposition by weak, unwinnowing currents. The deposition of calcite indicates a pH of greater than 7.8 and the presence of pyrite indicates an oxygen poor and reducing environment (Pettijohn, 1975, p. 423). *Choine*, *Macoma*, and *Anadara* indicate water depths of 0 to 50 m (Keen, 1963, p. 99-108) and the presence of complete *Mytilus* and

Panopea, and fragments of *Balanus* indicate close-by rocky shorelines and mudflats.

An environment with very similar characteristics exists in the Rockport area and is termed open high-salinity bay center (Parker, 1959, p. 2108, 2124-2126). Water depth is between 1 and 4 m. Salinities vary from 5 to 42 parts per thousand, but average slightly higher than the normal open ocean. Bottom sediments consist of sand, silty sand, clayey sand, and silty clay. Currents are weak. Mollusks are rare because the fine-grained bottom sediment is unfavorable for their survival, but other fauna lacking hard parts is present (Parker, 1959, p. 2158), which may help to explain the scarcity of fossils in the lower mudstone. Common genera in the Rockport area include *Chione*, *Anomia*, *Anadara*, and *Macoma*, the same genera that occur in the Vaqueros. *Ostrea* is present in areas of reduced circulation and higher salinity (Parker, 1959, p. 2123).

The interbedded and abundantly fossiliferous and somewhat shelly sandstone, mudstone, and limestone beds require additional interpretation. Brongersma-Sanders (1957) describes several methods for the concentration of a large amount of shell fragments in a bed. A sudden, drastic change in salinity may be fatal to open ocean species living near bay or lagoon inlets. Severe change in temperature, also possibly fatal, is known to occur in shallow water at low latitudes. Both of these environment variations occur regularly in the Rockport area (Parker, 1959, p. 2108-2109) and may have occurred to concentrate shell debris in the lower Vaqueros.

Another factor contributing to fossil concentration may be the effect of storms over Sespe Bay. Beds containing debris of *Balanus* may be storm-lag deposits, which are deposits formed from the transportation, fragmentation, and reorganization of shell material, sand, and silt by the passage of storm waves (Brenner and Davies, 1973, p. 1690-1692). The deeper water, fragmented *Turritella* may have been introduced into a shallower environment in this manner. A more common occurrence may be swell-lag deposits. These thin, shelly mudstone beds contain complete fossils which have been slightly moved and sorted from the sediment by the passing of a large swell (Brenner and Davies, 1973, p. 1692-1694). Individual beds, such as those containing *Ostrea*, *Chione*, *Anadara*, *Kewia*, *Anomia*, and some *Turritella* may be swell-lag deposits.

Alternately, the production of shell debris may be a normal function of the depositional environment. A buildup of shell debris may occur in areas of low terrigenous influx. For example, shell debris is forming today on the Kodiak Shelf and Cook Inlet of Alaska in 100 m of water (Colburn, pers. comm., 1978).

SHALLOW GRASSY BAY

All beds containing *Potamides* formed in a shallow, grassy lagoon or bay. Deposits of this environment are interbedded with those of the open bay environment in the lower third of the member. Other beds forming in this environment are the resistant limestone beds of the eastern outcrop area and fossiliferous medium to coarse sandstone in the western outcrop area.

The presence of *Potamides* in the lower member suggests deposition in the intertidal zone and in brackish, tropical water (Rogers, 1951,

p. 181). *Potamides* is usually oriented and aligned, indicating current activity to sort the shell debris. The association of medium and course sand with *Potamides* in the western area is further indication of a moderately strong, sorting current. *Potamides* in limestone beds indicates slow sedimentation rates.

The modern analogy is Redfish Bay near Rockport (Parker, 1959, p. 2109, 2132-2139; Shepard and Moore, 1955, p. 1529-1530), which contains environmental conditions probably similar to those that existed in Sespe Bay. Water depth is 1 to 2 m. Salinity is variable from 11 to 40 parts per thousand but averages higher than normal open oceanic salinity. No fresh water streams enter into the bay. The bottom of Redfish Bay is flat and has sediment of sand and shell fragments. The sand may come from inlet influenced tidal deltas. The shallow, warm, and clear water of the bay supports marine grasses that cover the bay bottom and grow quickly in the warm, shallow, transparent water. The grass in turn supports a large population of *Cerithidea*, a member of the same family as *Potamides*. Currents near the inlets are strong and supply sand, but sedimentation rates are low in other nearby areas.

Potamides-bearing beds represent a special time in Sespe Bay when patches of marine grass locally covered the bay floor. The grass supported enormous numbers of *Potamides*. Lime accumulated in areas of weak current activity and low sedimentation in the eastern outcrop area, whereas sand accumulated, perhaps near a tidal inlet, in areas of moderate currents in the western area.

Micrite in the modern Rockport model (Shepard and Moore, 1955, p. 1529-1532) is not as abundant as in the *Potamides* limestone of the Vaqueros, so the model must be amended to explain the presence of the limestone. Clearly limestone beds represent times of slow terrigenous deposition. The interbedding of micrite and high energy sand deposits indicates a shallow water environment (Folk, 1974, p. 171). Micrite may form from the direct chemical precipitation of calcite, or from the release of minute aragonitic needles in the degradation of algal tissue (Pettijohn, 1975, p. 334). Trapping of the micrite thus produced may then occur by a method similar to that in Florida Bay, where meadows of the sea grass *Thalassia* baffle turbulent waters and allow carbonate mud deposition (Pettijohn, 1975, p. 318). Matthews (1966) believes the origin of carbonate mud in turbulent waters is from the physical breakage and abrasion of shell material. Both grassy and turbulent conditions are thought to have existed in the shallow Sespe Bay, so either of the above procedures could have produced micrite during deposition of the Vaqueros.

INLET INFLUENCED BAY

This special facies of the open bay center environment is based on an assemblage of five genera found in both the lower Vaqueros and the modern bay model. This association of *Anadara*, *Anomia*, *Chione*, *Macoma*, and *Ostrea* occurs in mudstone and fine sandstone in the middle and upper portions of the lower member. The entire fossil assemblage indicates water depths between intertidal and 12 m (Keen, 1963, p. 99-108).

Properties of the modern Texas inlet influenced bay environment are summarized by Parker (1959, p. 2109, 2141-2143). Water depths range from 1 to 10 m and average 1.5 m. Salinity varies from 11 to 40 parts per thousand, but is usually close to that of the open ocean. Bottom sediments are sandy silt and a mixture of sand, silt, and clay. Currents are occasionally strong. The fauna is similar to that of the Gulf of Mexico, with a great diversity of species, but a smaller number of individuals.

The association of the five genera in the ancient environment indicates a strong influence of normal sea water into the outer bay area. This may indicate that late in the lower member, some of the physical barriers which had been restricting circulation broke down or were covered by rising water of the transgression.

PALEOCURRENT ANALYSIS

All current direction information is from beds in the lower third of the lower member. Current indicators are rare in the member and limited to sandstone and shelly fossiliferous limestone.

Oriented fossil samples from four locations are aligned *Potamides* shells of the grassy shallow bay environment. The smaller, pointed end of this small gastropod points in the direction of current flow unless the average orientation of many individuals is bipolar, in which case an oscillating current is indicated perpendicular to the bipolar direction (Fritsche, pers. comm., 1978). Measurements were taken from acetate peels that were made from slabs cut parallel to the bedding of the samples. The rose diagrams (Fig. 8a-d) show the orientation of 43 to 102 measurements per sample that have been restored to original horizontality.

The only location containing ripple marks is near the base of the section near Sespe Hot Springs in fine sandstone. The ripples are symmetrical, and suggest an oscillating bimodal current direction (Fig.

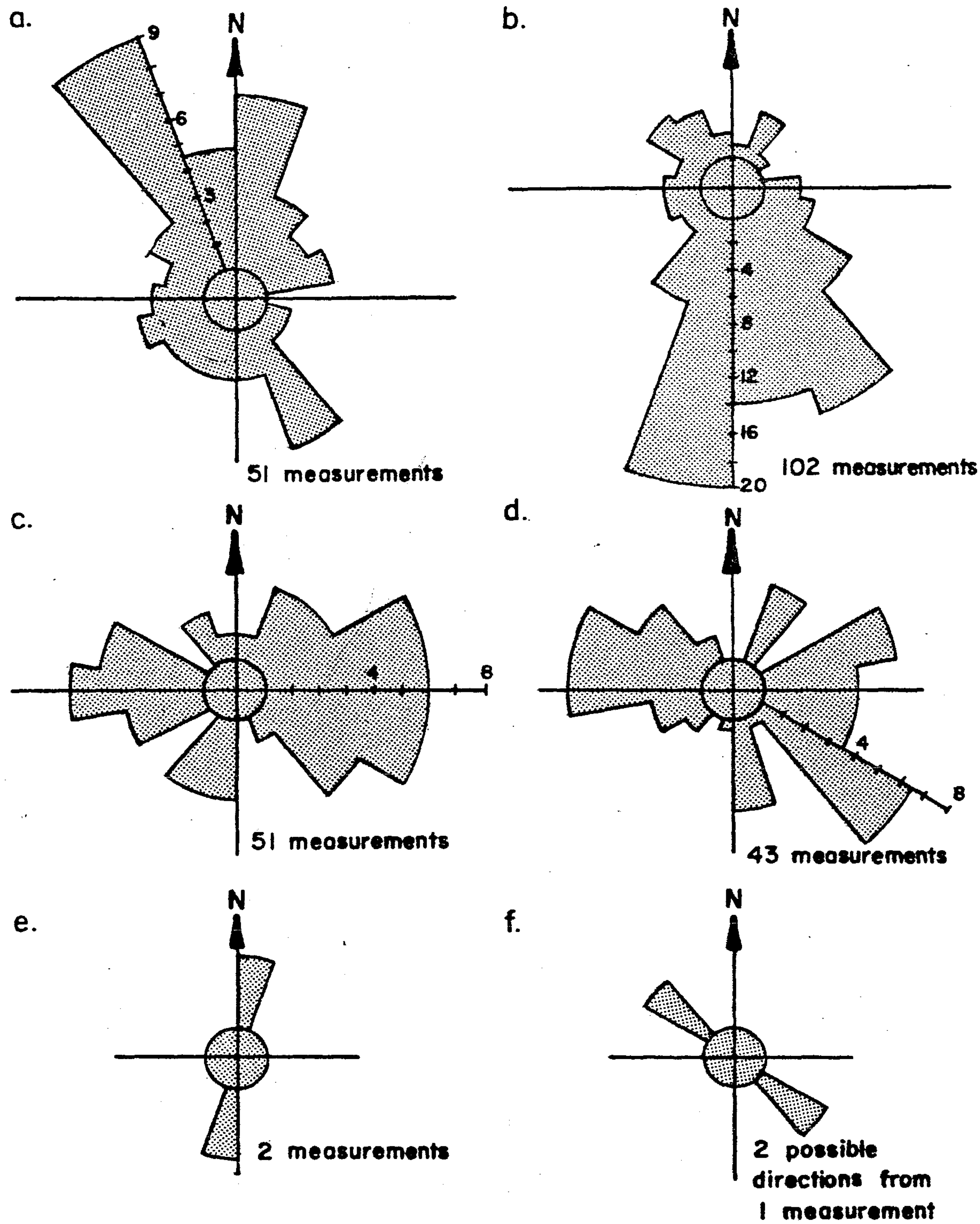


Figure 8. Current roses from the lower member of the Vaqueros Formation. Each arc of a rose represents the number of measurements in 20°. Letters refer to the type of current data (see Figure 9).

8f).

Trough-shaped cross bedding formed by the migration of lunate megaripples is present only in the shelly limestone at Trout Creek where two attitudes (Fig. 8e) indicate currents in two opposite directions.

The current distribution pattern for the lower member, although meager, is mostly bimodal (Fig. 9). The inference from the pattern and lack of data is that the currents in the bay were weak and oscillating, due perhaps to low waves or tidal action and that the shorelines were more or less perpendicular to the current directions.

SUMMARY

All subenvironments of the Vaqueros Sespe Bay deposits have more sand and silt to the west and more silt to the east. This is demonstrated well by the shallow grassy bay deposits, which are pure limestone in the central area and coarse sand in the west, and by the transition from marginal bay to muddy beach environments between measured sections 2 and 3.

Prior to the end of Sespe Formation deposition, there had formed a great distal floodplain that streached 30 km from Potrero John Creek to beyond Sespe Hot Springs. West of Potrero John Creek, the plain sloped up into alluvial fans fed from highlands. Evidence for these alluvial fans is based on the coarsening of the Sespe Formation to poorly sorted boulder conglomerate (Dickinson and Lowe, 1966, p. 2467). With the beginning of the Vaqueros transgression, the flat distal plain was rapidly covered with a thin layer of muddy sediment left by the aggrading shoreline. This low energy shoreline resulted from the lack of tidal influences over the newly formed, flat, shallow bay. As the

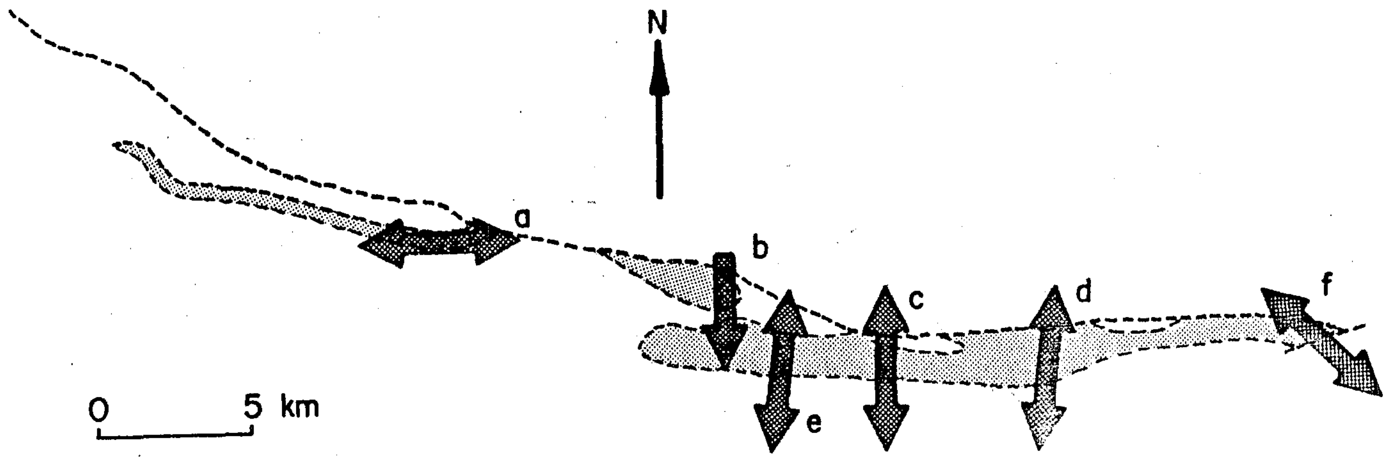


Figure 9. Paleocurrents from the lower member of the Vaqueros Formation. Shaded pattern is present Vaqueros outcrop. Letters refer to the type of paleocurrent data: (a-d) from oriented fossils, (e) from cross bedding, (f) from ripple marks.

waters deepened and lapped onto the steeper western slope, a somewhat sandier shoreline was established, but influx of terrigenous material was still slight. Vast grassy meadows at times covered parts of the warm, clear, bay and supported abundant *Potamides*. Renewed terrigenous sedimentation or deepening of the water eliminated the shallow grassy areas. The bay at no time was deeper than 10 m. Its salinity probably was higher than the open ocean because of restricted circulation. A topographic barrier, such as a mountain ridge, may have restricted the circulation, just as the San Francisco Peninsula restricts the circulation to San Francisco Bay. Variation in salinity and temperature in Sespe Bay may have been extreme and may have resulted in mass mortalities of invertebrates. Swells from storms over the bay may have produced lag deposits. By the time the middle of the lower member was being deposited, bottom sediment distribution was finest in the eastern area and coarsened toward the margins (Fig. 10). The shoreline was perhaps in the Chorro Grande area. Late in the deposition of the lower member, Sespe Bay became more open to normal oceanic circulation, which suggests that some distant barriers which earlier inhibited circulation were no longer influencing the bay.

DESCRIPTION OF MIDDLE MEMBER

GENERAL

The middle member of the Vaqueros Formation consists of calcitic and noncalcitic claystone, mudstone, and siltstone. The member is present in all measured sections (Plate II), but it pinches out in the western outcrop area between Godwin Creek and State Highway 33. The unit is recognizable by its dark brown color, its uniform texture, and

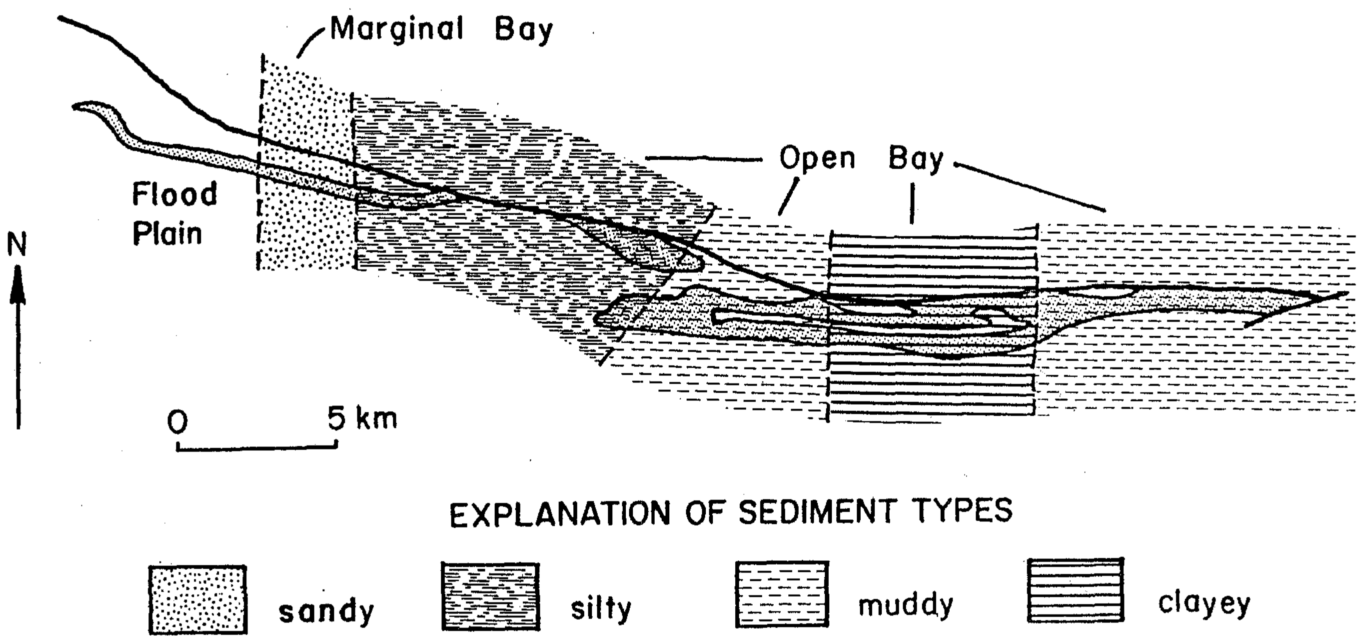


Figure 10. Geographic distribution of sedimentary environments and bottom sediment at an arbitary time during deposition of the lower member. Bottom sediment types are superimposed over modern Vaqueros outcrop pattern along Sespe Creek.

its scarcity of macrofossils. Thickness varies from 52 to 155 m and averages 110 m. The unit is tabular east of Potrero John Creek and wedge shaped west of the creek. Relief of the member is very poor, and rocks are exposed only in canyon bottoms. The best exposure is along Sespe Creek east of Sespe Hot Springs (Fig. 11). In most other areas the unit is covered with thick soil and brush.

The lower contact of the middle mudstone member is placed at the top of the stratigraphically highest macroinvertebrate bed in the underlying member (Plate II). At the top of the member in an interval of up to 8 m, there is first a 2 to 3 m fine sandstone bed, followed by 3 to 5 m of mudstone and finally the medium sandstone of the upper member. The contact is placed on top of the uppermost mudstone and is easily recognized by the changes in texture and slope. The contact west of Munson Creek may be an intraformational unconformity because mudstone appears to be truncated at a low angle by the upper member (Fig. 12). The middle member is entirely homogeneous and a single lithologic description will suffice.

MIDDLE MUDSTONE AND SILTSTONE

Lithology

The mudstone is characterized by the lack of any outstanding stratigraphic features. Fresh color is dark gray (N3), very pale orange (10YR8/2), and light olive gray (5Y5/2). Weathered color is moderate brown (5YR3/4) and dark reddish brown (10R3/4). Exposures are poor. The mudstone is unstratified except for an occasional silty concretion layer. In the Sespe Hot Springs area, these silty layers are 10 to 30 cm thick and occur about every 5 m throughout the entire member. In

Figure 11. Air view of the Vaqueros Formation along Sespe Creek at section 9 near Sespe Hot Springs; east is to the left. Exposures of the middle member (center) are flanked by limestone beds of the lower member (left) and sandstone beds of the upper member (right, at pool on creek).

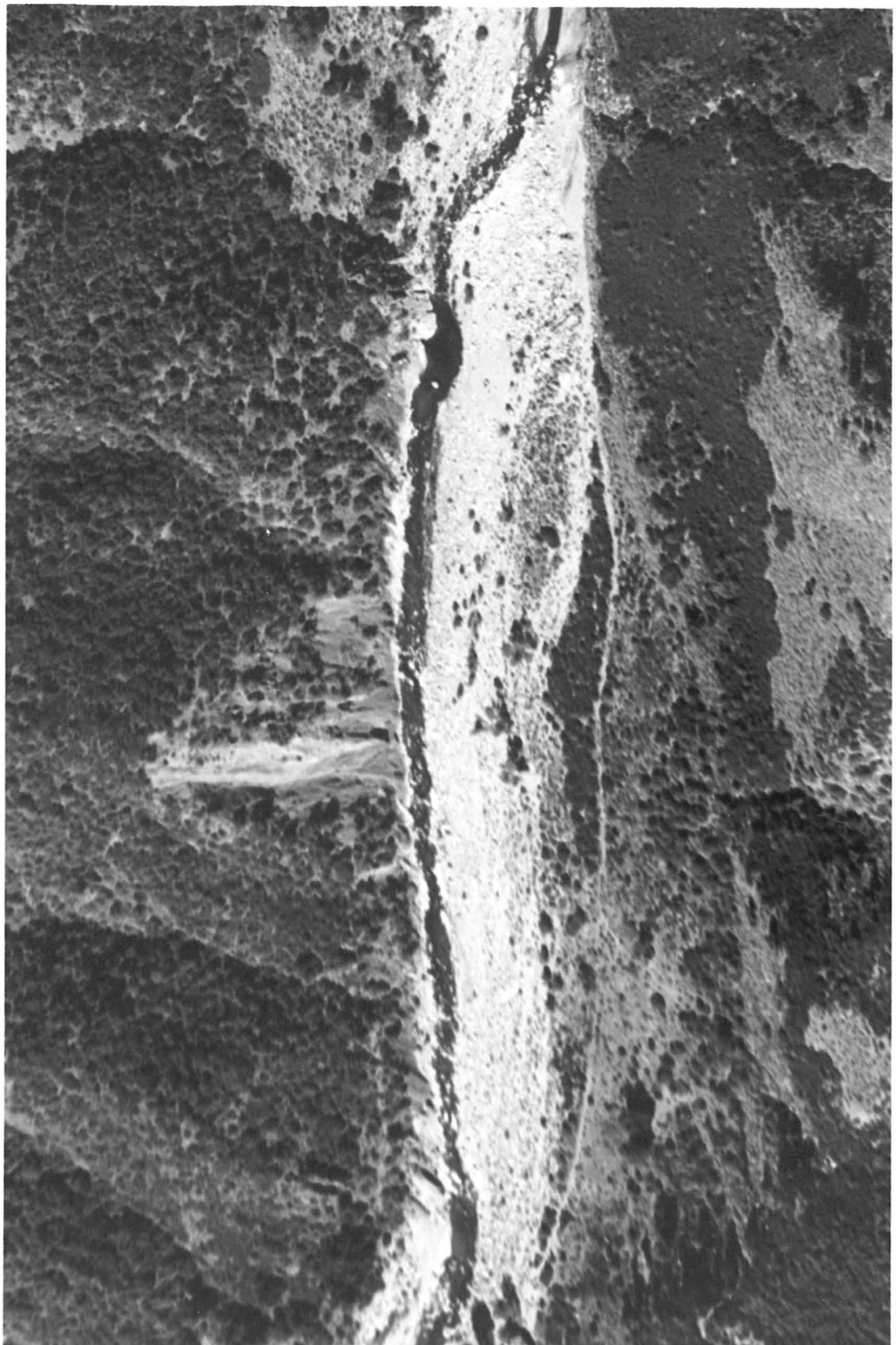


Figure 11

Figure 12. Air view of the Vaqueros looking north at Godwin Creek and down dip of the stratigraphic units. The Sespe Formation is at the lower margin. The intraformational unconformity between the middle member and upper member (center) reduces the thickness of the middle member to the west (left). Width of photograph is 2 km.

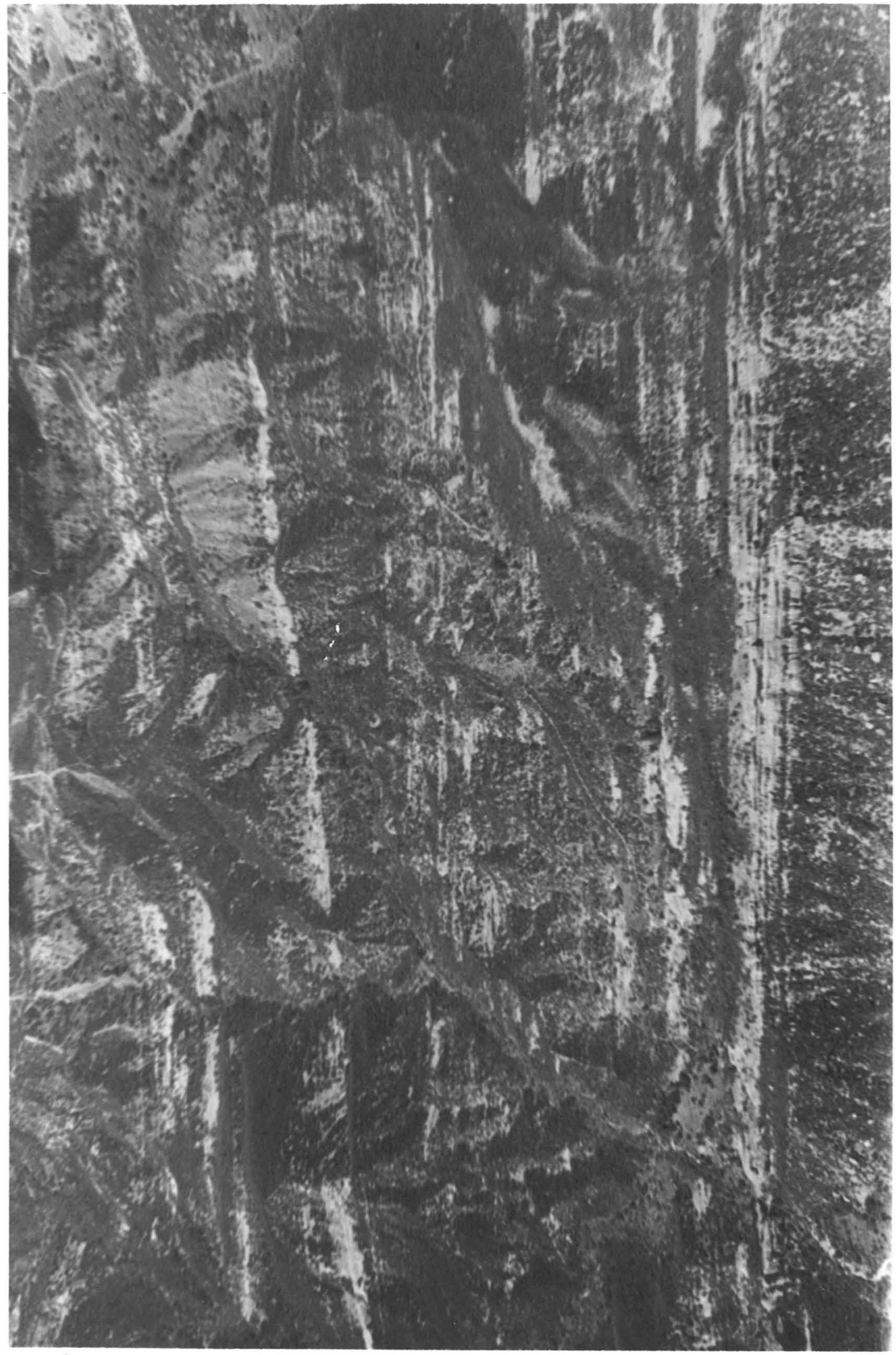


Figure 12

the Sespe Hot Springs area, these silty layers are 10 to 30 cm thick and occur about every 5 m throughout the entire member. The silty concretions are unstratified. In areas of poor exposure, the concretions are not recognizable. No sedimentary structures are present in the member. The member usually weathers into crumbly conchoidal cubes 4 mm in diameter.

Composition is difficult to determine because of the small grain size. The major components are 50 percent framework and 50 percent matrix. The framework consists of 92 percent silt-size angular quartz grains, 2 percent fish scales, and up to 6 percent opaque minerals. Microfossils are present, but commonly altered to pyrite. The matrix is a mixture of terrigenous clay, organic material, and micrite. There is no fabric.

Composition variations include a decrease in grain size to mudstone and claystone toward the top of the member. Organic matter and micrite are absent in the upper half of the member. Other characteristics remain unchanged.

Fossils

The scarcity of macroinvertebrate fossils defines the member. Although none were found in this study, Squires and Fritsche (1978) collected *Ostrea* from beds throughout the member. Other fossils collected from the member include a single shark tooth from CSUN 404, scattered vertebrate bones, and foraminifera. Many of the microfossils were replaced with pyrite and later with hematite and limonite.

ENVIRONMENT OF DEPOSITION

The environmental interpretation is based on *Ostrea*, the lack of other fossils, and the fine grain size. *Ostrea* indicates water depths shallower than 40 m, muddy bottom sediments, and near normal salinity (Keen, 1963, p. 106; Hopkins, 1957, p. 1129). The fine grain size and abundance of pyrite indicate the environment was dominated by muddy sediment deposited by weak currents under reducing conditions. Two modern environments form similar deposits: deep hypersaline bays and shallow inner shelves. Both environments occur close to the bay environments described for the lower member.

The deep hypersaline bay model is a drowned river valley near Laguna Madre on the southern Texas coast (Parker, 1959, p. 2109, 2147-2148). The bay is characterized by extremely high salinity values up to 102 parts per thousand caused by restricted circulation to the open ocean and the lack of a fresh water supply. Water depth is between 0.5 and 3 m. Currents are very weak and deposit sediment which averages 75 percent clay. Only one mollusk species lives scattered on the bay bottom. *Ostrea* is not present. These deep hypersaline bay deposits lithologically resemble those of the middle member mudstone.

Shallow inner shelf sediments along the Texas coast (Shepard and Moore, 1955, p. 1539-1545) are made up of over 90 percent terrigenous material with usually less than 1 percent shell debris. Mollusks are not known to exist and foraminifera are rare. For 10 km off the southern Texas coast the inner shelf is no deeper than 10 m. Sediment consists of silt and clay interbedded with lenses of fine sand and silt. The coarser layers may represent storm deposits. The siltstone beds of the western area might have been deposited in a similar environment.

A bay-inner shelf environment exists along the Louisiana coast (Morgan and others, 1953, p. 10, Fig. 14) that combines the characteristics of a restricted bay and a very shallow shelf. Fluid, gelatinous clay is being deposited in water 4 m deep at a distance of 20 km from the shore. The clay originates from fresh water rivers. As it enters and mixes with normal Gulf water, an ionic reaction causes the clay to flocculate and settle to the bay bottom. In such a high sedimentation environment few mollusks survive. However, oyster banks are present on the outer margin of the bay beyond areas of high sedimentation.

To differentiate between deposits of the deep hypersaline bay and the inner shelf is impossible because both environments produce deposits similar to the middle member. The presence of *Ostrea*, however, suggests near normal salinity and indicates open bay or inner shelf environments. Therefore, characteristics of Sespe Bay during deposition of the middle member are thought to be similar to the bay-inner shelf system described by Morgan and others (1953, p. 10), with a broad, flat bay of inner shelf depths. Few topographic barriers restricted circulation into the bay and perhaps the bay was open on one side permitting normal oceanic circulation.

DESCRIPTION OF UPPER MEMBER

GENERAL

The upper member consists of five distinguishable lithosomes: plane-bedded sandstone, massive and bioturbated sandstone, cross-bedded sandstone, muddy conglomerate, and glauconitic sandstone. The member is present in all measured sections (Plate II). Thickness of the member is variable: a minimum of 42 m at Sespe Hot Springs, a maximum of 165 m at Piedra Blanca, 50 m at Potrero John Creek, and 75 m at Godwin Creek. West of Godwin Creek it gradually thins and totally pinches out just west of State Highway 33. Shape of the unit is broadly wedge and lenticular. The member has good relief and forms resistant sandstone cliffs and hogback ridges (Fig. 13). Exposures are very good and easily followed with cover occurring only at Chorro Grande Creek. The upper member conformably overlies the middle member in the central and eastern outcrop areas, but west of Godwin Creek the upper member lies directly on the lower member with what may be an intraformational unconformity (Fig. 12). Near State Highway 33, the upper member rests directly on the Sespe Formation. The top contact of the upper member, conformable with the Rincon Formation at all locations east of Munson Creek, is gradational over a 2 to 10 m interval of glauconitic sandstone and brownish mudstone and is placed on top of the highest glauconitic sandstone. The top contact west of Munson Creek, where the Rincon Formation is not present, is sharp with the Monterey Formation and is placed between the highest glauconitic sandstone and the lowest shale.

Bedding composition types are variable and locally controlled. Plane-bedded sandstone is present in all stratigraphic sections, averages 20 percent of the member, ranges from 10 percent at section 7 to 35 percent at Piedra Blanca (section 5), and is concentrated at the bottom and top of the member. Massive and bioturbated sandstone averages 30 percent of the member and ranges from 15 percent at Potrero John Creek (section 1) to 80 percent at Trout Creek (section 6) with this lithosome concentrated in the middle and upper part of the member.

Figure 13. Exposure of upper member at Piedra Blanca, showing trough-shaped cross bedding.

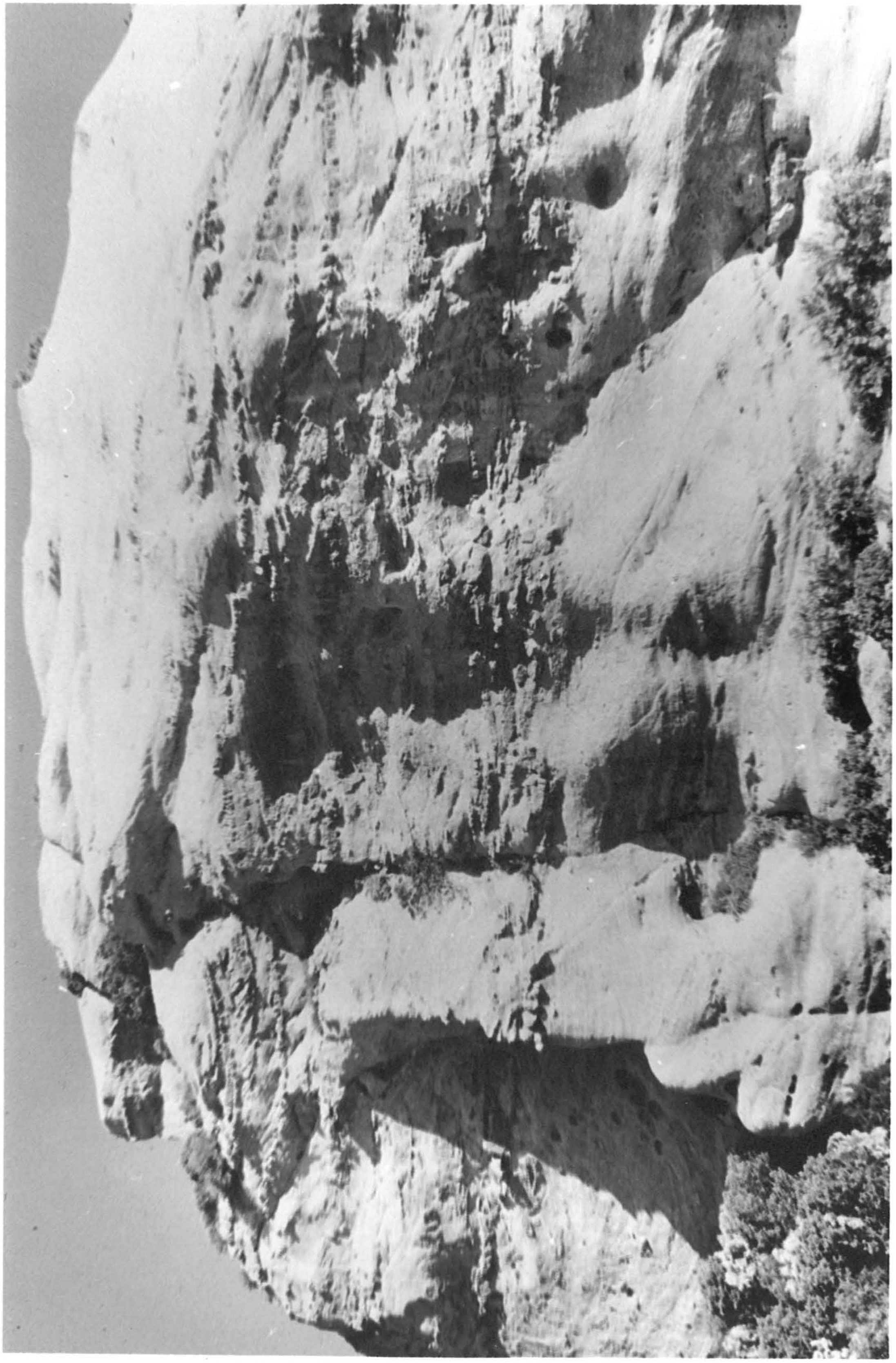


Figure 13

Cross-bedded sandstone is one of the most variable lithosomes of the upper member, averaging 40 percent of the member, ranging from 0 percent at Trout Creek to 75 percent at Kimball Canyon and occurring anywhere in the member, but usually in the upper third. Muddy conglomerate is present only near the top of the member, averages 6 percent of the member, and ranges from 0 percent at Sespe Hot Springs to 20 percent in the central outcrop area (section 2). Glauconitic sandstone is present at the top contact and averages 4 percent of the member, but it may make up as much as 10 percent (section 7).

UPPER PLANE-BEDDED SANDSTONE

Lithology

Plane-bedded sandstone is divided into two types: a shelly sandstone containing fossil debris present at the lower contact, and a darker colored sandstone lacking shell debris present higher in the member. Fresh color of the shelly sandstone is yellowish gray (5Y7/2) and weathered color grayish orange (10YR7/4). The shelly sandstone is very resistant and forms cliffs. Shape of the shelly sandstone intervals is tabular and extremely continuous, especially in the central and eastern outcrop areas. Thickness of the intervals is variable, averages 5 m, and has a range of 3 to 25 m. Only one or two plane-bedded shelly intervals are present in a section. Bedding within intervals averages 5 cm and ranges between 0.5 and 30 cm, with thickness usually consistant within intervals. Beds have a tabular shape and are commonly laminated, with laminations shown by layered fossil debris. No other lithosomes are interbedded within the lithosome. Sedimentary structures associated with the plane-bedded sandstone include, at Piedra Blanca, isolated sets of 40-cm-high, steep-faced tabular cross bedding, and near Kimball Canyon, laminated sandstone in 2-cm-thick beds which change laterally within 50 m from plane beds to 10-m-thick trough-shaped cross beds. The boundaries of shelly sandstone beds are usually sharp, but are occasionally gradational into overlying massive sandstone.

An average plane-bedded shelly sandstone consists of 55 percent terrigenous framework, 35 percent fossil debris, and 10 percent matrix (Table 8). Grain size of the framework ranges from 0.1 to 0.2 mm and averages fine sand. The rock is poorly sorted, immature, and grain shape averages subangular. There is no fabric apparent. Composition makes this rock an arkose (Table 8). Fossil debris is highly fragmented, averages 1 mm, and ranges from 0.25 to 4 mm. Fossil composition includes angular barnacle fragments and rounded echinoid and bivalve fragments. The matrix material is a mixture of terrigenous clay and micrite.

Several variations of texture and composition are present. Many shelly beds range from fine sandstone to moderately sorted, submature, medium- to coarse-grained sandstone with granules. In the western outcrop area, the lower plane beds lack the fossil component.

The stratigraphically higher plane-bedded sandstone lacks the shelly component. Fresh color is light olive gray (5Y6/1) and very light gray (N8). Weathered color is dusky yellow (5Y6/4) and moderate yellowish brown (10R5/4). Relief is moderate and rocky slopes common. Shape of non-shelly plane-bedded intervals is tabular. Interval thickness averages 8 m and varies between 4 and 16 m. One to three inter-

Table 8. Composition of upper member thin sections.

	bedded sandstone				massive sandstone			cross-bedded		conglo-merate			glau. ss.	
	R2-15d	R1-10h	R3-8cd	Pb-56	R1-12d	Pb-5	Pb-6	R4-8b	Pb-73	R110	R5-7a	R5-7e	R2-17c	R3-8f
percent terr. framework	55	85	75	97	85	90	92	65	60	36	70	60	80	90
percent matrix	10	15	--	3	5	10	--	--	--	20	--	--	--	10
percent fossils	35	--	--	--	--	--	--	15	20	24	20	25	--	--
percent cement	--	--	25	--	10	--	8	20	20	10	10	15	20	--
framework elements:														
quartz	55	60	65	32	50	40	57	40	55	30	30	30	30	40
rock frags.	2	10	2	2	3	3	--	15	15	18	35	40	7	2
weathered feldspar	25	--	6	15	15	16	15	15	5	5	15	13	4	30
plagioclase	7	10	9	7	10	10	7	10	8	10	10	5	10	10
perthite	--	--	--	3	--	1	1	--	--	--	--	--	1	--
orthoclase	5	5	4	25	9	15	10	12	11	5	5	9	15	5
microcline	--	2	--	2	2	2	1	--	--	--	--	--	1	--
chert	5	1	4	4	9	7	4	2	5	20	2	2	3	5
opaques	1	2	1	5	--	2	2	2	1	2	2	1	2	1
glauconite	--	8	2	2	2	1	--	--	--	10	--	--	25	2
phosphate	--	2	1	--	--	1	--	2	--	--	1	--	2	1
others	--	--	6	3	--	2	3	2	--	--	--	--	--	4

vals are present in a section. Individual beds are tabular and lenticular. Bed thickness averages 10 cm and ranges between 1 cm and 1 m. Larger lenses up to 0.5 m thick are rare. Beds are unlaminated and internally massive and bioturbated. Other lithosomes commonly are interbedded with the higher plane-bedded sandstone. Interval boundaries are usually gradational with massive sandstone.

An average plane-bedded non-shelly sandstone contains 85 percent terrigenous framework and 15 percent matrix (Table 8). Framework size range is .02 to 3 mm and averages medium sandstone. The rock is immature, poorly sorted, and is an arkose in composition (Table 8). Glauconite is common and imparts to the rock a greenish tint. The matrix consists of terrigenous clay but no micrite. The rock has no fabric.

Variations in the non-shelly plane-bedded sandstone are common. Sandstone in the eastern outcrop area at Sespe Hot Springs is moderately sorted, submature, and contains 25 percent calcitic cement. Grain size averages between fine and medium sand.

Fossils

Fossils are generally rare and occur mostly as debris in the lower third of the member. Recognized fragments include a 5-cm fragment of *Ostrea* and much smaller debris of barnacles, bivalves, and echinoids. West of Chorro Grande at the base of the member are abundant *Kewia fairbanksi* with complete individuals layered convex side up. The *Kewia* bed is traceable for over 4 km in the western outcrop area.

UPPER MASSIVE AND BIOTURBATED SANDSTONE

Lithology

Massive and bioturbated sandstone is present east of Piedra Blanca Creek and west of Chorro Grande Creek and occurs stratigraphically in thick intervals throughout the member. Two lithosomes are distinguishable: featureless massive sandstone and, usually within the massive sandstone, bioturbated zones. Fresh color varies from medium light gray (N6) to yellowish gray (5Y7/2) and pale greenish yellow (10Y8/2). Weathered surfaces are grayish yellow (5Y8/4). Lithosome shape is tabular, but the lithology may change laterally over several kilometers into another lithosome. Massive beds average 6 m thick and range from 1 to 20 m thick. Bioturbated zones are 1 to 10 m thick. Beds with extreme bioturbation have a mottled appearance whereas moderately bioturbated beds contain individual vertical burrows up to 0.5 m long. Occasional plane-bedded sandstone, pebbly layers, and small pebbly lenses are interbedded with the massive sandstone. No other stratification is apparent. Lithosome boundaries are in most places sharp with the other upper member lithosomes, but in some places gradational with glauconitic sandstone.

The average massive sandstone contains 90 percent terrigenous framework and 10 percent matrix (Table 8). Grain size ranges from .05 to 1 mm and averages medium sand. The rock is immature and poorly sorted. Terrigenous composition makes the rock an arkose. This rock, as are most of the massive sandstones, is not calcitic and does not contain fossil debris. Opaque minerals include hematite and limonite. The matrix consists of terrigenous silt and clay.

Variation in this remarkably consistent lithosome is slight. Average grain size varies between fine and coarse sand. West of Chorro Grande Creek the massive sandstone beds are thick and coarse, with some scattered pebbles and granules. Other massive sandstone beds are moderately sorted and submature. Calcite cement is present in some locations.

Fossils

Macroinvertebrate fossils are rare in the massive sandstone, but one 10-cm-thick bed of *Ostrea eldridgei* is present. This bed is traceable for several kilometers around the Piedra Blanca area. Individuals are common but disarticulated and rounded. Other fossils within this lithosome include shark teeth and scattered vertebrate fragments.

CROSS-BEDDED SANDSTONE

Lithology

General

Cross-bedded sandstone occurs stratigraphically anywhere within the lower two-thirds of the member (Plate II), but geographically is limited to Sespe Hot Springs, Kimball Canyon, Piedra Blanca, Potrero John Creek, and Godwin Creek. Cross bedding characteristics at each of these locations are unique.

Fresh color of the cross-bedded lithosome is pinkish gray (5Y8/1) and very pale orange (10YR8/2). Weathered color is pinkish gray (10YR8/2) and grayish orange (10YR7/4).

The average cross-bedded sandstone closely resembles the texture of plane-bedded sandstone and contains 65 percent terrigenous framework, 15 percent fossil fragments, and 20 percent calcitic cement (Table 8). Grain size ranges between .02 and 1.2 mm and averages medium sand. The rock is moderately sorted and submature and grains are subrounded and subangular. There is no fabric apparent. Composition makes this rock an arkose. Rock fragments are plutonic and volcanic and opaques are hematite and limonite. Fossil material is broken and consists of rounded barnacle, bivalve, and echinoid fragments averaging 0.3 mm in length and ranging from 0.1 to 0.5 mm in length. Cement is calcite spar and may represent some recrystallization of fossil debris.

Cross-bedded sandstone west of Munson Creek lacks the shelly component and texturally is similar to the massive sandstone lithosome.

Cross Bedding

Sespe Hot Springs: Cross bedding in the Sespe Hot Springs area consists of small- and large-scale sets in the middle of the member (Plate II, section 9). At the base of the lithosome, small-scale planar and trough - shaped cross-bedded fine sandstone is present above massive sandstone (Fig. 14). The sets range in thickness between 2 and 10 cm. Planar sets have low angle foresets. Between each cross bedding set is 2 to 5 cm of plane-bedded and bioturbated fine sandstone and siltstone. Five or six individual cross bedding sets are contained within this lowest interval. Separating the small- and large-scale cross-bedded sandstone is 8 m of plane-bedded laminated sandstone which contains large vertical burrows. Above this plane-bedded horizon is large-scale trough-shaped cross-bedded medium-grained sandstone. Each cross bedding set averages 2 m thick and total interval thickness is 5 m. Foreset angles range from 0^{o} near the center of troughs to 27^{o}

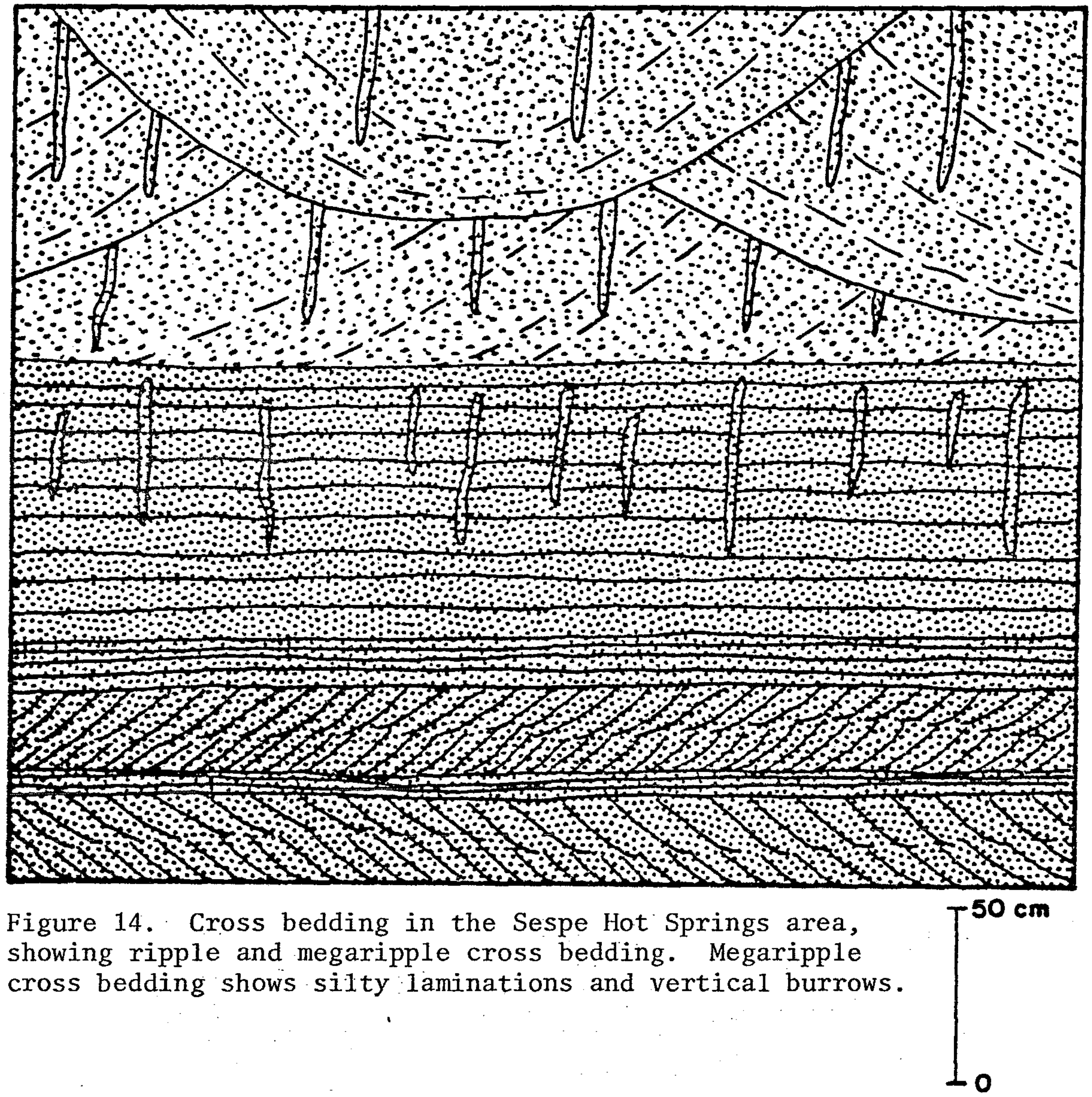


Figure 14. Cross bedding in the Sespe Hot Springs area, showing ripple and megaripple cross bedding. Megaripple cross bedding shows silty laminations and vertical burrows.

near the edges. Lamination of the foresets is shown by oriented sand grains and occasional 5 mm silty layers. All sets are moderately bioturbated with vertical burrows up to 0.5 m long. Burrows and cross bedding are truncated by the next higher trough. Only the Sespe Hot Springs cross bedding contains silty laminations and burrows.

Kimball Canyon: The largest sedimentary structures in the Vaqueros Formation are in the Kimball Canyon area, where trough-shaped cross beds in medium-grained sandstone are up to 10 m thick. The cross bedding is present in the lower two-thirds of the member. Up to five sets are present. No other sedimentary structures are interbedded within the cross-bedded interval. Foreset angles range from 0^{o} in the trough centers to 46^{o} near the trough edges. The large-scale cross bedding has a limited areal extent with no cross bedding present 0.5 km east or west of Kimball Canyon.

Piedra Blanca: Cross-bedded sandstone in the Piedra Blanca area consists of planar (Fig. 15) and trough-shaped (Fig. 16) sets and is characterized by the uniform size of sets and the almost complete lack of other interbedded sedimentary structures. Exposures are excellent over a 3-square-km area in the core of a gently plunging syncline where weathering along a north-trending vertical joint system provides outcrop exposures perpendicular to the fold. Cross bedding sets are easily followed and have good three-dimensional control.

The cross-bedded lithosome is 75 m thick at Piedra Blanca and consists of planar and trough sets. The planar sets, present in the eastern portion of the area, are between 1 and 2 m thick. Only an occasional pebbly lamination is present between planar sets. Foreset laminations are tangential on the bottom of each set and truncated on top at an average angle of 25^{o}. Concretions are common along set boundaries and along foreset laminations. Toward the west end of Piedra Blanca, all planar sets change laterally into 1 to 2 m thick trough-shaped sets.

Grain size changes from medium sandstone near the bottom to coarse sandstone with granules and pebbles near the top. Grain size also

Figure 15. Tabular cross bedding sets in the upper member of the Vaqueros at Piedra Blanca. Each set is about 2 m thick.

Figure 15

Figure 16. Curved foreset laminations from the Piedra Blanca area. Cross-sectional view of these laminations (Fig. 13) shows trough shapes.

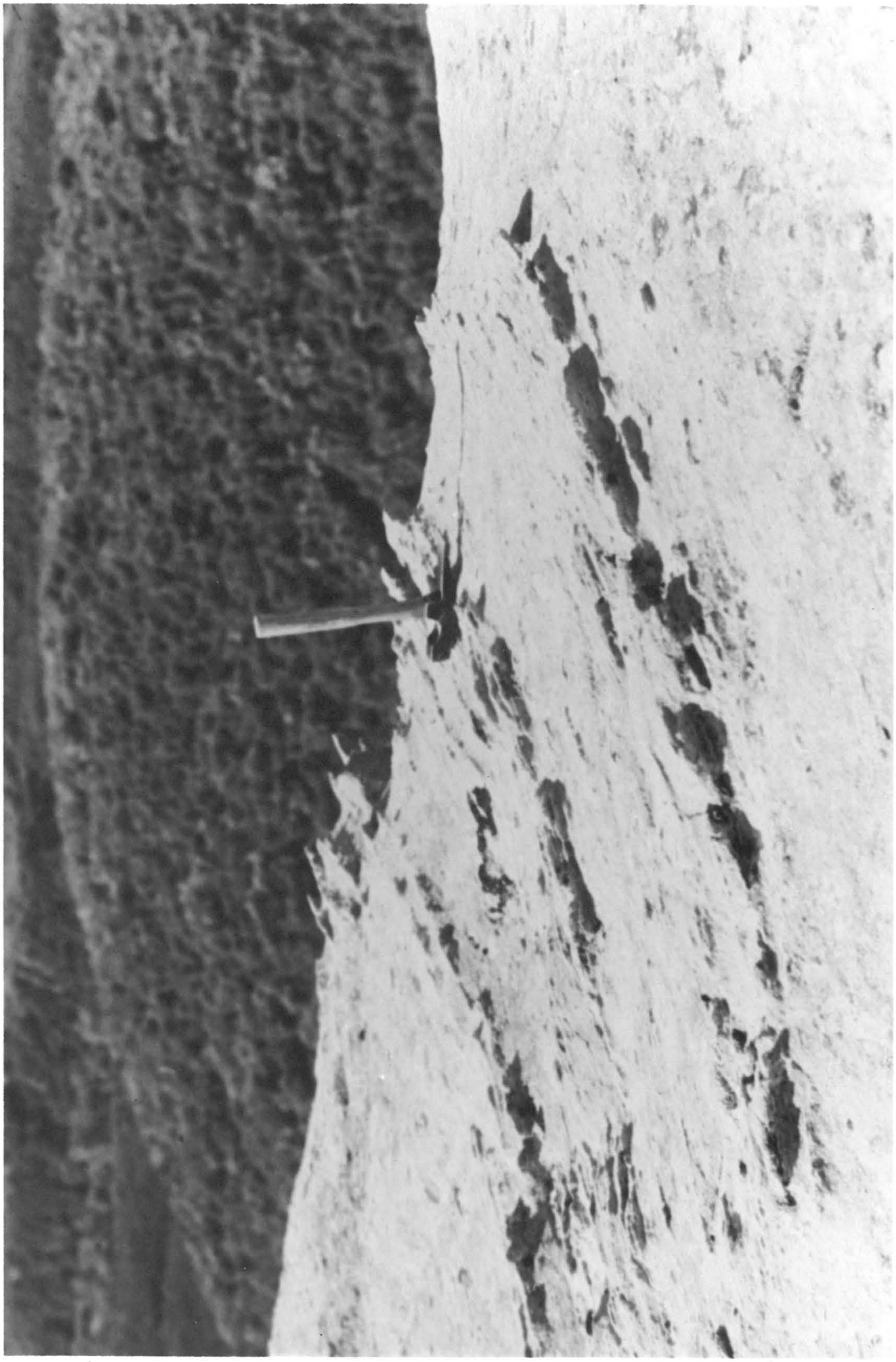


Figure 16

increases westward.

The Piedra Blanca cross-bedded sandstone changes laterally eastward to massive sandstone, so that at Trout Creek (section 6), 1 km east of Piedra Blanca, cross bedding is absent.

Potrero John Creek: Cross bedding at Potrero John Creek typifies cross-bedding at all other locations east of Munson Creek and consists of planar, wedge, and trough shapes of varying thicknesses. Commonly there is one planar set 2 m thick near the lower contact of the member, but the main cross-bedded interval is much higher. The lithosome is 20 to 30 m thick and consists of individual sets 0.4 to 1 m thick with thinner sets common near the top. An occasional plane bed separates the sets. Foresets are tangential on the bottom of each set and truncated on top. Average foreset inclination is 28^{o}. Similar cross bedding is common in the central and eastern outcrop areas, but is discontinuous and changes laterally to massive sandstone.

Godwin Creek: Cross bedding west of Munson Creek, entirely different than anywhere else, is characterized by exposures near Godwin Creek. Individual sets are 0.5 to 2 m thick and are isolated within a thick massive sandstone. Sets are planar, wedge, and trough shaped and seem to pinch and swell. Foresets are tangential on the bottom of each set and truncated on top. The main difference between this cross bedding and that seen elsewhere is the inclination of the foresets, which average 10^{o} to 15^{o}, almost half the angle of foresets to the east. Grain size is medium to coarse sand with occasional pebbles. The sandstone lacks a shelly component.

Fossils

Identifiable fossils are rare in the cross-bedded sandstone. In the Piedra Blanca area, disarticulated valves of *Ostrea* occur near the top of the cross-bedded lithosome. Individuals average 10 cm and are rounded but not broken. Other fossils include a few *Lyropecten* fragments in the central outcrop area (section 2).

UPPER CONGLOMERATE

Lithology

General

The conglomerate beds, which are tabular and nearly continuous from Kimball Canyon west to Munson Creek, are stratigraphically above cross-bedded and massive sandstone and below the topmost glauconitic sandstone, within a few meters of the overlying Rincon Formation. Between upper Piedra Blanca Creek (section 2) and Munson Creek, the conglomerate beds merge with the glauconitic sandstone and create one glauconitic conglomerate bed at the Vaqueros-Rincon contact. Individual beds are 0.3 to 2 m thick. Up to 3 beds are present in a stratigraphic section, with massive sandstone present between conglomerate beds. Fresh color of the beds varies from grayish orange (10YR8/6) to very pale orange (10YR8/2). The lower contact of the conglomerate beds is either sharp and erosional (Fig. 17) or gradational (Fig. 18). The upper contact is sharp or gradational with glauconitic sandstone or massive sandstone.

Two types of conglomerate beds are present with the most dominant being paraconglomerate tilloid. The tilloid beds occur from Trout Creek west to Munson Creek. Tilloid beds contain pebbles, sand and

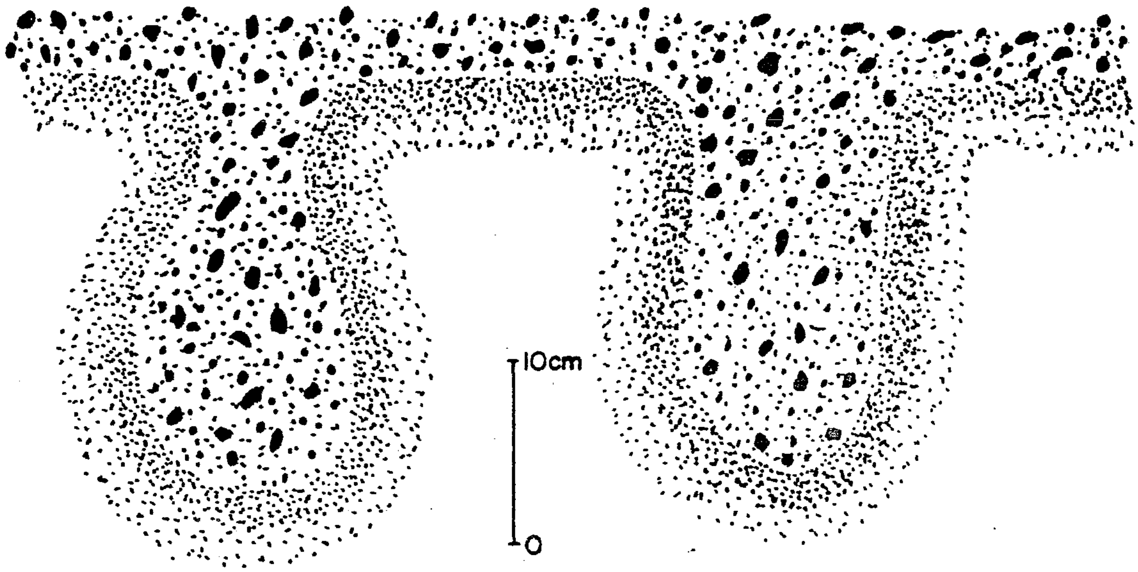


Figure 17. Erosional or load structures at the base of the conglomerate, Piedra Blanca area.

silt, clay and micrite, and fossils (Table 9), with each of the four components having independant grain size ranges (Fig. 19). Well rounded pebbles are scattered throughout the matrix. The framework is matrix supported; seldom do pebbles touch each other. The matrix in some samples consists entirely of sand and silt but in most samples is a mixture of sand, clay, and micrite. Barnacles and various bivalves are present as large angular fragments. Tilloid pebbles and fossils usually show no orientation or alignment. In some places there is a pocket of sand- or micrite-rich matrix.

An average conglomerate is R110 from Potrero John Creek (section 1) which consists of 36 percent pebbles and sand, 24 percent fossils, 20 percent micrite and clay, and 10 percent secondary calcitic cement (Table 8; Fig. 20). Grain size of terrigenous material is bimodal, with pebbles averaging 8 mm and sand averaging 0.6 mm. Very little

Figure 18. Photograph of a conglomerate bed showing gradational lower contact and conglomerate texture. Ruler is 15 cm long.

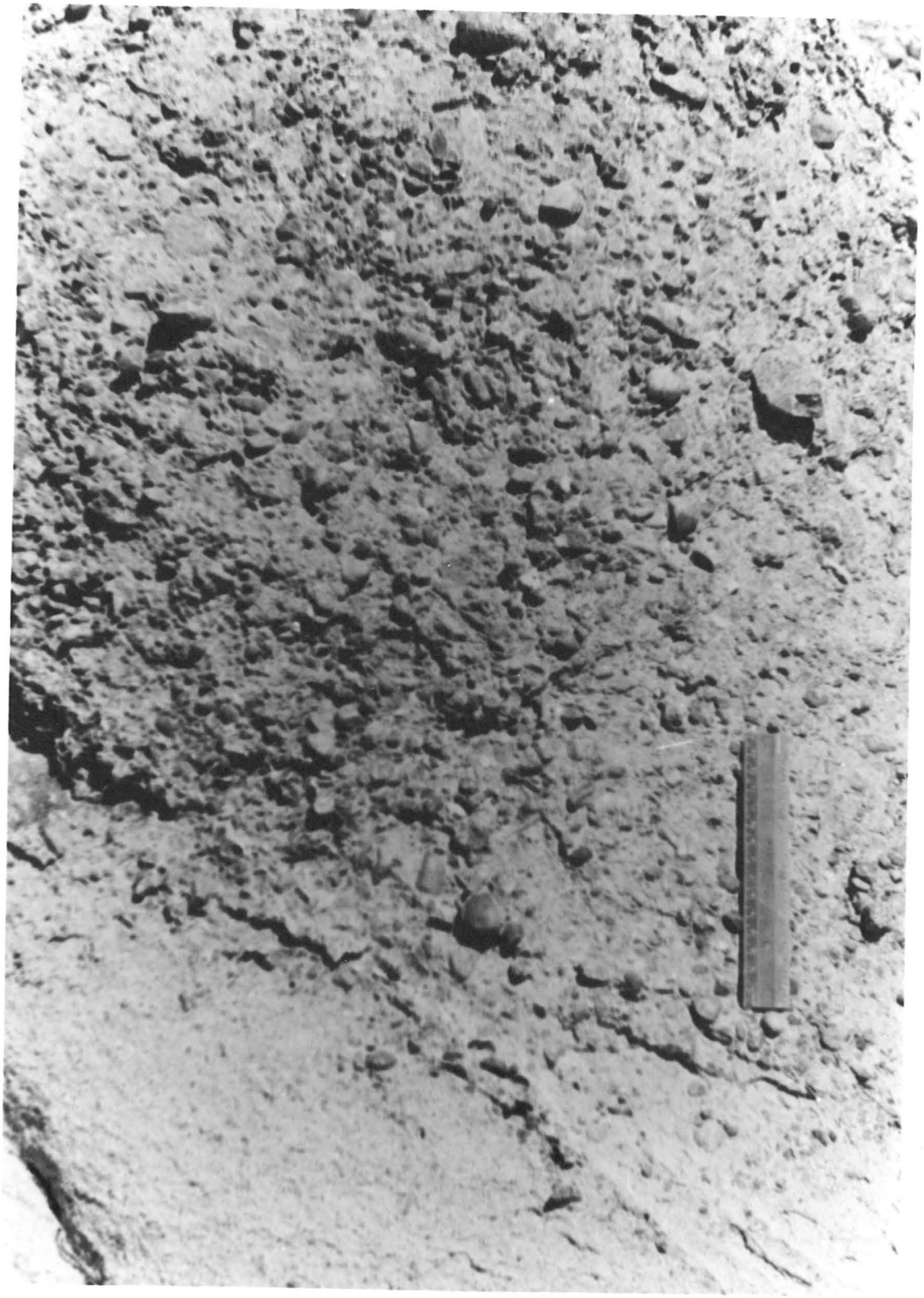


Figure 18

Table 9. Composition of conglomerate samples (from binocular microscope inspection).

sample	percent pebbles	percent sand	clay (*cement)	percent fossils	bimodal	sorting	bed shape	fabric	Folk classification	Pettijohn class.
R120b	15	70	10	5	yes	poor	?	none	pebbly muddy medium sandstone immature glauconite-bearing lithic arkose	tilloid
R110	7	18	20	55	yes	poor	tabular	none	pebbly medium sandy glauconite-bearing biomicrudite	tilloid
R5-7c	45	40	5*	10	yes	mod.	tabular	none	medium sandy pebbly conglomerate: calcitic submature fossiliferous litharenite	tilloid
R5-7e	25	35	20*	20	yes	mod.	tabular	none	fine sandy pebbly conglomerate: calcitic submature fossiliferous litharenite	tilloid
R5-8d	15	50	35	--	yes	poor	tabular	none	pebbly silty fine sandstone: immature lithic arkose	tilloid
649-4b	15	20	65	--	yes	poor	tabular	none	pebbly sandy micrite	tilloid
649-4a	15	20	65	--	yes	poor	tabular	none	pebbly sandy micrite	tilloid
R133	5	65	10*	20	no	mod.	?	none	slightly granular medium sandstone: calcitic submature fossiliferous arkose	sandstone
R125a	5	50	10*	35	no	mod.	?	none	slightly pebbly medium sandstone: calcitic submature fossiliferous lithic arkose	sandstone
R107	15	70	5*	10	no	mod.	?	none	pebbly medium sandstone: submature fossiliferous lithic arkose	sandstone

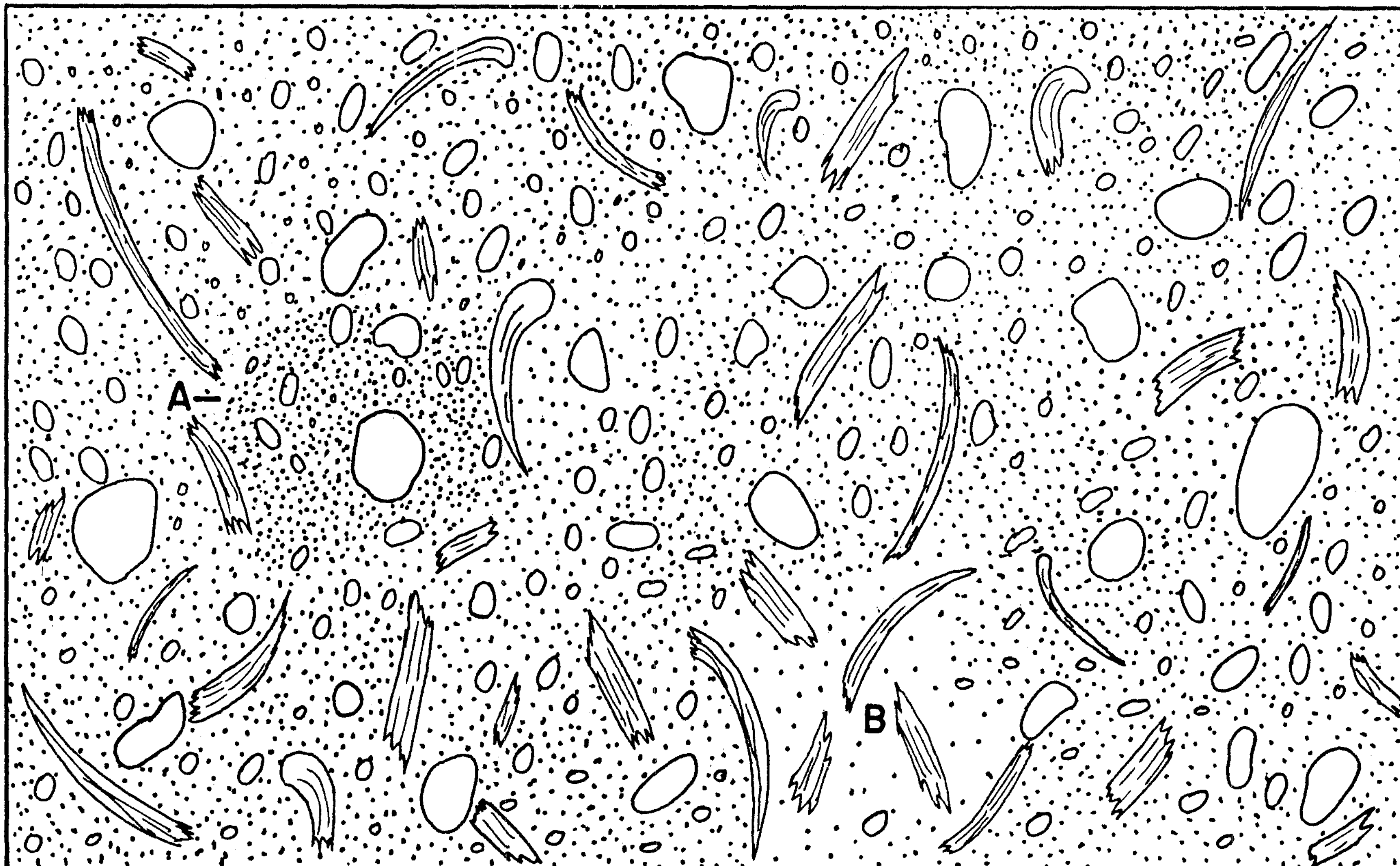


Figure 19. Drawing of conglomerate from Potrero John Creek showing distribution of pebbles, fossils, sand, and mud matrix (clear area) which is typical of the tilloid beds. Area A shows local concentration of terrigenous material. Area B shows local concentration of mud. Scale, 1:1.

Figure 20. Photomicrograph of thin section R110 (cross-nicols). Four elements of the tilloids are shown: pebbles (4 mm diameter dark grain in center), sand, fossils (barnacle at lower left) and a matrix of micrite.

Figure 20

material is present between the 1.5 to 2 mm size range. Fossils include 10 cm fragments of *Ostrea* and 0.3 to 10 mm angular fragments of barnacles and echinoids. Glauconite is scattered throughout the rock as rounded grains, but occasionally the grains are broken or angular. Terrigenous and glauconitic sand and micrite supports the framework of pebbles and fossils. Sorting of each individual element of pebbles, fossils, sand, and clay is good, but the mixture of framework and matrix elements result in a poorly sorted rock. The only orientation present is crudely layered fossil debris.

The other group of conglomerate beds (Table 9: R133, R125a, and R107) differ from the tilloid beds by having fewer pebbles, more sand, an uniform size gradation between sand and pebbles, no silt or clay, and an abundance of calcitic cement. Similarities with the tilloid beds include tabular beds and no internal fabric. Tilloid deposits which underwent some reworking and sorting would be similar to this group of pebble beds. The geographic distribution is limited to an area between Trout Creek and Bear Creek.

Pebble Composition and Distribution

Plutonic pebbles are the largest pebbles and, at locations with pebbles larger than 2 cm, are the most common. Pebbles average 1 cm and range between 0.3 and 5 cm. Most plutonic pebbles are classified as granite with less than 10 percent syenite, monzonite, and granodiorite (Table 10). Crystal grains range in size from medium to fine with phenocrysts of quartz, plagioclase, and K-feldspar of equal size within a pebble. Some plutonics show foliation. Plutonic pebbles average 14 percent of the pebble population and range from 0 to 50 per-

Table 10. Percent composition of pebbles from the upper member of the Vaqueros Formation.

	R120a	R120b	R110	R5-7c	R5-7e	R5-8d	649-4b	649-4a	R129	R133	R1-10f	R1-12d	R125a	R125b	R107	R2-17c	R2-17d	R103
number of pebbles	25	96	132	107	124	100	84	60	26	58	28	25	50	18	122	48	28	48
granite	4.0	2.1	13.6	11.2	0.8	13.0	13.4	6.7	38.5	--	10.7	24.0	--	--	8.1	4.2	3.6	12.5
granodiorite	--	1.0	0.8	0.9	--	4.0	1.1	3.3	--	--	--	--	--	--	--	--	--	2.1
monzonite	--	--	--	--	--	--	1.1	--	--	1.7	--	--	2.0	--	--	--	--	--
qtz monzonite	--	--	--	0.9	--	--	4.5	1.7	--	--	--	4.0	--	--	--	--	--	--
diorite	4.0	--	--	--	--	1.0	--	--	3.8	--	--	--	--	--	0.9	--	--	2.1
other	--	--	1.6	1.9	--	1.0	3.3	--	--	--	--	4.0	--	--	3.6	--	--	--
total plutonics	8.0	3.1	16.0	14.9	0.8	19.0	23.4	11.7	42.3	1.7	10.7	32.0	2.0	0.0	12.6	4.2	3.6	16.7
andesite	8.0	32.2	2.4	5.6	4.0	7.0	29.2	21.8	3.8	10.3	--	--	2.0	5.6	4.5	14.6	7.2	2.1
rhyolite	4.0	4.1	9.9	12.2	18.5	15.0	4.5	--	15.9	3.4	14.3	8.0	20.0	33.4	3.6	14.6	24.9	10.5
trachyte	40.0	39.4	39.4	22.4	33.0	31.0	34.7	53.4	26.8	41.4	46.5	44.0	34.0	39.0	30.0	37.5	25.0	33.2
other	--	1.0	--	0.4	--	1.0	--	1.7	3.8	--	--	4.0	2.0	--	--	--	3.6	4.2
total volcanics	52.0	77.3	51.7	43.1	55.5	54.0	68.4	76.9	49.8	55.1	60.8	56.0	58.0	77.9	38.4	66.7	60.7	50.0
clastic	--	7.2	18.9	29.0	29.8	16.0	1.1	5.0	--	29.0	7.1	12.0	24.0	11.1	17.0	4.2	14.3	18.0
chert	36.0	6.2	3.0	--	--	2.0	2.2	1.7	3.8	1.7	--	--	--	--	6.2	--	3.6	4.7
total sedimentary	36.0	13.4	21.9	29.0	29.8	18.0	3.3	6.7	3.8	30.7	7.1	12.0	24.0	11.1	23.2	4.2	17.9	22.7
quartzite	4.0	6.2	10.6	9.3	11.3	4.0	4.5	5.0	3.8	10.3	21.4	--	14.0	11.1	25.0	20.8	7.1	8.3
metasandstone	--	--	--	3.7	0.8	5.0	--	--	--	1.7	--	--	2.0	--	0.9	4.2	7.1	2.1
gneiss-schist	--	--	--	--	1.6	--	--	--	--	--	--	--	--	--	--	--	3.6	--
total metamorphics	4.0	6.2	10.6	13.0	13.7	9.0	4.5	5.0	3.8	12.0	21.4	0.0	16.0	11.1	25.9	25.0	17.8	10.4

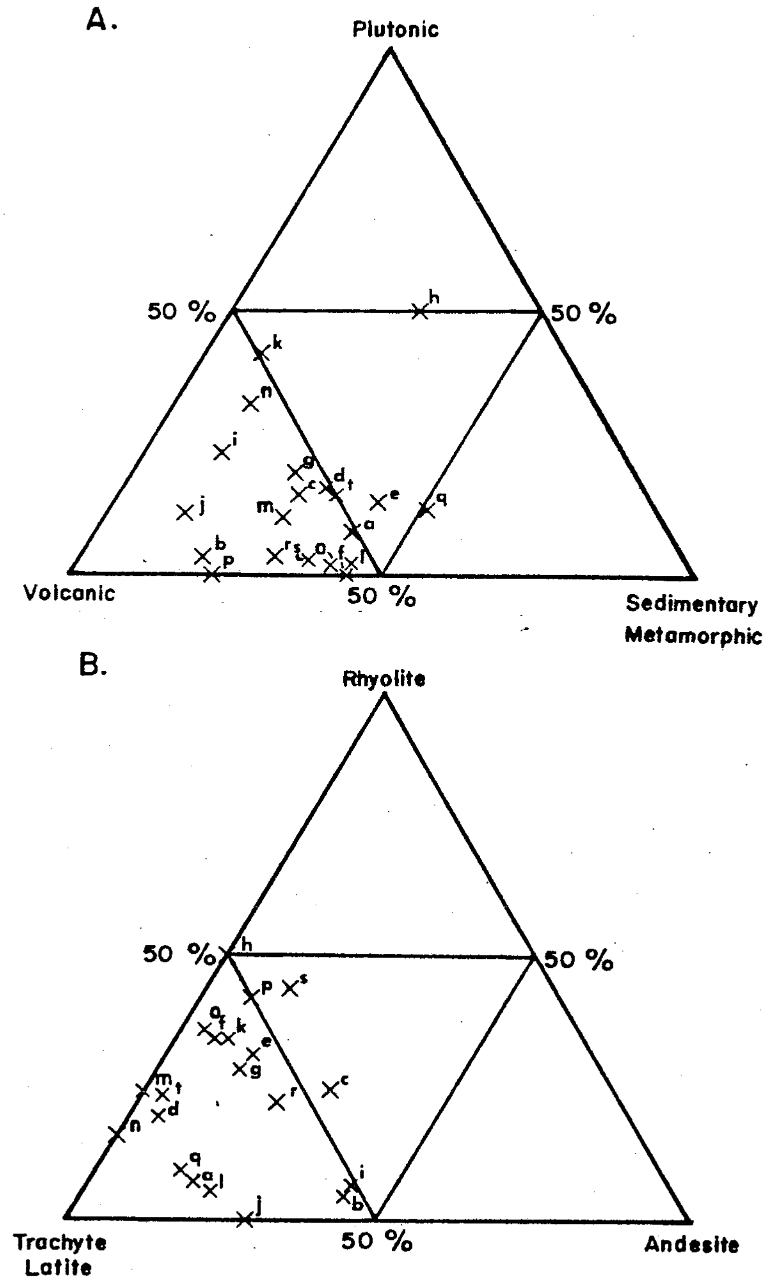
cent (Table 10; Plate I).

Metamorphic clasts are composed of free quartz, metasandstone, gneiss, and schist (Table 10). Quartz is the most common type, and consists of clear quartz granules, larger milky quartz, and rare black quartz. Metasandstone pebbles have interlocking sand grain boundaries. Gneiss and schist pebbles are very rare and are strongly foliated. The metamorphic group of pebbles averages 12 percent of the pebble population, and ranges from 0 to 26 percent.

Sedimentary pebbles include clasts of chert, sandstone, and siltstone (Table 10). Chert is gray and occasionally contains radiolarians. Coarser clastic pebbles are moderately sorted, submature, medium arkosic sandstone and finer clastic pebbles are poorly sorted, immature, fine sandstone and siltstone. Sedimentary pebbles average 19 percent of the total pebble population and range from 1 to 30 percent.

Volcanic pebbles are the most common of the Vaqueros pebbles, and include andesite, rhyolite, and latite-trachyte. Texture of the clasts consists of various mixtures of groundmass and euhedral phenocrysts of quartz, plagioclase, and K-feldspar. All glass has been devitrified. Volcanic pebbles average 55 percent of the pebble population. Latite-trachyte is the most common pebble type, averages 62 percent of the volcanic pebble population, and ranges from 43 to 79 percent. Andesite and plagioclase-rich volcanic pebbles average 14 percent of the volcanic pebbles and range from 0 to 43 percent. Rhyolite averages 23 percent of the volcanic pebbles and ranges from 0 to 50 percent.

Rock types from Table 10 have been plotted on ternary diagrams (Fig. 21). Percentages of the pebble types are shown near the sample



Sample numbers

a = R120a	f = R5-7e	k = R129	p = R125b
b = R120b	g = R5-8d	l = R133	q = R107
c = R4-1e	h = 650	m = R1-10f	r = R2-17c
d = R110	i = 649-4b	n = R1-12d	s = R2-17d
e = R5-7c	j = 649-4a	o = R125a	t = R103

Figure 21. Ternary diagram showing pebble composition. Data from Table 10 except R4-1e from the lower member.

locations on Plate I. The figures show a great amount of variability in composition between sample locations. The variations are inconsistent and follow no trend or pattern. Other observations based on the areal distribution are:

1. Granite seems to be most common in the Piedra Blanca-Trout Creek area, although it is common throughout all conglomerate beds.
2. Quartzite is higher in percentages west of Piedra Blanca and east of Trout Creek. This suggests that where quartzite is abundant, granite is reduced in percentage.
3. Sedimentary pebbles are more abundant west of Piedra Blanca and east of Munson Creek, although they are common nearly everywhere.
4. Andesite pebbles are slightly more dominant west of Piedra Blanca Creek.

Fossils

CSUN 425 contains abundant *Balanus* and *Ostrea*, which are present as 1 to 10 cm angular fragments within a matrix rich in micrite.

CSUN 432 contains common *Lyropecten magnolia*, *Vertipecten bowersi*, *V. perrini*, *Anadara santana*, and *Balanus*. Fossils are complete but disarticulated, up to 15 cm in size, and present in a thin pebbly sandstone bed between two tilloid beds.

GLAUCONITIC SANDSTONE

Lithology

The highest lithosome of the Vaqueros Formation is glauconitic sandstone. It is present at almost every location from Sespe Hot

Springs to State Highway 33 and is important because it marks the top of the formation and is a lithologically correlatable bed. The glauconitic sandstone is present with or above conglomerate or, where conglomerate is missing, above massive sandstone. The lower contact is sharp or gradational. Fresh color of the glauconitic sandstone is light olive gray (5Y6/1) to greenish gray (5GY6/1). Thickness varies from 0 to 18 m, but averages 5 m. The glauconitic lithosome is usually massive, but is in places layered, with unlaminated beds 1 to 5 cm thick. Glauconitic sandstone is the only lithosome in the state highway area, and is the last unit present before the formation pinches out to the west.

The average glauconitic sandstone contains 80 percent framework and 20 percent calcitic cement (Table 8). Grain size averages 0.15 mm (fine sandstone) and ranges between .05 and 2 mm. This rock is moderately sorted and submature. Grains are rounded to very angular. There is no fossil material present, which is unusual for the upper member. The rock is an arkose (Table 8) and up to 25 percent is rounded grains of glauconite. Cement is calcitic spar.

DEPOSITIONAL ENVIRONMENTS OF THE UPPER MEMBER

INTRODUCTION

The upper member of the Vaqueros Formation represents a transgressive sequence of environments from shallow continental shelf to outer shelf. Sandstone of the upper member was an extensive sand sheet on which submarine dune fields and interdune areas existed. The cross-bedded lithosome formed from the migration of submarine dunes in localized dune fields. Massive sandstone accumulated in calmer interdune areas, and plane-bedded sandstone formed on current-swept interdune areas. The conglomerate beds near the top of the formation represent submarine debris flows possibly generated by submarine slumping and the glauconitic sandstone at the top of the formation represents quiet and slow sedimentation on the deeper edges of the outer shelf. The relationship of these five environments to the lithosomes is shown in Figure 22.

Similar ancient environments of a marine sand sheet have never been described before in the literature. Modern environments have been described, with major sand bodies of similar size found in large bays, estuaries, straits, channels, and continental shelves.

PALEOCURRENT ANALYSIS

All current directions from the upper member are based on cross bedding measurements and are shown on Plate I.

Piedra Blanca: Over 90 current direction measurements from the Piedra Blanca area are shown in Figure 23. There is no stratigraphic control of data points on this diagram. Data from Figure 23 are combined into twenty geographically distributed rose diagrams (Fig. 24) which show a strong directional component from due south to S. 60° E. and a moderate component S. 40° W. Of the twenty grid locations, thirteen show a southeast current, six show a southwest current, and one shows a northeast current. No geographic control of the current direction is apparent. The current that formed the Piedra Blanca cross bedding must have been a strongly unimodal current that moved from north to south, with minor variations to the southeast and southwest.

Kimball Canyon: The average cross-bedding direction of 15 mea-

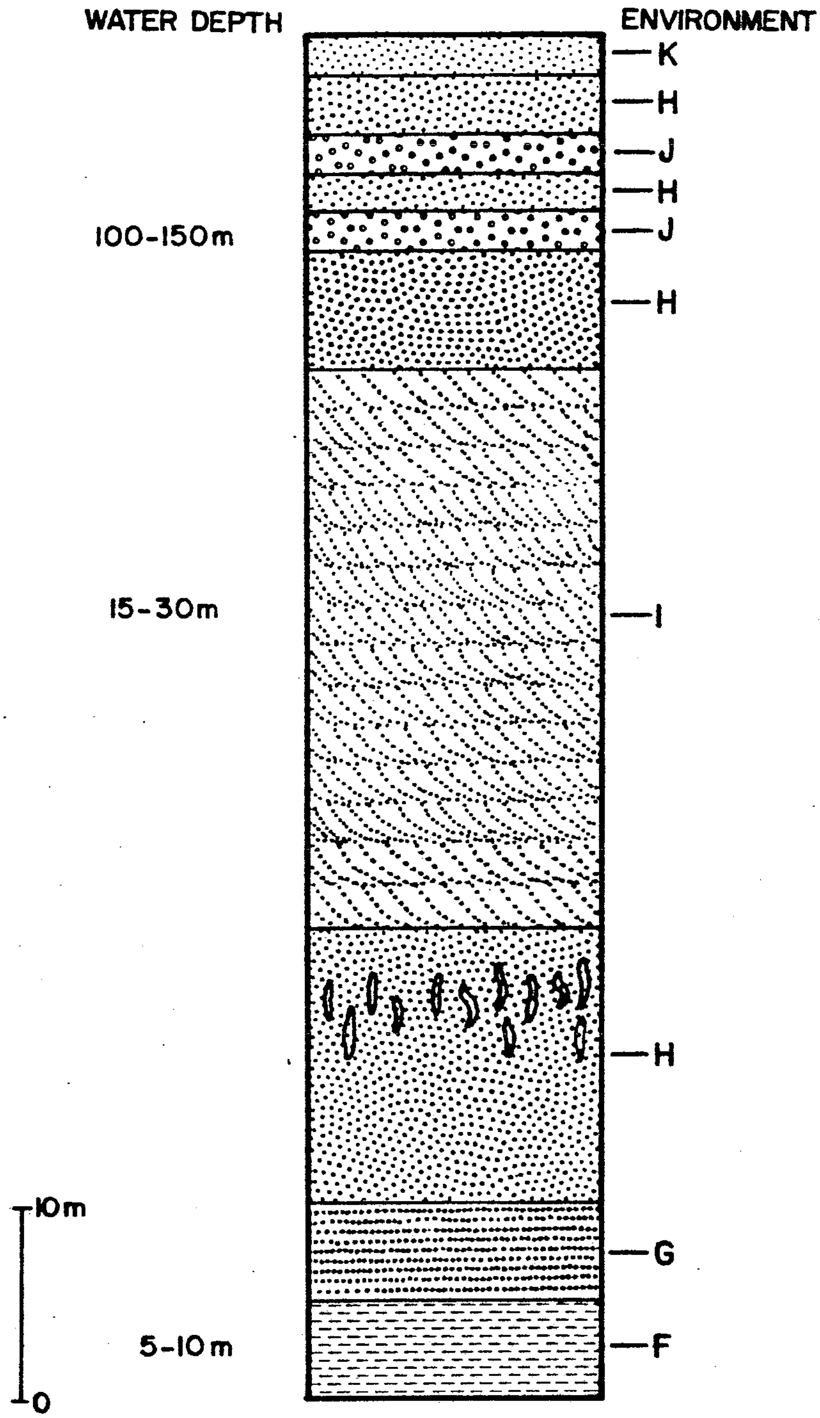


Figure 22. Lithology and sedimentary environments of the middle and upper members in the Piedra Blanca area. Letters show stratigraphic position of environments: (F) open bay-inner shelf, (G) plane-bedded facies and (H) massive and bioturbated facies of the interdune environment of the sand sheet, (I) submarine dune field, (J) submarine debris flows, (K) outer shelf.

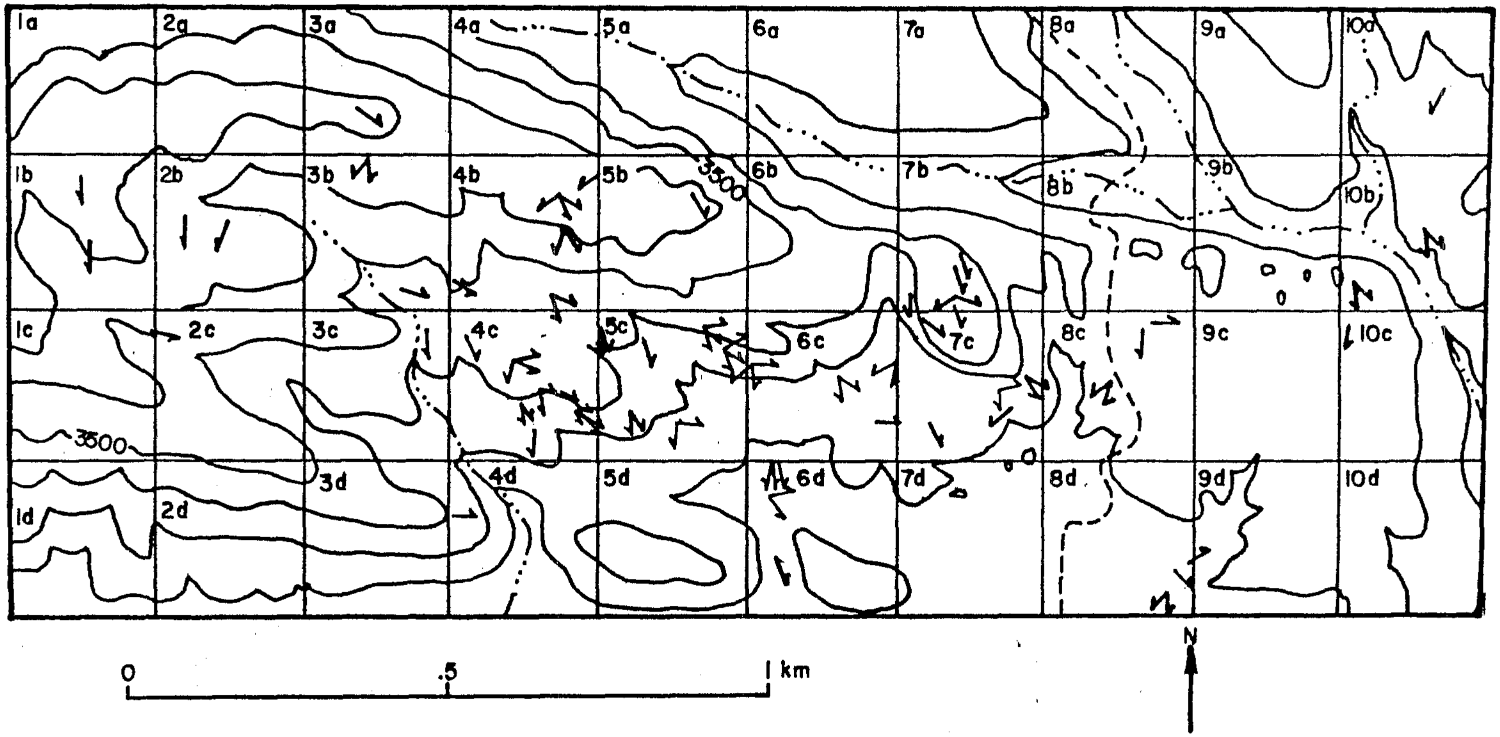


Figure 23. Current directions of the upper member from the Piedra Blanca area. Area of each grid corresponds to the area of grids in Figure 24.

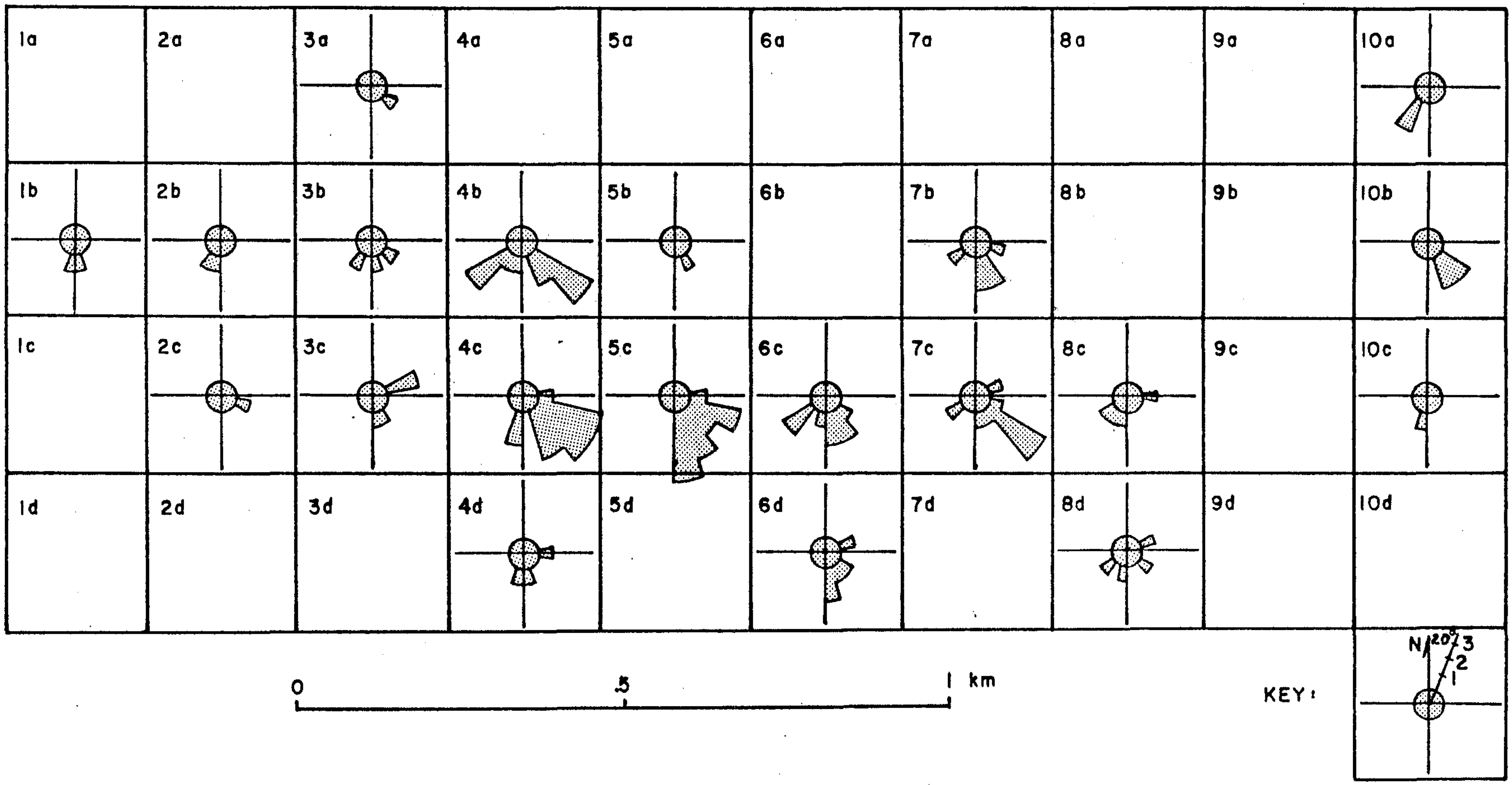


Figure 24. Distribution of current direction data from the Piedra Blanca area. Area of each grid corresponds to the area of grids in Figure 23.

surements faces S. 40° W., the same direction as the minor component at Piedra Blanca (Plate I). The conclusion is that an unimodal current also created the large cross bedding at Kimball Canyon.

Godwin Creek and Sespe Hot Springs: These are the only areas in the upper member where cross bedding faces in two opposite directions, thus indicating a bimodal current (Plate I).

Other locations: The current direction distribution at Kimball Canyon is typical of these other locations with current distribution extremely unidirectional and varing little from the average direction.

The average direction of currents for the major cross bedding occurrences are plotted on Figure 25. As can be seen from this figure, the current responsible for creation of upper member cross bedding was mostly unimodal and consistent at any one location. The current was variable over the entire area and was southerly in the central area and northwest near the margins of the outcrop pattern.

SUBMARINE DUNE FIELDS

At Piedra Blanca, Kimball Canyon, and other localities cross-bedded sandstone with abundant megaripples formed in a submarine dune field environment. Small, isolated megaripples in the plane-bedded lithosome are excluded from the dune field environment.

Three types of megaripples formed the cross bedding in the upper member: asymmetric straight-crested, undulatory, and lunate megaripples. The migration of straight-crested megaripples formed the planar cross bedding at Piedra Blanca, whereas undulatory and lunate megaripples formed the trough cross bedding at Piedra Blanca and Kimball Canyon. Cross bedding elsewhere formed from a combination of the three

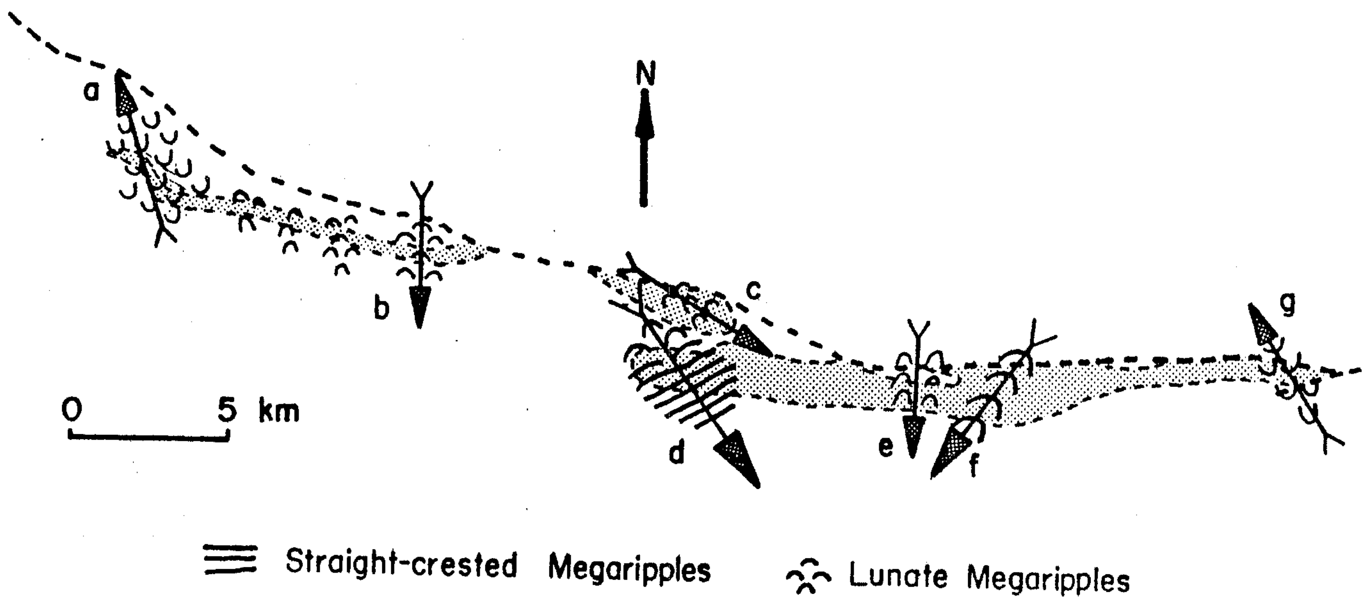


Figure 25. Paleocurrent averages and bedform distribution of the upper member for the Sespe Creek area: (a) state highway, (b) Potrero John Creek, (c) upper Piedra Blanca Creek, (d) Piedra Blanca, (e) and (f) Kimball Canyon area, (g) Sespe Hot Springs.

megaripple types.

The stratigraphic distribution of cross bedding at Piedra Blanca is suggestive of constant currents and constant sedimentation rates because no other sedimentary structures are present between cross bedding sets. Had the current fluctuated or had the sedimentation rate changed, there would have been other rock types deposited. The Piedra Blanca cross bedding contrasts with cross bedding at Sespe Hot Springs, where silty foreset laminations and bioturbation are indicative of periods of fluctuating currents and slow sedimentation.

The facies change from the cross-bedded lithosome to the massive and bioturbated lithosome between Piedra Blanca and Trout Creeks is suggestive of a boundary between megaripples and interdune areas. Similar facies changes near Kimball Canyon are suggestive of other boundaries.

The environment of deposition of the cross-bedded lithosome was one in which megaripples formed under a strongly unimodal current. Klein (1967, p. 373) reports that fluvial, coastal dune, tidalflat channel, delta foreset and bottomset, ocean basin, and continental shelf and shallow sea environments have unimodal currents. Only continental shelves and shallow seas, however, contain megaripples similar to those which formed the cross-bedded lithosome.

Two modern areas contain megaripples similar in size to those which created the cross-bedded lithosome. The first area, the Langeland Belt, is a 10-km-wide strait between the North Sea and the Baltic Sea (Werner and Newton, 1975, p. 29-59). Megaripples forming there have a height of 3 m, a wavelength of less than 100 m, and occur in water less than 15 m deep. Megaripples occur in dune fields averaging 1 km wide and 5 km long. Currents producing the megaripples are controlled by circulation into the Baltic Sea and tidal activity.

The second area containing megaripples similar to those that created the cross-bedded lithosome is in the North Sea, where straight-crested megaripples 2 to 4 m high occur in water 30 m deep (Stride, 1970, p. 467-477). Currents are tidal, but unidirectional, and have velocities up to 155 cm per second.

Characteristics of the ancient sand dune environment were similar to those of the modern examples. Megaripple height was at least 2 m at Piedra Blanca and 10 m at Kimball Canyon. Megaripple wavelength, which is based on megaripples of equal height in modern environments (Jordan, 1962, p. 845), was 100 m for the smaller dunes and 800 m for the larger ones. Dune fields were 0.2 km wide at Kimball Canyon and 3 km wide at Piedra Blanca.

Bedform types change with variations in stream power (Reineck and Singh, 1975, p. 11-12) and is demonstrated by the Piedra Blanca outcrops. Straight-crested megaripples form at lower stream powers and, with higher power, undulatory and lunate megaripples form. Because paleocurrent information indicates a south or southeast current, the undulatory and lunate megaripples, which are in the northwestern portion of Piedra Blanca, are upstream from the straight-crested megaripples. This change in megaripple type shows a decrease in stream power as the current traveled to the south and southeast.

INTERDUNE AREAS

Between dune fields on the sand sheet are interdune areas in which massive and plane-bedded sand accumulated. Similar deposits also formed prior to and after the dune fields existed. Modern interdune areas have not been defined or described in the literature, but their existence is predictable when stream power is less than or greater than in the dune fields (Allen, 1970, p. 78-79).

True massive sandstone forms with very rapid sedimentation and the dumping of sediment as a homogeneous mass (Reineck and Singh, 1975, p. 113). The fine to medium grain size of the massive and bioturbated lithosome indicates deposition by weak, unsorting, but continuous currents. Vertical burrows in the bioturbated areas are shallow water indicators suggesting times of slowed sedimentation in a well-aerated environment (Reineck and Singh, 1975, p. 144-145).

The occurrence of *Ostrea eldridgei* in the massive sandstone indicates open ocean conditions and depths between 0 and 40 m (Keen, 1963, p. 106). The lack of fragmentation indicates little post-mortem transport.

Plane-bedded sandstone forms at current velocities of the upper and lower flow regimes (Allen, 1970, p. 78-79). At Kimball Canyon, plane-bedded sandstone is traceable laterally into the largest dune features present in the Vaqueros. This relationship between large bedforms at the higher end of the lower flow regime and plane beds suggests the plane beds formed at velocities of the upper flow regime. At other localities, where plane beds are associated with ripples and small megaripples, velocities may have been of the lower flow regime.

Enviornmental characteristics of the interdune areas are very similar to those of the submarine dune fields, with the major difference being current strength. Wide-spread plane-bedded sandstone in the lower third of the member, usually associated with small megaripples, probably formed on the sand sheet at low flow regime velocities before establishment of a localized current pattern which created the dune fields. Other plane-bedded sandstone formed close to the dune fields from currents slightly stronger than those that formed megaripples. Massive sand accumulated in areas with weaker currents. The width of the interdune areas averaged 3 km and at any one time in the lower two-thirds of the member most of the shallow shelf was accumulating massive sand. The massive sandstone overlying the cross bedding indicates weak currents and constant sedimentation dominated the entire shelf after the localized current pattern ended.

SUBMARINE DEBRIS FLOWS

The tilloid conglomerate beds are submarine debris flows. Pettijohn (1975, p. 181) interprets paraconglomerate tilloids as forming in submarine environment from slumping and gravity movements. The potential for slumping is provided by saturated mud deposits and the oversteepening of rapidly deposited material (Crowell, 1957, p. 1004).

Pebbles occur on muddy bottoms today in land-enclosed mobile basins (Stanley and Unrug, 1972, p. 305). Storms shift pebbles from small deltas out onto muddy shelves and slumping mixes the pebbles and mud together.

Submarine slumps occur today along the southern California coast on slopes averaging 3.5^{o} and at depths as shallow as 100 to 150 m (Fischer and others, 1977, p. 43-44). Although these slumps may not produce debris flows, the potential is present.

The different components of the tilloid beds suggest a variety of sources for the debris flows. The barnacles, oysters, and micrite in the tilloid beds indicate shallow marine environments as sources that may have been similar to the muddy beach and bay environments present in the lower member. Pebbles indicate a source of coarse clastics, such as a delta, on the shelf at the head of the slides.

Mechanics of the Vaqueros debris flows are summarized from observations on other muddy conglomerates in modern and ancient environments by Harms and others (1975, p. 154) and Stanley and Unrug (1972, p. 305). Failure of the slope caused pebbles and fossils to mix with terrigenous clay, micrite, and water, forming a single viscous fluid that moved down slope. The diffuse nature of the lower contact of the conglomerate beds at some places suggests that the flows were fluid on the unlithified and uncompacted surface.

Up to three different slumping events may have occurred at any one area, producing three conglomerate beds. Direct correlation of all conglomerate beds is not possible, so more than three events may have occurred throughout the region in general. However, overlapping or thinning of individual beds is not present, and it is likely that the tilloid deposits in separated areas represent the same slump events.

The pebble beds east of the tilloid beds (east of Trout Creek) may represent material of the same slump events that has been slightly washed and sorted during transport. Alternately, these conglomerate beds may represent secondary erosion, transportation, and redeposition of tilloid material from the debris flows.

The tilloid beds indicate a terminus of a drainage system in the upper Piedra Blanca Creek area. Submarine debris flows commonly form near the source of input along the basin margin (Stanley and Unrug, 1972, p. 307-308). Tilloid beds are the thickest and most abundant at upper Piedra Blanca Creek, so this area must be near to where the material accumulated before being slumped. No tilloid beds occur east of Bear Creek, suggesting the lack of major streams entering the ocean in the eastern area.

OUTER SHELF

The glauconitic sandstone beds at the top of the Vaqueros are interpreted as forming on the outer shelf. This interpretation is based on the presence of glauconite and on the stratigraphic and environmental sequence.

The formation of glauconite is restricted to the marine continental shelf (Reineck and Singh, 1975, p. 132), where it occurs in the greatest concentrations deeper than 100 m (Hein and others, 1974, p. 569). Authigenetic glauconite forms in areas of normal salinity, near normal oxidation potential, and low sedimentation rates (Pettijohn, 1975, p. 426). Phosphate occurring in association with glauconite is evidence for the organic nature of the shelf (Pettijohn, 1975, p. 426-428). The bedding and moderate sorting suggest turbulent and fluctuating currents, which are common conditions in areas where glauconite forms (Reineck and Singh, 1975, p. 132).

SUMMARY

By the end of deposition of the lower member, Sespe Bay had near normal salinity and open ocean circulation and could be described as a shallow shelf rather than a restricted enclosed bay. The bay gradually deepened during deposition of the middle member. Currents were calm throughout the transgression as mud accumulated rapidly in an environment characterized by reducing conditions and the lack of mollusks, but these conditions abruptly changed when renewed current activity resulted in deposition of the first sand of the upper member.

A uniform current spread sand over the flat-bottomed shelf, moving medium and fine sand into plane laminations and occasional small dunes at a minimum depth of 15 to 30 m. Gradually the current strength increased and currents became channelized, creating dune fields at Piedra Blanca, Kimball Canyon, and other locations. Currents up to 155 cm per second created dunes up to 10 m high. The dune fields migrated south, pushed by a strong current and supplied with abundant sediment at a constant rate.

Extensive interdune areas up to 3 km wide covered the shelf floor between dune fields. Sedimentation in these areas was rapid and consistent, but currents were weak and unsorting. Stronger currents near dune fields created plane laminations.

The top of the cross-bedded lithosome signals a change in the depositional character. Currents slackened although deposition remained constant. Megaripples could not be produced and troughs between existing megaripples became filled with slowly accumulating sand. Shelf depths deepened as the sedimentation rate approached its lowest level since the beginning of the member. Glauconite began to form in the western area.

The shelf deepened to 100 or 150 m and deposits became unstable and slid. Shallow water deposits at the head of the slide were mixed, creating a viscous fluid which moved down slope. The slide and subsequent debris flows originated several kilometers away and spread an even sheet of pebbly mud over the shelf. Slides occurred at least two more times.

The slow sedimentation rate continued after the last of the debris flows, and glauconite began forming on the entire outer shelf. With the end of strong currents come the end of the sand supply. During later periods of no current activity, the first mudstone beds of the Rincon Formation were deposited.

PROVENANCE

THIN SECTION ANALYSIS

A source terrain is suggested by the composition of the clastic components of the Vaqueros (Tables 2, 6, and 8). The high concentration of quartz and feldspar indicates a granitic source terrane. Other minor source areas indicated by thin section analysis are sedimentary and volcanic terranes. The weathered feldspar suggests the source was close by. There is little geographic or stratigraphic change in composition through the members, suggesting the same source fed the entire Vaqueros Formation.

CONGLOMERATE ANALYSIS

Sedimentary rock types are common as pebbles throughout all conglomerate beds and are uniform in composition, grain size, and maturity. It is believed they are all representative of a single sedimentary rock source terrane. Sedimentary pebbles are also among the softest of the rock fragments present in the Vaqueros pebble population and therefore must have come from a nearby source area, possibly from nearby Oligocene and Eocene strata. The remaining pebbles can be original erosional products of several source terranes, they can be second generation pebbles eroding from the same source as the sedimentary clasts, or they can be a combination of both these explanations.

No prospective primary volcanic terranes are identifiable southeast, south, or southwest of Sespe Creek. Franciscan volcanic rocks are present 50 km to the west, but are basalt rather than the acidic latite and trachyte present in the Vaqueros. Oligocene volcanic rocks in the Soledad basin are 25 km east of Sespe Creek after right-lateral offset of 60 km on the San Gabriel fault is removed. Interbedded with the volcanic rocks are Oligocene to Miocene continental conglomerate of the Vasquez Formation, which contains clasts of anorthosite, basalt, syenite, and gneiss (Bohannon, 1975, p. 79). The association of volcanic, plutonic, and metamorphic clasts from the Soledad basin were carried west into the Lockwood basin, which was later severed from the Soledad basin by the San Gabriel fault. Further westward transport of the Soledad basin clasts into the Sespe Creek area is unlikely because clasts of anorthosite, gabbro, and gneiss, which were transported with the volcanic clasts, are not present.

Volcanic clasts could also have been carried south across the Cuyama Valley area and into the Sespe Creek area. If so, equivalent aged Vaqueros exposures in the Cuyama area should contain pebbles similar to those at Sespe Creek, but Blake (pers. comm., 1977) reports the conglomerate in the Vaqueros at Santa Barbara Canyon contains anorthosite and Pelona Schist pebbles from the Soledad basin area and few volcanic pebbles.

With no identifiable volcanic rock source terrane, a sedimentary source containing volcanic clasts seems likely to have contributed pebbles to the Vaqueros. However, Oligocene and Eocene strata near Sespe Creek and in the Cuyama Valley area are conformable beneath the Vaqueros and therefore could not have been eroded during Vaqueros deposition.

Eocene strata are common north of Sespe Creek in the Pine Mountain area. Conglomerate from the Thorn Meadow Formation at Reyes Peak (Pine Mountain) contains over 50 percent volcanic pebbles, with less than 20 percent each of sedimentary, plutonic, and quartzite pebbles (Jestes, 1963, p. 174-178). The volcanic pebbles are small and concentrated in finer gravels. Pine Mountain pebble types and percentages, therefore, are similar to the Sespe Creek Vaqueros pebbles and the prospect that an Eocene source terrane from the Pine Mountain area supplied volcanic pebbles into the Vaqueros is likely.

Granite pebbles may be second generation or may have come from one of the nearby plutonic outcrops. The plutonic rocks, which are known as the Mount Pinos Granite (Carman, 1964, p. 18-19), are exposed today within 2 km of the Sespe Hot Springs Vaqueros exposure, but the lack of granitic pebbles there indicates that this close-by granite was not exposed during Vaqueros deposition. The Mount Pinos Granite also is exposed near Alamo Mountain, 15 km northeast of the greatest plutonic pebble concentration, and consists of biotite-quartz diorite and fine-grained granite containing 40 percent K-feldspar, 40 percent quartz, 15 percent plagioclase, and 5 percent other minerals (Kiessling, 1958, p. 13-14). The composition of the Mount Pinos Granite is similar to the granite pebbles in the Vaqueros, and, therefore, this more distant granite may have been part of the Vaqueros source terrane.

The possibility of a granitic basement source is reinforced by an examination of the sources of the Sespe Formation. Bohannon (1976, p. 115) concludes the Sespe Formation had two sources: reworked pebbles and sandstone clasts from Eocene strata, and a basement source supplying large granitic cobbles. Both sources continued to supply pebbles through the end of Sespe continental deposition and into marine Vaqueros deposition. The sources were further away during Vaqueros deposition because the granitic pebbles in the Vaqueros are smaller and sandstone pebbles are fewer than in the Sespe Formation.

PALEOGEOGRAPHY

INTRODUCTION

All paleogeographic reconstructions are plotted on Figure 26, which is a partial palinspastic map in which left-lateral offset of 16 km on the Big Pine fault is removed. Paleogeographic maps are shortened in a north-south direction because folding has not been removed.

Provenance and paleocurrent constraints help to define paleotopographic features which were in existence throughout the depositional history of the Vaqueros. A major constraint governing paleogeography is the lack of anorthosite in the Sespe Creek Vaqueros. The presence of anorthosite in the Vasquez Formation in the Soledad basin indicates the San Gabriel Mountains, the only known primary source for anorthosite, were exposed and eroding prior to and during deposition of the Vaqueros. The anorthosite-bearing Vaqueros in the Cuyama area, therefore, must have been separated from the anorthosite-lacking Vaqueros in the Sespe Creek area by a landmass. This highland, called the San Rafael uplift, is shown on paleogeographic maps by Corey (1954, p. 78) and Fischer (1976, p. 37). It connected the ancestral Sierra Madre Mountains with the Alamo Mountain area and had an almost east-west trend, parallel to the present trend of Pine Mountain.

The geology of the San Rafael uplift, which is based on the pebble analysis, was similar to that exposed today in the Pine Mountain-Alamo Mountain area and consisted of Eocene sedimentary rocks with a few outcrops of granite to the east. Pre-Vaqueros uplift along the Ozena fault may have given the San Rafael uplift an asymmetrical shape, with a steep northern face and a gentle south face.

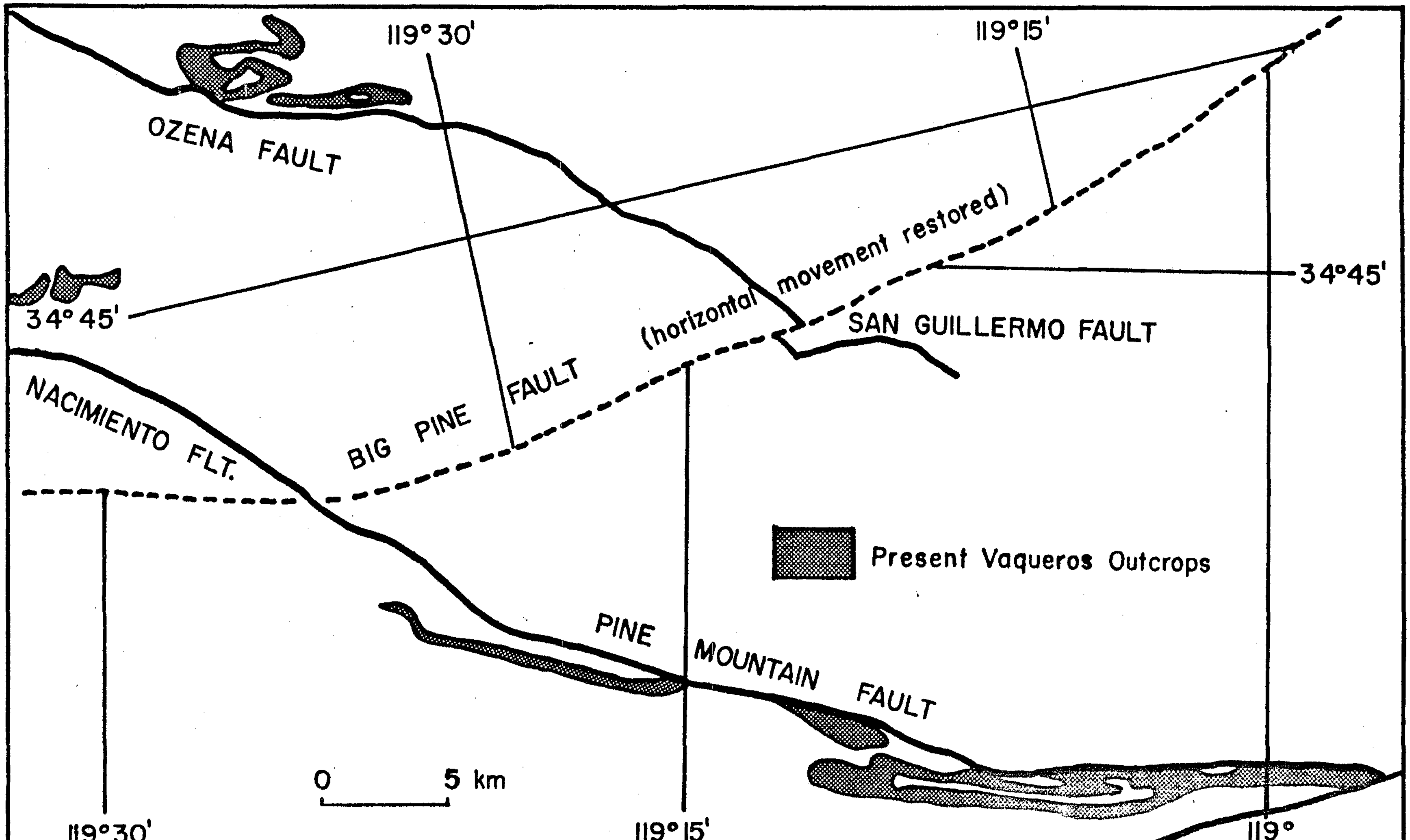


Figure 26. Partial palinspastic base map for paleogeographic reconstructions. Left-slip movement of 16 km on the Big Pine fault has been removed, but no adjustment has been made for effects of north-south folding.

The slight variations in pebble composition suggest two or three conduits supplying material. A principle conduit drained granitic and Eocene terranes with part of this stream system flowing west 15 km from the granitic terrane of the Alamo Mountain area. The terminus of this system was near upper Piedra Blanca Creek, where most of the conglomerate deposits are. Smaller drainage systems, which avoided much of the granitic terrane, dumped lesser amounts of material east and west of the main Piedra Blanca terminus.

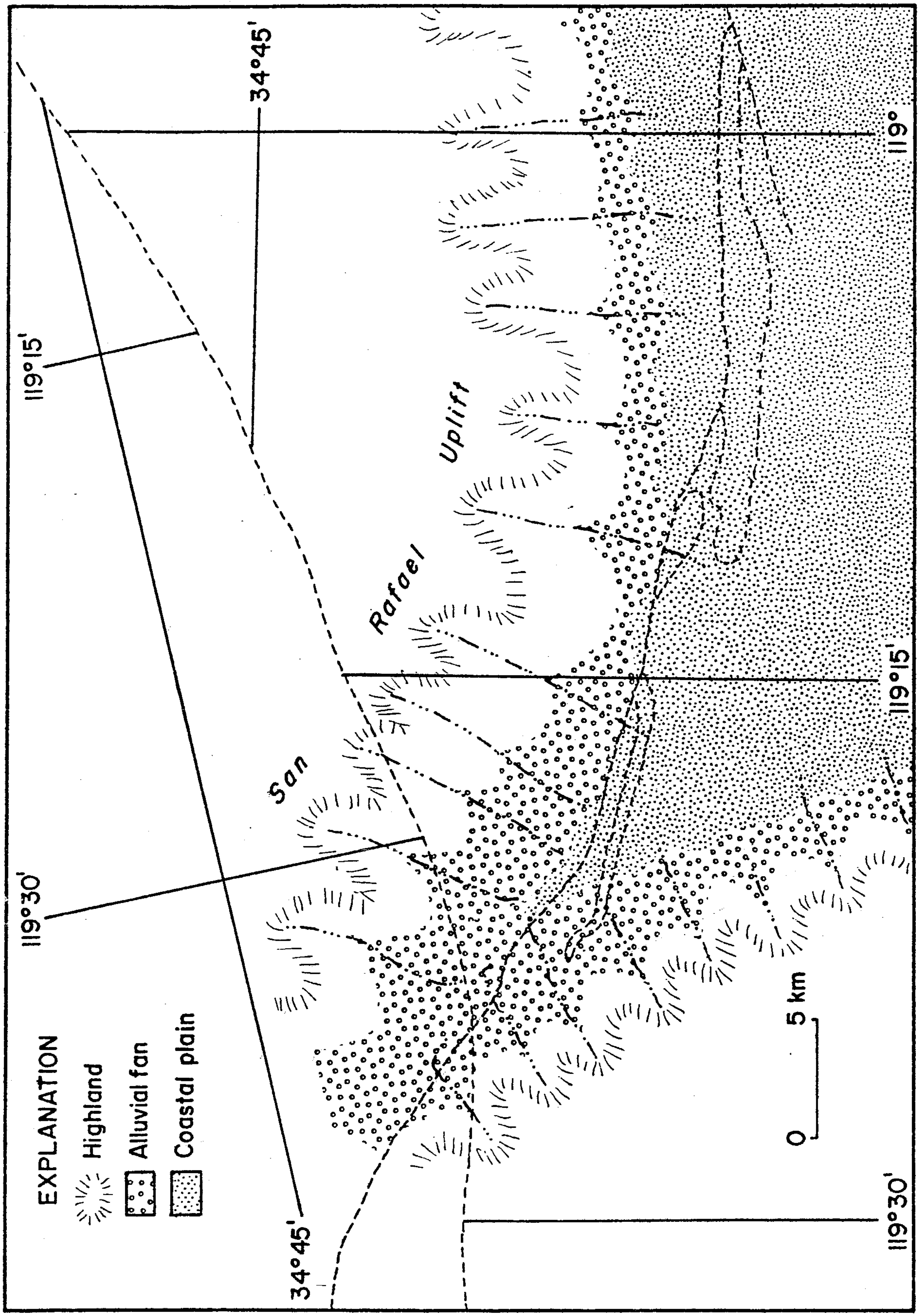
Any shoreline north of the present Vaqueros outcrops would have to parallel the trend of the San Rafael uplift and be just a few kilometers north of the outcrops because rocks in the Pine Mountain area were probably part of the source material. The pinching out of the Vaqueros in the western area indicates a shoreline may have been present there.

The western shoreline indicates another landmass existed west of the Vaqueros outcrops. Leol and Corey (1932, opp. p. 50) named this highland Ynez Island because during Vaqueros deposition it became isolated from the mainland.

PRE-VAQUEROS PALEOGEOGRAPHY

The basics of the paleogeography are shown in Figure 27. Between the two highlands that were described above was a flat coastal valley. The valley opened to the south and east and tapered to the northwest. Surrounding the coastal valley adjacent to the highlands were two bajadas. Tapering of the valley to the northwest may have been caused by the overlapping of fans from the north and west. The valley was extremely flat in the eastern areas, but, west of Munson Creek, sloped up

Figure 27. Pre-Vaqueros paleogeography constructed in part from interpretations of Dickinson and Lowe (1966) and McCracken (1969). Paleogeography base map from Figure 26. Dashed lines represent major faults and Vaqueros outcrops.



EXPLANATION
Highland
Alluvial fan
Coastal plain
San Rafael Uplift
34°45'
34°45'
119°15'
119°30'
119°
119°15'
119°30'
0
5 km

to the west and north at 2^{o} to 3^{o}. Elevation of the San Rafael uplift in the Sierra Madre area was at least 550 m (Fritsche, 1969, p. 132).

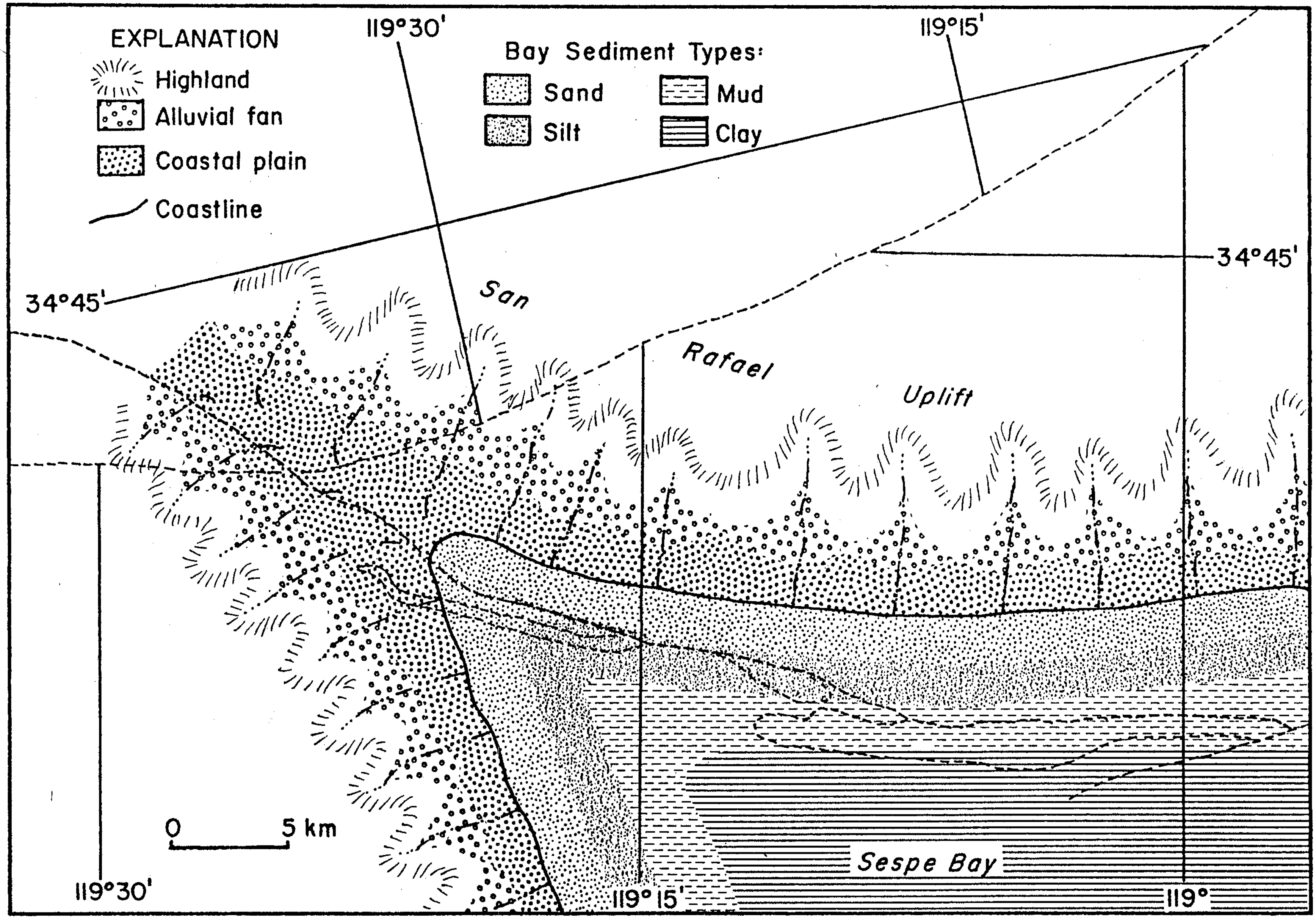
LOWER MEMBER PALEOGEOGRAPHY

Figure 28 is a paleogeographic map of the lower member of the Vaqueros taken at an arbitary time. The transgression seems to have begun to the south and east, with rising waters rapidly covering the coastal valley. Low energy beaches lapped against the base of the bajadas. Bottom sediment distribution, from Figure 10, tends to become finer toward the center of the bay. The bay was extremely shallow, with few areas deeper than 5 m. Currents were weak and tidally influenced (Fig. 9). The shallowness of the bay may have been enough to restrict circulation, but the presence of the landmass which was to become Ynez Island certainly protected the bay from coastal ocean currents. The bay probably had little fresh water influx from the San Rafael uplift. The bay in size and shape may have been similar to Florida Bay although the characteristics compare closely to Laguna Madre on the Texas coast.

MIDDLE MEMBER PALEOGEOGRAPHY

Sespe Bay, during deposition of the Vaqueros middle member, deepened to between 15 and 30 m. Coarser bottom sediment moved toward the edges of the bay and left fine silt and clay to accumulate in all areas of the bay except the far west. The bay had the characteristics of the shelf but continued with the same shape present during deposition of the lower member. During this time, the bay resembled the shallow open bay-inner shelf areas of the Louisiana coast. By late in the time of

Figure 28. Paleogeography during deposition of the lower member showing the encroachment of Sespe Bay onto the Sespe coastal plain and sediment distribution within Sespe Bay. Paleogeography base map from Figure 26. Dashed lines represent Holocene geology and show major faults and Vaqueros outcrops.


EXPLANATION
Highland
Alluvial fan
Coastal plain
Coastline
Bay Sediment Types:
Sand
Silt
Mud
Clay
119°30'
119°15'
34°45'
34°45'
San
Rafael
Uplift
0
5 km
119°30'
119°15'
119°
Sespe Bay

deposition of the member only a thin isthmus continued to connect the San Rafael uplift and the future Ynez Island.

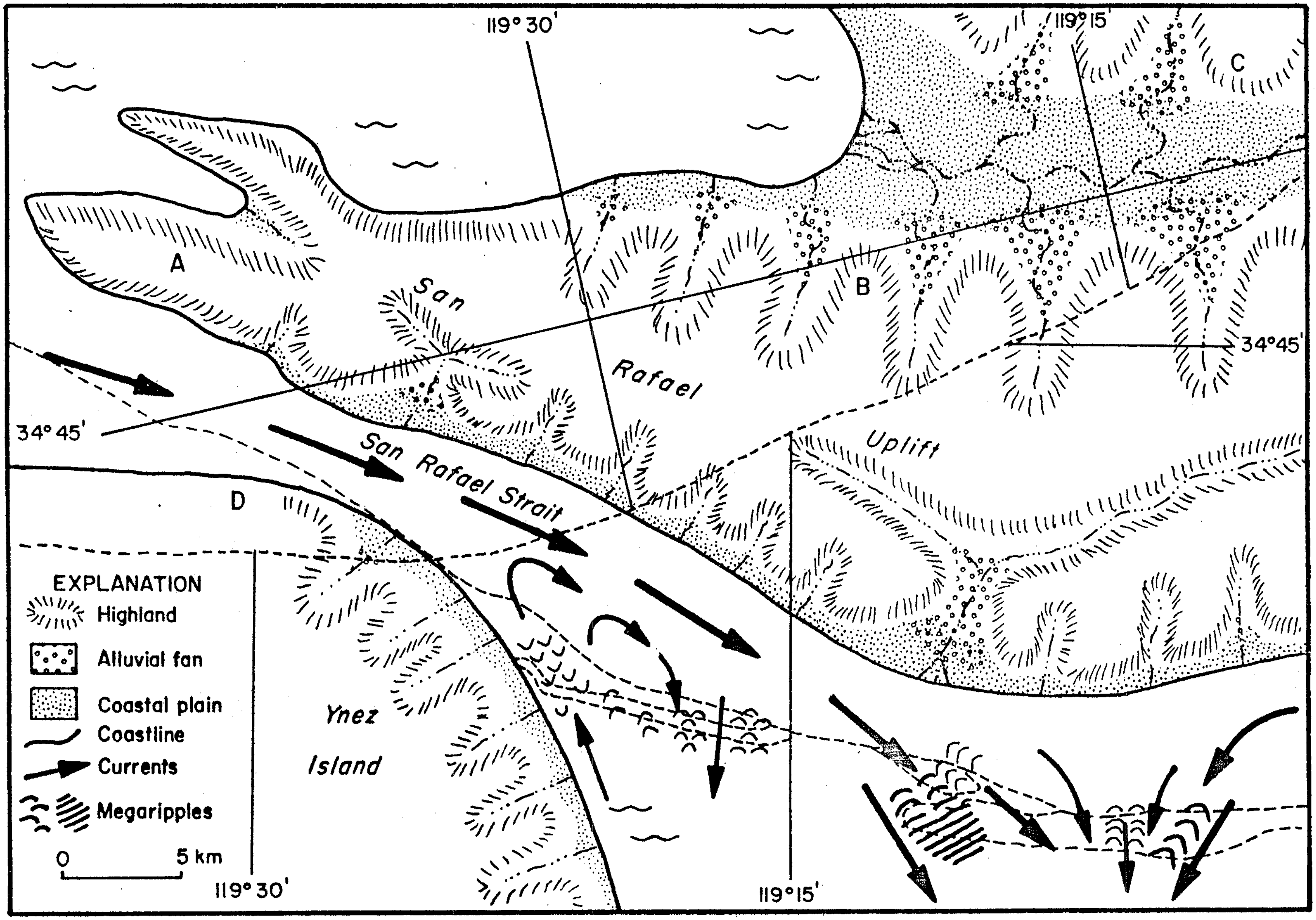
UPPER MEMBER PALEOGEOGRAPHY

Water from the transgression moved up the coastal valley that separated the two highlands. At the same time, the transgression in the southern Sierra Madre area pushed the sea further south and east. Finally, the two bays connected to form one waterway that separated the San Rafael uplift from Ynez Island (Fig. 29) and oceanic currents flowed freely through the newly created strait, called San Rafael Strait by Loel and Corey (1932, opp. p. 50).

During deposition of the upper member, San Rafael Strait connected two large water bodies in the Ventura and Santa Maria areas and water flowed southeast through the strait from the Santa Maria area. The San Rafael uplift may have been a peninsula, with large bodies of water on the north, west, and south. One shoreline of the strait south of the San Rafael uplift connected the Sierra Madre area with the area north of Sespe Creek. The strait's opposite shoreline is poorly defined, but may have had a northwest trend.

The need for a strait or a large, active body of water north of the Sespe Creek area is based in part on the size and abundance of cross bedding and the paleocurrent directions. The large scale cross bedding of the dune fields could have been created only by the continuous movement of large quanities of water at moderate velocities to the south, southeast, and southwest. Such features would not seem likely to form in a small bay with little water movement, but rather in an area with a large volume of water moving southward.

Figure 29. Paleogeography during deposition of the upper member showing development of San Rafael Strait and Ynez Island. Letters represent areas where paleogeography is constructed in part from interpretations of: (A) Fritsche (1969), (B) Blake (pers. comm., 1977), (C) Bohannon (1976), (D) Loel and Corey (1932). Paleogeography base map from Figure 26. Dashed lines represent Holocene geology and show major faults and Vaqueros outcrops.


119° 30'
119° 15'
C
A
San
B
34°45'
Rafael
34° 45'
San Rafael Strait
Uplift
D
EXPLANATION
Highland
Alluvial fan
Coastal plain
Coastline
Currents
Megaripples
0
5 km
Ynez
Island
119° 30'
119° 15'

The current distribution pattern is modeled from the English Channel (Stride, 1963), where the main current in the center of the channel is moving in opposite directions to those currents at the margins. The paleocurrent pattern in the Vaqueros is very similar, with the Piedra Blanca area representing the path of the main current. The northwest-trending paleocurrents at Sespe Hot Springs and near State Highway 33 may represent currents near the margins of the depositional basin. Splinters of the main current passed over Potrero John Creek, upper Piedra Blanca Creek, and Kimball Canyon.

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