CALIFORNIA STATE UNIVERSITY, NORTHRIDGE

GEOLOGY OF A PART OF THE

ZACA LAKE QUADRANGLE,

SANTA BARBARA 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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ABSTRACT

GEOLOGY OF A PART OF THE ZACA LAKE QUADRANGLE,
SANTA BARBARA COUNTY, CALIFORNIA

by

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Master of Science in Geology

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Detailed geologic mapping and study of the northeastern portion of the Zaca Lake quadrangle, Santa Barbara County, California, reveals the following stratigraphic and structural features.

The oldest unit in the area, a melange of mudstone, sandstone, greenstone, serpentinite, chert, and coarse-grained igneous rocks, is the Cretaceous and Jurassic Franciscan Complex basement. In fault contact with the Franciscan is the Espada Formation, a series of marine mudstone beds with lesser amounts of thin turbidite sandstone beds and channel-filling conglomerate of eastern provenance, which is probably of Late Jurassic and

Cretaceous age. In conformable contact with the Espada, the Fish Creek conglomerate is of probable turbidite origin with a western provenance and is early Late Cretaceous in age. In fault contact with the Fish Creek, the Unnamed shale and Unnamed sandstone of Dibblee (1966) combined mainly is marine mudstone and turbidite sandstone with an eastern provenance and is Late Cretaceous in age. Unconformably overlying the Unnamed shale and sandstone, the Carrie Creek Formation is mostly amalgamated turbidite sandstone with lesser amounts of conglomerate and mudstone with an eastern provenance and is Late Cretaceous in age. Unconformably overlying the Carrie Creek, the Branch Canyon Formation is a transgressive marine sequence consisting primarily of sandstone of early Miocene age. Conformably overlying the Branch Canyon, the Monterey Formation mainly is marine mudstone and shale in the lower part with porcelanite and porcelaneous mudstone becoming dominant in the upper part and is middle Miocene in age.

The oldest structural event recorded in the area, other than those related to the Franciscan melange, is a major uplift of Franciscan terrane to the west. After subsidence of this terrane, the next younger structural event was the migration of a submarine fan channel which resulted in a Late Cretaceous parallel unconformity between the Unnamed shale and sandstone and the Carrie

Creek. Uplift, tilting, erosion, and subsequent submergence resulted in a post-Carrie Creek, pre-Branch Canyon slightly angular unconformity. The Hurricane Deck syncline and several associated folds and faults, as well as uplift, resulted from post-Monterey, pre-Pleistocene compression. A northwest-southeast-trending fault is related to the Big Pine Fault of Miocene to Recent age.

INTRODUCTION

Purpose, Location and Geographic Setting

The purpose of this project is to present a detailed map and report on the geology of the northeastern part of the Zaca Lake quadrangle in order to partially fulfill the requirements for a Master of Science degree in Geology at California State University, Northridge.

The mapped area is in the San Rafael Mountains about 50 km northwest of Santa Barbara in the northeastern part of the Zaca Lake quadrangle, Santa Barbara County, California (Fig. 1). The area is accessible during most of the year by dirt roads, except during times of heavy winter run off.

The terrain is rugged, with a maximum relief of about 800 m. Slopes are steep and brush is dense, impassable in some places, except along larger streams and on a few grassy slopes north of the Sisquoc River. Vegetation varies from Yellow Pine forests along the higher ridges to oak woodland on dry southern slopes to typical California chaparral in most areas. North-facing slopes and many of the smaller streams have the densest brush cover, commonly with lots of poison oak.

Because of soil development and brush, exposures in

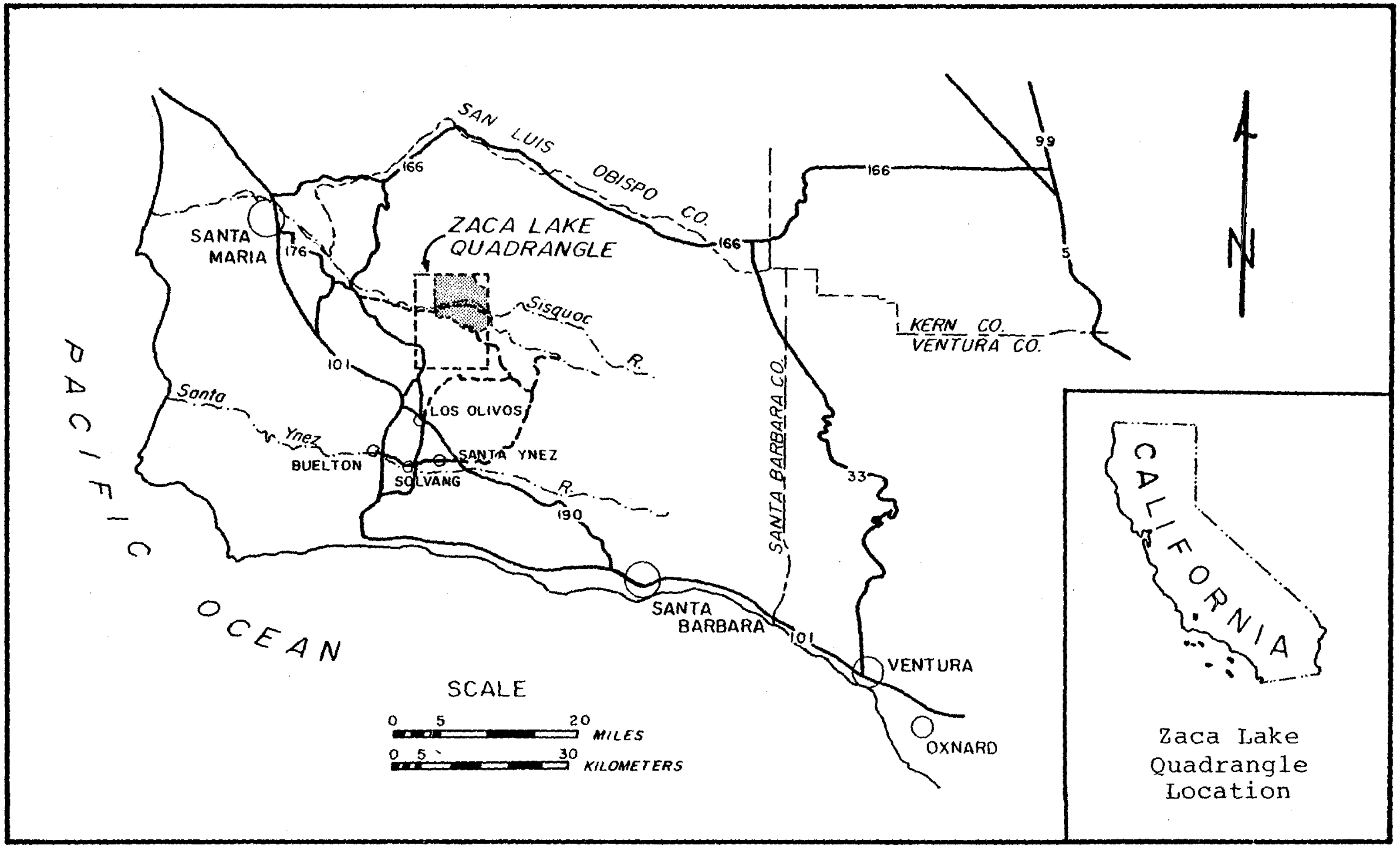

Figure 1. Location of the Zaca Lake quadrangle and the study area (shaded).

many places are poor, difficult to locate, and difficult to get to. Contacts, with a few exceptions, can be traced only for short distances and are approximately located between outcrops, commonly on the basis of topography, soil, or vegetation changes.

Regional Geologic Setting

The map area is at the juncture between California's Coast Ranges and Transverse Ranges provinces. The Transverse Ranges province is characterized by east-west-trending folded mountain ranges bounded by left-slip faults. Basement in the eastern part of this province is composed of Mesozoic granitic rocks. In the western part Franciscan age rocks form basement. The Coast Ranges province is structurally complex and underlain by Franciscan Complex rocks with the exception of the upper Mesozoic granitic rocks of the Salinian block, which is bounded by the San Andreas and Sur-Nacimiento faults. Right-slip faults are common in the Coast Ranges and are associated with folding, thrust faults, and normal faults. The thick Great Valley sedimentary sequence of Late Jurassic to Late Cretaceous age crops out along the eastern margin of the Coast Ranges and extends eastward beneath the Great Valley; outliers of these rocks commonly are associated with younger rocks and rest on the Franciscan both east and west of the Salinian block (Nilsen, 1977a).

Previous work

Before the present study, the geology of the northeastern part of the Zaca Lake quadrangle was not well known. Arnold and Anderson (1907) include the area on a geologic map of the Santa Maria area at a scale of 1:125,000. They did not recognize many of the units present and mapped all Cretaceous rocks as undifferentiated "pre-Monterey" and Franciscan rocks as "post-Monterey intrusive diabase". Redwine and others in 1953 mapped the area at a scale of 1:62,500. This report is unpublished. The study area is included on several maps and reports at a regional scale (Diller and others, 1915; Reed and Hollister, 1936; Jennings, 1959).

Field and Laboratory Work

Field work was done at various times between July, 1976, and June, 1979. Mapping was done on aerial photographs taken in May and June, 1968, for the U.S. Forest Service at a scale of approximately 1:16,000. Information was later transferred to a portion of the Zaca Lake quadrangle (1:24,000) which had been photographically enlarged to a scale of 1:12,000. Thickness of stratigraphic units was measured from cross sections drawn approximately perpendicular to strike. Rock units are described from field notes and from microscopic examination of hand samples and thin sections. Sedimentary rock terminology follows Folk (1974). Color codes follow Goddard (1970).

Micrófossil samples were soaked in water or boiled in water and trisodium phosphate in order to disaggregate the rock. Disaggregated microfossil samples were wet sieved through 10, 115, and 230 mesh screens and residues were dried and examined with the binocular microscope.

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FRANCISCAN COMPLEX

General

The Franciscan Complex is a complicated assemblage of many rock types, mostly sedimentary with some volcanic and metamorphic rocks. It is exposed along the western United States coast from southwestern Oregon southerly to at least Santa Catalina Island off southern California. Exposures generally are bounded on the east by the Klamath Mountains and the Coast Range thrust fault at the edge of the Great Valley (Bailey and others, 1970). The Franciscan Complex along with possible correlative rocks in Baja California, Washington, Canada, and Alaska are typical of rocks of orogenic continental margins (Schlocker, 1974) where subduction has taken place.

Nomenclature

Lawson (1895) used the name Franciscan Series to refer to the chaotic assemblage of graywacke, shale, altered volcanic rocks, chert, limestone, and metamorphic rocks in the vicinity of San Francisco. Since then the term "Franciscan", with several modifications, has been used for similar rock assemblages throughout much of the state. A specific type locality is not designated, but the San Francisco peninsula generally is accepted as the type area (Bailey and others, 1964).

Hsu (1968) defined a melange as a mappable body of deformed rocks that contains "native" and "exotic" blocks (which may be up to several kilometers long) in a pervasively sheared, fine-grained, commonly pelitic matrix. Franciscan rocks in the map area fit this definition and thus are considered a melange in this paper.

Franciscan rocks commonly are termed Franciscan Formation. The American Code of Stratigraphic Nomenclature, however, defines a formation as a body of rock characterized by its lithologic homogeneity (ACSN, 1961, Article 6). The Franciscan is characterized by lithologic inhomogeneity and therefore should not be called a formation. As Hsu (1968) points out, the American Code of Stratigraphic Nomenclature states: "If a mass of rock is composed of diverse types of any class or classes or is characterized by highly complicated structure, the word 'complex' may be used as part of the formal name instead of a lithologic or rank term (ACSN, 1961, Article 6j). Hsu does not use this terminology, however, and suggests the word melange be used. The name Franciscan Complex is used in many recent papers (Ramberg and Johnson, 1976; Cowan, 1978; Page and others, 1979) and hence will be used here.

The Franciscan Complex cannot be traced from the type area into the Zaca Lake quadrangle, but the lithology described below is sufficiently similar to the type area Franciscan to allow correlation.

Rocks herein mapped as Franciscan Complex were mapped in 1953 as "Miocene volcanic: basalt" by Redwine and others (unpublished; shown on Jennings, 1959) and in 1906 by Fairbanks (unpublished; in Arnold and Anderson, 1907, p. 65, Pl. 1) as "post-Monterey intrusive diabase". Fairbanks apparently believed that the Monterey Shale was baked near its contact with the "intrusion". No such bake zone was found by this author within the map area. Fairbanks found sandstone, which he thought was brought up from below, and "sheared serpentinous facies." Both of these early studies were reconnaissance in nature, and the authors did not recognize the wide range of rock types exposed here.

Distribution and Thickness

The Franciscan Complex is exposed as a narrow band, about 1 km wide, along Catway Ridge in the southern part of the map area (Pl. 1). Stratigraphic thickness (Fig. 2) cannot be determined because the complex consists of chaotically arranged broken blocks which are not stacked in a normal sort of stratigraphic superposition.

The Franciscan Complex is penetrated in the subsurface to the southwest of the map area by General Petroleum Corporation wells Giorgi No. 1, Wickenden No. 1, and

System and series		Formation	Thickness m	Graphic log	Rock description
CRETACEOUS	Upper Cretaceous	Unnamed shale and Unnamed sandstone of Dibblee (1966) combined	2,300 (column condensed)		Predominantly a series of interbedded gray to black mudstone and grayish fine to coarse turbidite sandstone with minor amounts of conglomerate. Sandstone mostly occurs in "packages" of beds that generally show a coarsening and thickening-up cycle.
					Fault
CRETACEOUS	Upper Cretaceous	Fish Creek conglomerate	>180		Dusky-brown "disorganized" conglomerate which is more resistant than surrounding rocks and typically forms low ridges.
JURASSIC and CRETACEOUS		Espada Formation	>320		Mainly grayish-olive-green mudstone interbedded with thin turbidite sandstone and rare channelized conglomerate beds.
					Fault
JURASSIC and CRETACEOUS		Franciscan Complex	?		Tectonic melange of sandstone, greenstone, serpentinite, chert, peridotite, and tuff contained in a pervasively sheared mudstone matrix.

Figure 2. Generalized columnar section of rocks in a part of the Zaca Lake quadrangle.

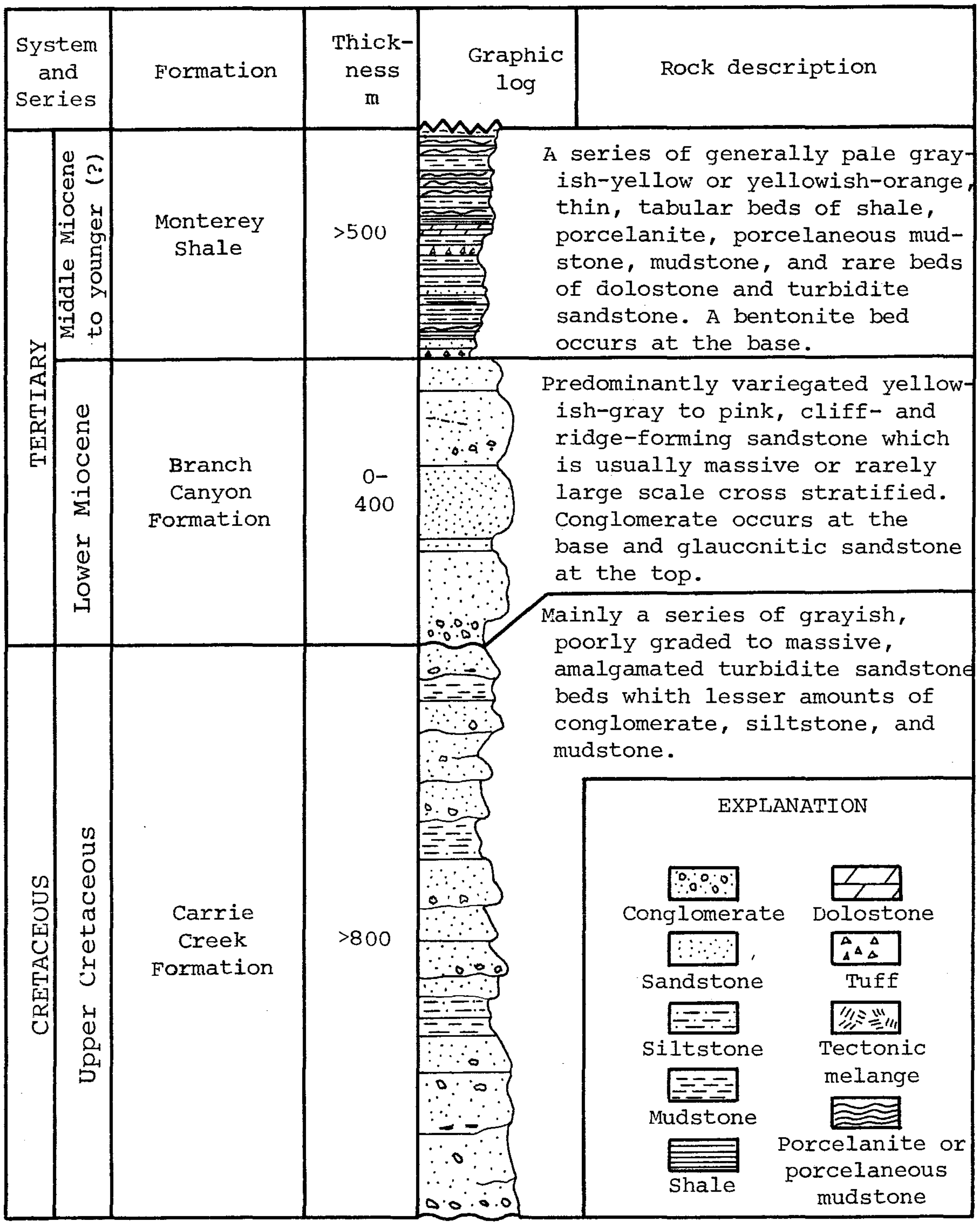


Figure 2. *(Continued).*

Wickenden No. 2. The complex is considered to be basement in this area (Woodring and Bramlette, 1950).

Lithology

The Franciscan Complex is poorly exposed in the map area. Many lithologies crop out in a chaotic, unsystematic assemblage, and their relative percentages of the whole can only roughly be estimated. The most common outcrops are of mudstone and sandstone, although these are likely much more abundant than their lack of outcrop suggests. They probably are the most common rock type, but they are poorly consolidated and weather easily to form the thick clayey and sandy soils of the densely brush-covered slopes common where the complex occurs. The various rock types occur as chaotic blocks and pods. A few of these blocks or pods are well exposed. These range in size from a diameter of about 3 m to a block about 150 m by more than 300 m. Internally, these blocks are either of one undeformed rock type (as for a large chert block near Wildhorse Peak) or are extremely sheared (as for all the serpentinite and most mudstone blocks).

Mudstone - The Franciscan mudstone is grayish olive (10 Y 4/2), weathering to olive gray (5 Y 3/2) or slightly darker. It weathers easily and there are few outcrops. In all but one outcrop, bedding is completely destroyed by pervasive shearing, and the mudstone crumbles easily upon exposure into hard, small (0.5 to 3 cm), ovate to irregular fragments bounded by shiny slickensided surfaces.

The mudstone is compositionally homogeneous. It contains about 50 percent angular, silt-sized grains which are composed of about 55 percent quartz, 40 percent feldspar, and 5 percent biotite, muscovite, chlorite, and rock fragments. The rest of the rock is a clay-sized matrix of undetermined composition.

One poorly exposed outcrop of unsheared mudstone contains a thin (3 cm), parallel-laminated siltstone layer which grades upward into massive mudstone. This suggests Bouma (1962) layers "d" and "e".

Sandstone - The Franciscan sandstone is dark greenish gray (5 G 4/1) to medium bluish gray (5 B 5/1), weathering light olive gray (5 Y 6/1). The sandstone is poorly exposed in a few small outcrops. The rock is massive and undeformed except in one outcrop which is brecciated due to faulting. A rare, fresh sample is moderately to well indurated with calcareous cement. More commonly however, the sandstone is deeply weathered and friable.

The sandstone is medium to very coarse grained and submature. It contains less than 5 percent clay matrix and is moderately sorted. Sand grains range in shape from angular to rounded, being predominantly subround. Harder mineral species such as quartz and chert tend to be more angular than softer types such as igneous and metamorphic rock fragments. Grains show interpenetration due to solution along grain boundaries.

Two samples of the sandstone are feldspathic litharenite and one is a lithic arkose (Table 1). Quartz grains are of common (plutonic), recrystallized metamorphic, and stretched metamorphic types. Other grains include feldspars, most of which are moderately weathered (mostly sericitized), and a large percentage of rock fragments, most of which are fine-grained volcanics and a few of which are fine-grained foliated metamorphics and siltstones. Biotite and muscovite are rare or absent. One sample contains 16 percent unidentifiable, calcareous, bivalve shell fragments which are about 5 percent replaced by hematite.

Greenstone - These rocks are mafic volcanics that are at least somewhat altered and customarily are referred to as greenstone. Color is grayish olive (10 Y 4/2) to pale yellowish green (5 GY 7/2) on fresh surfaces; weathering produces a moderate yellowish brown (10 YR 5/4) surface stain. Greenstones generally are more resistant to weathering than surrounding rocks and commonly crop out as slightly protruding masses on hillsides. Larger blocks

Table 1. Composition in percent of thin sections of three sandstone samples from the Franciscan Complex. Sample number 128B is from near Sulfur Creek and 128C and 128D are from near West Fork Mill Creek. *Represents percentage of just Q, F, and R constituents, not whole-rock percentages.

	sandstone			
Sample number	128B	128C	128D	composite total
Average grain size (mm)	0.5	1.2	0.35	0.68
Quartz	21	19	25	21.7
Chert	17	13	15	15.0
-Q	41*	44*	42*	42.3*
Orthoclase	13	17	19	16.3
Plagioclase	9	5	4	6
-F	24*	29*	24*	25.7*
Igneous rock fragments	26	17	23	22.0
Metamorphic rock fragments	5	3	6	4.7
Sedimentary rock fragments	2	--	3	1.7
-R	35*	27*	34*	32.0*
Biotite and muscovite	1	--	<1	<0.7
Hematite	<1	<1	<1	<1
Pyrite	--	<1	<1	<0.7
Fossils	--	16	--	5.3
Clay matrix	2	3	1	2
Calcite cement	3	5	2	3.3

may form low ridges. In the map area these altered basaltic rocks occur as blocks which have no apparent internal structure, except for one small block which is brecciated. It could not be determined if this fragmentation was original (e.g., volcanic rubble) or due to tectonic effects.

Of seven samples examined, six are diabase and one is a pyroxene basalt. In the six diabases, pyroxene is interstitial to plagioclase and is primarily anhedral. Although the diabases are texturally similar, grain size ranges from fine to coarse. These rocks are 45 to 90 percent altered. Original crystal outlines and remaining primary material indicate primary igneous phases were:

Plagioclase	50-60%
Pyroxene (aegerine augite?)	40-50%

Pyroxene is 90 percent replaced by amphibole which occurs as pseudomorphs. Plagioclase is primarily altered to talc, sericite, zeolites, and kaolinite. Other secondary minerals include magnetite (which is primarily interstitial to plagioclase and may have formed as a result of alteration of pyroxene), chlorite, serpentine, prehnite, pyrophyllite, periclase (?), and chamosite (?).

Oscillatory zonation of large plagioclase laths (greater than 1mm) occurs in a coarse-grained diabase, and in one of the finer grained rocks, continuously zoned cores of plagioclase are mantled by optically discontinuous rims.

The pyroxene basalt is holocrystalline and was originally a fine- to medium-grained pyroxene porphyry in which pyroxene phenocrysts ranged in size from about 0.5 to 1 mm. Vesicles are not present. The pyroxene basalt is 95 percent altered, but original crystal outlines and remaining primary material indicate primary igneous phases were:

Pyroxene	∿60%
Plagioclase	∿35%
Olivine	∿ 5%

The most abundant secondary minerals are tremolite-actinolite occurring as pseudomorphs after pyroxene. Plagioclase is altered to zeolites and talc. Other secondary phases, occurring primarily in the ground mass of the rock, are chlorite, serpentine, and magnetite.

Pyroxene in some greenstone samples is granulated. Grains which were originally about 0.5 mm in size are broken up into optically distinct subrounded grains less than 0.1 mm in diameter. The original outline of the larger crystal is preserved. The granulation may have formed in response to tectonic deformation after the rock cooled. Deformation has either not affected the plagioclase or this effect is masked by alteration of the grains.

Serpentinite - The serpentinite varies from pale blue green (5 BG 7/2) to greenish black (5 G 2/1) in color, but most commonly is grayish green (10 GY 5/2). Color changes very little during weathering. The rock is moderately resistant and small outcrops are common. The rock is always highly sheared, having many closely spaced, shiny, slickensided surfaces. Where blocks of serpentine are well exposed it can be seen that shearing is greatest near the edge of the block. Bake and chill zones do not occur. Thin sections show only randomly arranged, fine-grained crystals dissected by a web-like network of veinlets. The rock is composed almost entirely of antigorite and chrysotile with a few percent of opaque minerals.

Chert - On fresh surfaces the chert is greenish gray (5 GY 6/1) and has irregular light olive-gray (5 Y 5/2) laminations paralleling bedding. The rock weathers to a mottled dusky brown (5 YR 2/2) and moderate yellowish brown (10 YR 5/4).

Outcrops include only one small pod (1.5 m X 5 m) in a roadcut near Sulfur Spring and a large block (150 m by more than 300 m) along a spur below Wildhorse Peak. Beds are 5 cm to 20 cm thick, averaging about 10 cm. Bedding surfaces are contorted. A space of about 0.25 cm occurs between beds where another interbedded, undetermined rock is weathered away. The undetermined rock may have been shale, which commonly is interbedded in Franciscan cherts (Bailey and others, 1964). The chert is highly fractured at various angles but most fractures are healed with quartz. The chert is hard and dense and breaks with subconchoidal fracture.

The rock consists of about 75 percent matrix, 24 percent radiolarian tests, and 1 percent mineral grains of pyrite and secondary chlorite. The matrix is composed of microcrystalline quartz and chalcedony, clouded with very fine particles of hematite and collophane which give a thin section an overall reddish-orange color. Alterations in concentration of hematite and collophane give the rock its laminated appearance. Radiolaria are of both conically and spherically shaped forms. A few radiolaria are well preserved; their borders have sharp spines and their interiors show a delicate mesh structure. More commonly, however, only their general outline can be seen and the tests are filled with iron-free silica (generally radial fibers of chalcedony) or collophane. Pyrite occurs as subhedral crystals 0.05 to 0.1 mm in size. A few scattered "shard-shaped" grains of chlorite occur. Bailey and others (1964, p. 63) suggest that such chlorite grains in Franciscan chert may be altered mafic glass.

Olivine gabbro - Overall color of the olivine gabbro is a mottled grayish green (10 GY 5/2) on fresh surfaces. The mottles are composed of pale-green (5 GY 7/2) labradorite crystals, brassy grayish-olive-green (5 GY 3/2) pyroxene crystals, and black (N 1) magnetite-mantled olivine crystals. The rock weathers to a mottled grayish yellow green (5 GY 5/2). In the map area this rock was found in only a few locations as small, poorly exposed, knobby outcrops. No structures were seen. The rock is hard, but develops a deeply pitted, rough surface upon weathering.

The olivine gabbro is a holocrystalline, medium-grained, hypidiomorphic orthocumulate. Olivine and labradorite are the cumulus phases. Labradorite occurs as euhedral to subhedral grains 1 to 5 mm in size and olivine occurs as anhedral, equant, rounded grains about 2 mm in diameter. Clinopyroxene is a cumulus and intercumulus phase. Clinopyroxene occurs as subhedral grains 2 to 3 mm in size. In the intercumulus phase hypersthene occurs as large anhedral crystals 3 to 6 mm in size which poikiolitically include labradorite, olivine, and sometimes clinopyroxene.

The rock is about 45 percent altered. Based on crystal outlines and preserved primary material the original mineralogy was:

Labradorite, An54	10-25%
Hypersthene	15-50%
Clinopyroxene	15-75%
Olivine	10-15%
Magnetite	<1%

Labradorite is more or less altered to talc, chlorite, and sericite. Secondary magnetite fills curving cracks in olivine grains. Olivine is also mantled by rims of magnetite and actinolite and is partly to completely replaced by serpentine and chlorite. Hypersthene is primarily altered along cracks and cleavage planes to talc and serpentine or chlorite, but is also partially altered to amphiboles. Clinopyroxene is partly altered to orthopyroxene. Minor amounts of actinolite form rims around clinopyroxene. Patches of talc, chlorite, and micas(?) also replace portions of the mineral with a grainy texture. Hypersthene is replaced extensively by amphibole pseudomorphs, primarily actinolite, and to a lesser extent, hornblende. Less common secondary minerals of the gabbros include prehnite, magnetite, serpentine, chlorite, talc, and rare biotite and phlogopite.

<u>Peridotite</u> - Color of the peridotite is a mottled greenish gray (5 G 6/1) and moderate olive brown (5 Y 4/4), weathering to a rough, pitted, dark reddish-brown (10 R 3/4) surface. This rock type was found at only one location as several large boulders.

The rock is a holocrystalline, medium- to coarse-grained, hypidiomorphic cumulate. Olivine, which forms the cumulus phase, occurs as rounded grains 1 to 5 mm in diameter. Pyroxenes form the interstitial, or adcumulus, phases.

The peridotite is 85 percent altered. Based on crystal outlines and remaining primary phases, the original mineralogy was:

Clinopyroxene	∿50%
Orthopyroxene	∿25%
Olivine	∿25%

Clinopyroxene is sometimes twinned with exsolution lamellae of orthopyroxene. It displays oscillatory extinction and is rimmed with amphiboles or replaced by amphibole pseudomorphs. Olivine grains are kink banded, have oscillatory extinction, and are 50 to 100 percent altered to serpentine and magnetite.

The rock is highly serpentinized and amphibolitized. Serpentine also occurs in veinlets up to 1 mm wide. Other secondary minerals include chlorite, talc, and magnetite.

<u>Tuff</u> - The Franciscan tuff of the map area is medium light gray (N 6), weathering to moderate yellowish brown (10 YR 5/4). Only one small, poorly exposed outcrop was found. The rock is hard, but fractured at 1 to 2 cm intervals at various angles. A few of the fractures are slickensided.

The tuff is an andesitic crystal tuff composed of about

95 percent extremely fine-grained ground mass and 5 percent phenocrysts. A flow banding is indicated by preferential alignment of the long axes of phenocrysts and relict texture of ground mass (long axis of crystals parallels that of phenocrysts). Phenocrysts are about 0.1 to 0.5 mm in size and composed of about 95 percent euhedral plagioclase, 3 percent amphibole (actinolite?), and 2 percent of a mineral which has completely altered to carbonate. The ground mass is devitrified and is composed of anhedral intergrowths of about 95 percent plagioclase, 3 percent mafic minerals (pyroxene?), and 2 percent opaque minerals.

<u>Olivine basalt (?)</u> - The probable olivine basalt is dusky yellowish brown (10 YR 2/2) on freshly broken surfaces. Surfaces exposed in outcrop weather to moderate brown (5 YR 3/4). Only one very poorly exposed, deeply weathered outcrop was found. The rock seems to be massive, but breaks readily into small (2 to 4 cm) ovate pieces.

Deep weathering of the rock makes mineralogical determinations difficult. Originally, about 2 percent of the rock probably was composed of small (0.1 to 0.5 mm) olivine crystals. Only a few crystals can still be identified; most have weathered out leaving tiny pits. The ground mass is completely altered to unidentified clays. Alteration is greater than that typical of a greenstone.

Contacts and Recognition

Contacts of the Franciscan Complex are nowhere well enough exposed within the map area to determine their character with certainty, but both north and south contacts seem to be faulted. Evidence for this is a breccia within the Monterey Shale near its contact with the Franciscan in the vicinity of West Fork Mill Creek; a mineralized ($CaCO_3$), slickensided breccia of greenstone found in float near the southern contact 1 km east of Wildhorse Peak; and a mineralized ($CaCO_3$) breccia in Franciscan sandstone near the southern contact near Sulfur Spring. Additional evidence is that both contacts cut almost straight across topography, which suggests that the contacts are nearly vertical, whereas dips in adjoining units are only moderate.

The southern contact of the Franciscan, with the Monterey Shale, is never actually exposed in the map area. Mapping of this contact, in various locations, was on the basis of one or more of several criteria: 1) between outcrops of Monterey Shale and Franciscan rocks where closely spaced; 2) at the location of last or first occurrences of Monterey rock chips or Franciscan rock chips in soil (the white or cream-colored Monterey Shale is easily distinguished from any of the Franciscan rock types);

3) at a marked change in soil color from gray over Monterey to orange or brown over Franciscan; 4) at a change in slope (a distinct "bench" or a gully typically coincides with the contact); and 5) at a change in vegetation from the low, dense, manzanita-dominated chaparral with oaks and Coulter Pine typical over the Monterey on Catway Ridge to the tall, dense, chamise-dominated chaparral over the Franciscan.

The northern contact of the Franciscan Complex with the Espada Formation is more difficult to distinguish and is less accurately mapped than the southern contact. Access to the area of the northern contact is extremely difficult, due to steep slopes and nearly impassable brush, except along Sulfur Creek. The contact was located at only about 10 spots, these along spurs on the north of Catway Ridge and in the Sulfur Creek area. Criteria for distinguishing this contact was first occurrence in soil of brownish-weathering Espada mudstone chips (Franciscan mudstones weather greenish gray) going down slope from Catway Ridge.

Age and Fossils

Only unidentifiable radiolarians and bivalve shell fragments were found in Franciscan rocks in the map area. Elsewhere within the complex in the San Rafael and Santa

Ynez Mountains region, fossils have not been reported (Dibblee, 1966). Because contacts in the map area are faulted, the age of the Franciscan Complex here is not known.

Dibblee (1966, p. 13, Pl. 1) apparently found the Espada Formation in depositional contact with underlying Franciscan rocks in the vicinity of Camuesa Peak about 15 km north of Santa Barbara. If this is true, the Franciscan, at least in that area, must be somewhat older than Espada rocks, the lower beds of which have yielded the Late Jurassic bivalve *Buchia piochii*.

Although the Franciscan generally is unfossiliferous, many age diagnostic fossils have been found in rocks mapped as Franciscan at various locations in the state. These range from Late Jurassic (Tithonian) to Late Cretaceous (Campanian) (Bailey and others, 1964).

Based on these fossils and the age of the overlying Espada, an approximate age assignment of Jurassic and Cretaceous seems reasonable. But as Hsu (1968) points out, assignments of a time range of deposition to all rocks in a melange based on the oldest and youngest fossils found in the melange may be wrong. A normal stratigraphic superposition does not exist in the Franciscan and this melange may contain unfossiliferous blocks derived from rock units much older or younger than rocks units from which the fossiliferous rocks were derived.

Origin and Geologic History

The poor quality of exposure, weathered condition, and deformation of Franciscan Complex rocks within the map area makes it difficult to conclude much about the origin of the specific rock types. Detailed interpretations for these rock types exposed in other areas are found in Bailey and others (1964, 1970), Bailey (1966), Burch (1968), and Hsu (1968).

The unsheared mudstone in the map area probably represents deposition in a basin plain environment near a turbidite fan. This interpretation is based on a very thin, parallel-laminated siltstone layer which grades into thicker massive mudstone. Such a feature is considered typical of the basin plain (Nelson, 1975). Most mudstone, however, is so extensively sheared that all primary structures are destroyed.

The sandstone in the map area probably was deposited, after short transportation in a humid climate, by a turbulent current. This is suggested by its coarse and submature nature and by its content of unstable rock fragments and weathered feldspars. Because of its massive nature in the map area, the sandstone gives little indication of the mode of deposition. Structures found in other areas suggest that much of the sandstone was deposited by mass flows and turbidity currents (Bailey and others, 1964; Page, 1966). A mixed plutonic and metamorphic provenance is suggested for the sandstone by its content of common plutonic, stretched metamorphic, and recrystallized metamorphic quartz as well as foliated metamorphic rock fragment grains.

Diabasic greenstones of the map area probably were emplaced as shallow sills or dikes. This is suggested by the diabasic texture, lack of vesicles, and fine- to coarse-grained nature of the rock. The pyroxene basalt probably solidified in the inner portion of a massive flow or near the margin of a shallow sill or dike. This environment is suggested by its fine grain size, porphyritic texture and lack of vesicles. Plagioclase crystals in these rocks commonly are zoned and the zoning differs between samples. This suggests differing cooling environments for the different rocks as well as changing cooling environments. Pillows were not observed in the map area, but do occur locally in other areas where they sometimes are associated with microfossiliferous marine limestone and chert, thus indicating a submarine origin (Page, 1966).

Serpentinite blocks in the map area were either tectonically mixed into the complex or were diapirically intruded. This mode of implacement is indicated by the pervasively sheared nature of the rock. Shearing is greatest near the edge of the blocks and there are no bake or chill zones. Serpentinized masses in some areas contain fragments of partially serpentinized peridotite and dunite (Bailey and others, 1964) suggesting Franciscan serpentine was originally peridotite or dunite.

Franciscan cherts of the map area probably were deposited as radiolarian oozes at abyssal depths below carbonate compensation depth. This is suggested by the lack of any carbonate or calcareous fossils, the large content of radiolarian fossils, and the microcrystalline silica matrix of the rock. Bailey and others (1964) found that bedded Franciscan cherts commonly are associated with greenstone. They suggest the cherts formed due to reactions between hot lava and sea water at "...depths comparable to the average depths of the ocean".

The olivine gabbro probably was formed by cooling of a magma chamber. This is indicated by the cumulate, holocrystalline texture, large grain size, and lack of vesicles. Complex twinning and wavy extinction of plagioclase and pyroxene may indicate tectonic deformation or may be the result of stresses placed on the crystal lattice due to volume change during alteration.

Peridotite may have been formed as a cumulate at the base of a magma chamber or may represent mantle material. This is suggested by the holocrystalline, coarse-grained, cumulate texture. Kink banding of olivines probably was caused by moderate deformation during tectonic emplacement to shallower depths.

The tuff must be the result of nearby subaerial volcanic eruption.

The olivine basalt is too poorly preserved to allow any speculation as to its origin.

The mechanism by which the above rocks were mixed into the Franciscan Complex melange is only briefly discussed here. Theoretical details relating to its origin are found in Dietz (1963), Hsu (1968), Karig and Sharman (1975), and many other papers.

According to Dietz (1963) the Franciscan melange probably was formed by subduction and mixing of oceanic lithosphere and eugeoclinal sediments which had been deposited upon oceanic basement. This is indicated by the chaotic association of the particular igneous and sedimentary rocks. The mafic-ultramafic igneous rock types (greenstone, serpentinite, gabbro, peridotite) are thought to be typical of the rocks which form the modern oceanic basement crust, and volcanic rocks, chert, mudstone, and turbidite sandstone are typical of modern eugeoclinal (base of slope to basin plain) sediments deposited on the ocean floor (Dietz, 1963).

Basement has never been seen below the Franciscan, but probably it is oceanic. Basal sediments of the coeval

Great Valley sequence rest depositionally on oceanic basement (Bailey and others, 1970) and Franciscan rocks were deposited further west, further away from the continent, than Great Valley rocks.

Dietz (1963) suggests that a melange complex, such as the Franciscan, contains a mix of blocks of basement, ultramafic, and sedimentary rocks because these are tectonically brought together as an oceanic lithospheric plate is subducted beneath a continental plate. It seems logical, therefore, that Franciscan serpentinite, gabbro, peridotite, and at least some of the greenstone are part of the basement of the Franciscan which was included tectonically into the Franciscan during subduction. Lack of metamorphism of Franciscan sedimentary rocks in the field area suggests that these rocks were not dragged down to a very great depth.

The assumption that the various blocks of rock types within the Franciscan of the map area were tectonically mixed is supported by several lines of evidence found within the map area. First is evidence of shearing; slickensides are present in most outcrops, especially those of mudstone and serpentine. Second, contacts between rock types, where exposed, are accompanied by intense shear and have numerous shiny slickensided surfaces. Third, there is no apparent depositional or stratigraphic relationship between blocks of the various rock types. Fourth, there are no normal intrusive relationships between the mafic or ultramafic rocks and the rocks they contact.

The process of tectonic mixing is poorly understood, but rotation and displacement of brittle tectonic inclusions in a ductile matrix is always present in melanges (Hsu, 1968). In the map area Franciscan mudstone is intensely sheared in all but one outcrop. The mudstone constitutes a large percentage of the melange and probably is the ductile matrix in which the other more brittle rock types float as chaotic blocks. Blocks of chert, sandstone, and greenstone could be considered "native" blocks because they were once interbedded with the now ductily deformed matrix and all were derived from oceanic, near-surface, sediments and volcanics. Serpentinite and peridotite blocks could be considered "exotic" blocks because they are detached from a rock unit foreign to the rest of the melange, perhaps oceanic basement.

ESPADA FORMATION

Nomenclature

The Espada Formation was named by Dibblee (1950) who designated the type section as the south side of Canada Honda, about 5 km east of Point Pedernales in the Point Arguello quadrangle, Santa Barbara County. He described the formation as follows:

> In all exposures the Espada Formation is a series of dark greenish-brown, thin bedded silty shales and a lesser amount of thin interbeds of hard fine-grained sandstones. Crude rhythmic bedding is general throughout. The Espada formation is characterized by its prevailing dark greenish-brown color in the shales and sandstones alike, and by the abundant black specks of carbonaceous material in parting planes. Locally the Espada contains thin lenses of conglomerate with well rounded pebbles of black chert.

MacKinnon (1978), in Agua Caliente Canyon and Mono Creek near Santa Barbara, recognized a paraconformity within the Espada and divided the Espada into two units, one above and one below the paraconformity. He based this division on fossils and on petrographic evidence. He referred to these as the "Tithonian to Valanginian section" and the "Upper Cretaceous pre-Campanian section". These units, however, could not be recognized in the map area.

The Espada Formation cannot be traced from the type area into the Zaca Lake quadrangle, but the lithology described below is sufficiently similar to the type area Espada to allow correlation. Additionally, rocks recognized as Espada by Vedder and others (1967) and Dibblee (1966) in the Sunset Valley and Davey Brown Creek area, several kilometers southeast of the map area, can be traced into the map area.

Arnold and Anderson (1907) referred to the Espada of the map area as "pre-Monterey rocks". Jennings (1959) shows these rocks as "Lower Cretaceous marine". Espada Formation rocks can be considered to be part of the Great Valley sequence (Bailey and others, 1964; Howell and others, 1977; MacKinnon, 1978).

Distribution and Thickness

The Espada occurs as a narrow band approximately 0.5 km wide along the northern slope of Catway Ridge in the southern part of the map area. Thickness throughout the area is approximately 320 m.

Lithology

All rock types of the Espada have the same color, grayish olive green (5 GY 3/2), weathering to brownish gray (5 YR 4/1), with parting planes typically having large quantities of black carbonaceous particles that range from less than 1 to 3 mm in diameter. Access to the Espada within the map area is difficult and exposure is very poor. The only exception is in road cuts along the jeep trail in the Sulfur Creek area where about 30 percent of its thickness is exposed (although mostly poorly). The unit weathers easily, forming steep brush-covered slopes.

The Espada consists of a series of mudstone beds interbedded with thin turbidite sandstone and rare conglomerate beds. Mudstone composes more than 80 percent of the formation, siltstone and sandstone less than 20 percent, and conglomerate less than 1 percent.

The mudstone is thinly bedded (less than 4 cm to approximately 50 cm) to very thick bedded and is silty to fine sandy (silt and sand comprising only a few percent of the rock). The mudstone breaks up into irregular, angular chips 0.5 to 3 cm in diameter. Weathering in place often results in spheroidal lumps 1 to 5 cm in diameter on outcrop surfaces. Thick beds commonly contain a very few scattered, shiny, black, calcareous concretions, some of which weather to buff. These concretions are irregular to subspheroidal blobs 1 cm in diameter to as large as 0.5 to 1 m, averaging about 2.5 cm in diameter.

Sandstone beds have no systematic distribution throughout the formation but seem to increase in abundance toward the top. Beds are tabular at outcrop scale and range in thickness from about 3 cm to 1 m, averaging about 5 cm. The beds are hard and are well indurated with calcareous cement. Internally, most sandstone beds are massive, but about 30 percent have a poorly defined grading. These beds have a sharp, non-erosive base and grade from medium grained up into overlying mudstone. Faint, parallel lamination and small-scale cross stratification are common in these beds. Thus, Bouma divisions "de" or "cde" are represented. Some beds have thin laminations of fine-grained carbonaceous material in 1-cm-thick layers parallel to bedding. One sandstone bed contains a very few, scattered, approximately 7-cm-diameter pebbles.

Texturally the sandstone is muddy sandstone, being composed of approximately 50 percent fine to medium sand, 30 percent silt and 20 percent clay. It is immature, with angular to rounded grains, most of which are subangular and show little evidence of transportation. Two sandstone samples examined are feldspathic litharenites (Table 2). Nearly all quartz grains are common (plutonic) with straight or slightly undulose extinction. A few quartz grains are composite grains of stretched metamorphic type with highly undulose extinction and crenulated composite grain boundaries. Other grains include feld-

Table 2. Composition in percent of thin sections of two sandstones and a conglomerate matrix sample from the Espada Formation. The samples are from outcrops along the jeep road near Sulfur Creek. *Represents percentage of just Q, F, and R constituents, not whole-rock percentages.

	sandstone		conglomerate matrix	
Sample number	129	129A	133	composite total
Average grain size (mm)	0.15	0.2	0.7	0.35
Quartz	20	22	13	18.3
Chert	1	1	<1	<1
-Q	34*	32*	17*	27.7*
Orthoclase	2	3	4	3.0
Plagioclase	13	17	9	13.0
Microcline	--	--	2	0.7
-F	24*	27*	20*	23.7*
Igneous rock fragments	23	27	33	21.0
Metamorphic rock fragments	2	<1	5	<2.7
Sedimentary rock fragments	1	<1	10	<4.0
-R	42*	41*	63*	48.7*
Biotite and muscovite	1	1	1	1
Secondary chlorite	1	1	<1	<1
Epidote	<1	<1	1	<1
Hematite	<1	<1	1	<1
Pyrite	1	<1	<1	<1
Clay matrix	25	20	10	18.3
Calcite cement	7	5	11	7.7
Carbonaceous material	3	--	--	1

spars, some of which are moderately weathered, and a high percentage of igneous rock fragments most of which are fine-grained volcanic. Biotite is rare and altered to chlorite. Carbonaceous plant fragments occur in one sample. Preservation of this material is such that a few of the fragments still show their cellular structure.

A few conglomerate beds occur. These are trough-shaped channel fillings, the channels being about 1 m deep cut into the Espada sandstone and mudstone. Texturally the conglomerate is sandy pebblestone with a matrix similar to the Espada sandstone, but coarser. Clasts are 0.5 to 12 cm in size, averaging about 2 cm. The pebbles and cobbles are composed mostly of well-rounded hard rock types which predominantly are medium-gray chert (about 50 percent), dark-gray, red, and green chert (these three totalling about 40 percent), along with a few percent each of dark-green to dark-gray porphyritic volcanic rocks, angular sandstone ripup clasts, and well-rounded granitic clasts. The matrix is similar in composition to the sandstone (Table 2) but contains a higher percentage of cement and sand-sized rock fragments.

Contacts and Recognition

Contacts of the Espada Formation are not well exposed within the map area, so their character is not known with certainty. The lower contact, with the Franciscan Complex, is assumed to be faulted as discussed earlier. The upper contact is assumed to be conformable because attitudes of bedding on both sides of the contact are similar, and no evidence of faulting or erosion of the upper Espada was found. This contact was placed between the last occurrence of outcrops of grayish-green Espada mudstone or grayish-green mudstone chips in soil and first occurrence of outcrops or clasts in soil of the overlying Fish Creek conglomerate. This contact is usually associated with an abrupt change in slope. The Espada weathers easily and forms steep northern slopes. The overlying Fish Creek conglomerate is more resistant and, because it is down the main slope from the Espada, gullies form along the contact with the conglomerate and drainage is abruptly deflected.

Age

No fossils were found in the Espada Formation within the map area. Dibblee (1966), however, reports *Buchia piochii* and *B. crassicolis* from the lower part of the Espada near Santa Barbara Reservoir and Camuesa Peak, respectively. These are thought to be Tithonian and Valanginian in age, respectively (Jones and others, 1969). Other fossils reported by Dibblee are from the upper part of the formation and indicate a Late Cretaceous age.

Espada rocks within the map area are assumed to be of similar age, Late Jurassic and Cretaceous. The Espada is thus at least partly coeval with the Franciscan.

Origin and Geologic History

The Espada Formation may have been deposited in a distal turbidite fan to basin plain environment. Grain size, structures, and sequence of structures found in the Espada sandstone (silt to medium sand grading upward into mudstone, a ripple-laminated layer followed by a faintly parallel-laminated layer which in turn grades into mudstone), along with a low ratio of sandstone to mudstone, are thought to be typical of modern distal turbidite fan to basin plain deposition (Nelson, 1975; Walker, 1976; Mutti and Ricci Lucchi, 1978). Common, but not restricted, to turbidity current deposits are the floating pebbles which remain suspended in the turbidity current due to the high effective viscosity of the sediment-laden flow.

The channel-filling conglomerates of the Espada are typical of Walker and Mutti's (1973) disorganized conglomerate. They lack stratification, graded bedding, and preferred clast elongation and imbrication, but have a sandy matrix. Such conglomerates are thought to be typical deposits of modern inner-turbidite fan channels (Walker and Mutti, 1973). These conglomerates, however, are poorly understood (Walker, 1976). The Espada channel-fill conglomerates may be the result of particularly large turbidity current flows which were able to carry coarse material out to the distal turbidite fan. The channels thus are likely the furthest extremes of larger upfan channels. The conglomerates' content of ripup clasts indicates that the turbidity currents cut the channels their deposits filled.

Although the above interpretation seems consistent with the data, it leaves one factor to be reconciled. The interpretation implies deep water deposition of Espada sediments beyond the base of the continental slope. Because the Franciscan and the Espada are at least partly coeval (this thesis; Dibblee, 1966; Howell and others, 1977, Table 1) and the Franciscan is a tectonic melange of base-of-slope to basin-plain sediments, as discussed in the Franciscan section, there is a conflict in the geographic distribution of the two formations. Espada sediments, as distal turbidite fan to basin plain deposits, would have been deposited to the west, seaward, of Franciscan sediments. In present geographic distribution (this thesis, Pl. 1; Dibblee, 1966, Pl. 1 and 3), extensive Espada outcrops occur eastward of Franciscan outcrops. Furthermore, the probable subduction origin of the Franciscan melange requires beyond-base-of-slope deposits be incorporated into the melange, or thrust over the melange, during subduction. Although the Espada rocks in the map area are in fault contact with the Franciscan, there is no evidence that they rest on a thrust fault. Because Espada and Franciscan mudstone are similar, it is possible that Franciscan mudstone is crushed and deformed Espada mudstone. That possibility, however, does not explain the present geographic distribution of relatively undeformed Espada rocks.

An alternate interpretation of the Espada depositional environment which resolves this apparent conflict is that the Espada represents continental slope deposition (MacKinnon, 1978) eastward, landward, of coevel Franciscan rocks. Walker (1979) found that strong modern storms, such as hurricanes, generate turbidity currents in relatively shallow water (beach to 36 m depth) that spread graded sand layers over the shelf and slope as far as 15 km from the beach. These layers are as thick as 9 cm. If the Espada-time shelf was narrow, storm-generated turbidity currents could continue to the shelf edge and out over the slope, thus depositing the thin, graded sandstone beds and channeled conglomerate lenses of the Espada. On modern upper and middle continental slopes hemipelagic rain of fine sediment is the predominant depositional process (Stanley and Unrug, 1972). Mudstone of the Espada of the map area thus may represent normal slope deposition.

This interpretation is consistent with the geology of the map area and is further conferred by sedimentary structures found in the Espada in nearby areas. McLean and others (1977) found penecontemporaneous slumping and sliding in Espada rocks near Davey Brown Campground, several kilometers east of the map area. This suggests deposition on a steep surface; slumped beds are a common feature of the slope (Walker and Mutti, 1973). A distal turbidite fan has very low gradients (Nelson, 1975) and is not likely to have slumping or sliding. Additional evidence suggestive of a slope environment was found by MacKinnon (1978) in a study of Espada rocks near Santa Barbara. He found indicators of a consistent westward paleocurrent. This might be expected for turbidity currents on a fairly steep north-south-trending Jurassic-Cretaceous continental slope, whereas a distal turbidite fan would be expected to have diverse paleocurrents due to the splaying out of currents as they cross the fan. In this sort of slope environment, coeval Franciscan turbidite fan sediments would bypass the slope via submarine canyons.

In this scheme some Espada sediments will be younger than some of the Franciscan melange and will be deposited upon the melange. This is because the Franciscan melange was being accreted against the continent, forming the continental slope, during the time Espada sediments were being deposited (Ingersoll, 1978). Detailed theoretical relationships of the Espada to the Franciscan, however, are beyond the scope of this paper. Such reconstructions require regional synthesis and rocks seen in this area add little to what is already known. The interested reader is directed to Karig and Sharman (1975) and Ingersoll (1978) for a more complete discussion.

Dibblee (1966) found the tropical rudistid Coralli-chama oscutti in the upper part of the Espada, thus suggesting warm water conditions. The general lack of fossils suggests, however, that conditions for life in the Espada sea were poor. The dark color of the rock and its content of carbonaceous wood fragments indicate anoxic bottom conditions.

The Espada sandstone's immature nature and its content of unstable rock fragments, carbonaceous wood fragments, angular grains, and weathered feldspars suggests a short distance of transportation and rapid burial in a humid climate. A mixed provenance is indicated for Espada sandstone and conglomerate. Predominantly granitic and volcanic source terranes are suggested by the high concentration of common plutonic quartz, feldspar, and volcanic rock fragments observed in thin section and porphyritic volcanic clasts in the conglomerate. Other minor source areas were sedimentary and metamorphic terranes. During the times when Espada rocks were being deposited, continental rocks were exposed to the east (Ingersoll, 1978; Howell and others, 1977) and likely were in the source area for the Espada.

FISH CREEK CONGLOMERATE

Nomenclature

A type section and formal name for the Fish Creek conglomerate have not been proposed even though the unit now bearing this name has been studied and/or mapped by several workers. The unit was first seen by Fairbanks (1894) who assigned it to his Cretaceous rocks. Arnold and Anderson (1907) mapped this unit in the Zaca Lake quadrangle as "Vaqueros, Sespe, and Tejon Formations, undifferentiated". Jennings (1959) includes it within "Upper Cretaceous marine" based on unpublished mapping by Redwine and others in 1953. Dibblee (1966) mapped these rocks as Upper Cretaceous "Unnamed conglomerate" in the area of Cachuma Mountain and Fish Creek, San Rafael Mountain quadrangle, several kilometers to the southeast of the map area, but he only briefly described it as a lens at the base of his "Unnamed shale". Gower and others (1966) mapped this unit in the same region as Dibblee and gave a brief description of the thickness and lithology, but did not apply a name. On their reconnaissance geologic map of the San Rafael Mountains, which adjoins the Zaca Lake quadrangle on the east, Vedder and others (1967) show this conglomerate as Upper Cretaceous, but do not name the unit. McLean and others (1977) first used the name Fish Creek conglomerate to refer to these rocks, apparently because of good exposures in Fish Creek. Their Fish Creek conglomerate can be traced directly from exposures in the Fish Creek and Cachuma Mountain area into the Zaca Lake quadrangle, so their informal name will be used in this report.

Distribution and Thickness

The Fish Creek conglomerate is exposed as a narrow band, approximately 0.3 km wide, in the southeastern part of the map area from Wildhorse Canyon eastward to the edge of the quadrangle. Exposed thickness is approximately 180 m throughout the area.

Lithology

The Fish Creek conglomerate has an overall dusky-brown (5 YR 2/2) color with a moderate yellowish-brown (10 YR 5/4) to light olive-gray (5 Y 5/2) sandstone matrix that weathers to grayish brown (5 Y 3/2). The unit is more resistant than surrounding rocks and typically forms low ridges which deflect streams along the north-facing slope of Catway Ridge. Exposure generally is poor, however. Weathering produces a distinctive, thin, sandy and bouldery soil over most of the unit. Where exposed, the rock is only moderately indurated.

Bedding is rare and is poorly defined by lenses of fine- to coarse-grained muddy sandstone which also forms the conglomerate matrix. The lenses, which average about 0.5 m thick and 2 m long, are internally massive. Other sedimentary structures were not observed in the map area. The conglomerate fits into the Walker and Mutti (1973) classification as a "disorganized conglomerate" which is characterized by having a sandy matrix and a lack of stratification, graded bedding, preferred clast elongation, or imbrication.

Conglomerate clasts range in size from 1.5 to about 30 cm, averaging 5 to 10 cm. Clasts are moderately well sorted and subrounded to well rounded. Approximate percentages of clast types are:

Basalt	50%
Dacite and rhyolite porphyries	30%
Diorite to Gabbro	10%
White and dark gray quartzite	6%
Greenstone (Franciscan?)	4%
Green chert (Franciscan?)	rare
Sandstone (Wildhorse Canyon only)	rare

Matrix composes about 60 percent of the rock in the lower part of the unit with an irregular gradational change upward to only about 20 percent near the top; framework changes upward from matrix supported to clast supported. Both a matrix sample and a sandstone lens sample (Table 3) are medium grained and submature. They contain less than 5 percent clay and are moderately sorted. Grains are mostly subangular to angular; a few percent are subround. Framework grains show interpenetration due to

Table 3. Composition in percent of thin sections of one conglomerate matrix and one sandstone lens sample from the Fish Creek conglomerate. The samples are from outcrops along the jeep road near Sulfur Creek. *Represents percentage of just Q, F, and R constituents, not whole-rock percentages.

	conglomerate matrix	sandstone lens	composite total
Sample number	55	131A	
Average grain size (mm)	0.35	0.3	0.32
Quartz	12	15	13.5
Chert	22	22	22.0
-Q	38*	41*	39.5*
Orthoclase	10	12	11.0
Plagioclase	2	3	2.5
-F	13*	17*	15.0*
Igneous rock fragments	36	33	34.5
Metamorphic rock fragments	6	4	5.0
Sedimentary rock fragments	1	1	1
-R	49*	42*	45.5*
Biotite and muscovite	7	4	5.5
Secondary chlorite	<1	<1	<1
Epidote	--	<1	<0.5
Hematite	1	1	1
Pyrite	<1	<1	<1
Clay matrix	3	3	3.5

solution along grain boundaries. The conglomerate matrix sample is a litharenite, and the sandstone lens sample is a feldspathic litharenite. Quartz grains are common (plutonic) with slightly undulose extinction and recrystallized metamorphic with straight and granulated composite grain boundaries. Other grains include feldspars, most of which are moderately to well weathered, and a large percentage of rock fragments, most of which are fine-grained mafic volcanics and foliated metamorphics.

Contacts and Recognition

The lower contact of the Fish Creek conglomerate is apparently conformable, as discussed in the Espada Formation section.

The upper contact of the Fish Creek is faulted. Evidence found in the Wildhorse Canyon and Sulfur Creek areas is brecciation between the conglomerate and the overlying Unnamed shale and sandstone and abrupt folding of the overlying rocks near the contact so that there is a change in attitude across the contact. The upper contact, however, apparently is depositional in the area near Manzana Creek, just a few kilometers east of the Zaca Lake quadrangle (Vedder and others, 1967; McLean and others, 1977).

The upper contact is accessible only in the Sulfur Creek-Dry Creek-West Fork Mill Creek area and in Wildhorse

Canyon. Because the unit, however, is more resistant to weathering than the underlying and overlying rocks it forms topographic highs and ridges, typically with gullies at the contacts, making it easily mapped into inaccessible areas from the air or from nearby peaks.

Age

Fossils were not found within the map area. Vedder and others (1967) report a Cenomanian "Mantelliceratid ammonite, either *Calycoceras* or *Mantelliceras*" from the upper part of the conglomerate unit near Nira Camp several kilometers east of the Zaca Lake quadrangle. The underlying Espada is considered to be Late Jurassic and Cretaceous and the overlying Unnamed shale and sandstone is considered to be Upper Cretaceous (this report). This evidence suggests the age of the Fish Creek conglomerate is early Late Cretaceous (Cenomanian) and possibly older.

Origin and Geologic History

The fossil ammonite (Vedder and others, 1967) indicates marine deposition. Walker and Mutti (1973) and Mutti and Ricci Lucchi (1978) suggest that disorganized conglomerates of this type are deposited as channel fill in inner- to middle-fan channels of modern and ancient turbidite fans. The internally massive sandstone lenses within the conglomerate are likely the remnants of the deposits of sandy flows. Massive sandstones are thought to be deposited in inner- to middle-fan channels by smaller flows in the channels (Walker, 1979). Most of the sandy deposits are removed by erosion by later strong flows which deposit more conglomerate. The rare sandstone ripup clasts are likely derived from erosion of these sandy deposits. The conglomerate, thus, represents an amalgamation of successive flows, rather than a single flow. On the inner fan, channels can migrate laterally, and the channel deposits tend to be wide (Walker and Mutti, 1973).

Composition of the conglomerate clasts (mafic igneous rocks, along with greenstone and green chert that are possibly Franciscan) suggests a source terrane of Franciscan Complex rocks. The abundance of fine-grained, mafic volcanic and foliated metamorphic sand grains supports this hypothesis. An additional source area of continental rocks, or the reworking of Franciscan sandstone and conglomerate, is suggested by the subordinate occurrence of siliceous volcanic and quartzite clasts as well as common (plutonic) quartz sandgrains.

These rocks suggest a paleogeographic setting in which deposition of Espada slope sediments by hemipelagic processes and by rare turbidity currents derived from the continent to the east, was interrupted by deposition from turbidity currents derived from a newly uplifted, nearby

Franciscan terrane to the west. In accordance with the Late Cretaceous subduction tectonic regime, this likely occurred as oceanic crust and sediments (now the Franciscan) were offscraped from the descending oceanic plate and accreted to the continental plate (Karig and Sharman, 1975; Ingersoll, 1978) and uplifted enough to become exposed to subaerial erosion. The later cessation of this style of deposition over the area probably indicates submergence of the Franciscan terrane highlands.

The submature nature of the rock and its content of sand grains that are mostly angular, unstable, sand-sized rock fragments, and weathered feldspar grains, suggests a short distance of transportation and rapid deposition in a humid climate.

UNNAMED SHALE AND UNNAMED SANDSTONE OF DIBBLEE (1966) COMBINED

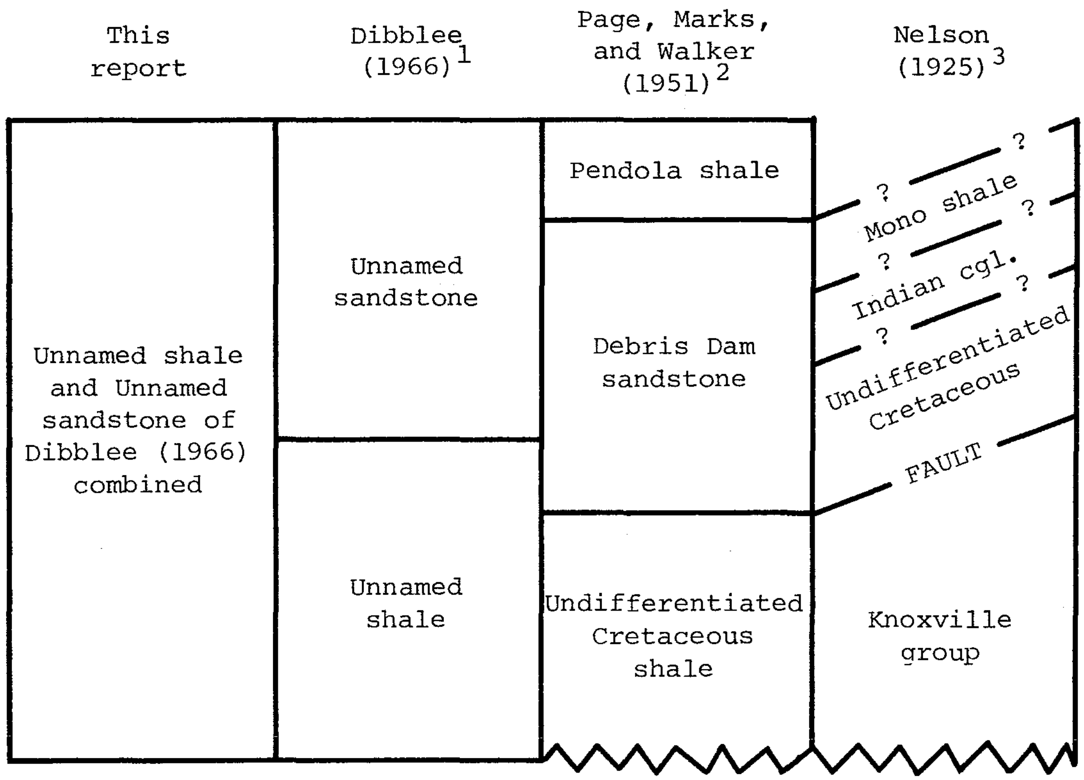
Nomenclature

Dibblee (1966) used the terms Unnamed shale and Unnamed sandstone for two units of Late Cretaceous age that he mapped in the San Rafael Mountains just to the southeast of the Zaca Lake quadrangle. However, he did not formally propose the names nor designate type sections. The Unnamed shale and Unnamed sandstone can be traced directly into the Zaca Lake quadrangle from exposures mapped as such by Dibblee (1966) in the San Rafael Mountains. In the Zaca Lake area, however, Dibblee's two units are not distinguishable and are mapped as one unit. In addition, this author examined Dibblee's two units where Dibblee mapped their contact near Cachuma Mountain, San Rafael Mountain quadrangle, and could find no reasonable means of differentiating the two units. Dibblee described his Unnamed shale as mostly shale with lesser amounts of interbedded sandstone and his Unnamed sandstone as a sequence of sandstone with lesser amounts of interbedded shale. He described the contact as gradational and divided the two units at the point where sandstone predominates over mudstone. Examination of the rocks indicates, however, that both in the Zaca Lake quadrangle and in the area near Cachuma Mountain, there is no simple upward gradation:

An upward gradation to a sandier facies is repeated many times throughout the whole sequence.

Dibblee (1966) included in his Unnamed shale some rocks which were previously mapped as "Undifferentiated Cretaceous shale" by Page, Marks, and Walker (1951) as well as the lower part of their Debris Dam sandstone (Fig. 3). He included into his Unnamed sandstone rocks previously mapped as the Indian conglomerate and Mono shale by Nelson (1925) as well as the upper portion of the Debris Dam sandstone and the Pendola shale of Page, Marks, and Walker (1951). The terminology used by all of these authors is confusing because they do not adequately, if at all, define the relationship of their units to units of previous workers. Because this sequence of rocks is in fact characterized by little change in lithologic character, it is treated here as one unit and informally termed the Unnamed shale and Unnamed sandstone of Dibblee (1966) combined.

In the Zaca Lake quadrangle Arnold and Anderson (1907) mapped this unit as "pre-Monterey". Jennings (1959) shows it as "Upper Cretaceous marine" based on unpublished mapping by Redwine and others in 1953. On their reconnaisance geologic map of the San Rafael Mountains, which adjoins and slightly overlaps the Zaca Lake quadrangle on the east, Vedder and others (1967) show these rocks as Upper Creta-



[1]Santa Ynez Mountains area.

[2]Agua Caliente Canyon to Mono Creek (Hildreth Peak and Little Pine Mountain quadrangles).

[3]Mono Creek to Cachuma Creek-McKinley Mountain area (Hildreth Peak, Little Pine Mountain, and San Rafael Mountain quadrangles). Nelson assigned the Mono shale and Indian conglomerate to the Eocene but these units have proven to be Cretaceous in age (Dibblee, 1966).

Figure 3. Relationship of "Unnamed shale and Unnamed sandstone of Dibblee (1966) combined", as used in this report, to terminology used by previous workers in this region.

ceous, but do not name the unit.

Distribution and Thickness

The Unnamed shale and sandstone is exposed in the northeastern corner of the map area and also as a band 3 to 4 km wide through the central portion, where it forms most of the north-facing slopes between Catway Ridge and the Sisquoc River. Maximum exposed thickness is approximately 2,300 m. The unit may be thicker, but its southern contact is faulted.

Lithology

Over most of its exposure within the map area, access to this unit is difficult due to long distances from roads combined with steep slopes and a nearly impassable to impassable brush cover. Poor to fair, but accessible, exposure occurs in Wildhorse Canyon, which cuts through the entire exposed section of this unit. Good exposures of parts of the section are along Manzana Creek and Sisquoc River. Exposure generally is poor and the unit weathers to form thick, brush-covered soils.

The Unnamed shale and sandstone in the map area is a sequence of interbedded mudstone and turbidite sandstone beds. Overall, mudstone slightly predominates over sandstone. Siltstone occurs as a small portion of some graded mudstone and sandstone beds, and a small percentage of conglomerate occurs at the base of some thicker sandstone beds. Progressing up section, sandstone beds gradually, but irregularly, increase in predominance, bed thickness, and coarseness. Sandstone beds typically occur in "packages", or intervals, within which sandstone beds are common and may, or may not, predominate over interbedded mudstone. Between sandstone packages are mudstone intervals that contain no sandstone, or only a few isolated sandstone beds.

Low in the section the sandstone packages contain thin sandstone beds (2 cm to 1 m) with thick interbedded mudstone beds (0.5 to 2 m), have a small overall thickness (3 to 10 m), and are separated by a great thickness of mudstone (as thick as 50 m). High in the section the sandstone packages contain thicker sandstone beds (2 cm to 10 m) and thinner mudstone beds (0.1 to 1.5 m), are thicker overall (10 to 30 m), and are separated by a lesser thickness of mudstone. Several sandstone packages in the middle and upper portion of the unit show a coarsening- and thickening-upward cycle. At the bottom of each cycle, sandstone beds are medium grained at their base and 2 cm to 1 m thick. Toward the top of each cycle, beds coarsen to medium or coarse grained to conglomeratic at their base and are several meters thick.

Soft sediment slumps were found at several locations.

Each slump consists of a block of up to 10 m square of essentially undeformed beds. These beds have an attitude similar to that of underlying beds, but are separated from underlying beds by a thickness of approximately 0.5 m of crumpled and folded thin sandstone and mudstone beds.

The mudstone is olive gray (5 Y 3/2) to black (N 1) on fresh surfaces and weathers to moderate yellowish brown (10 YR 5/4) to light brown (5 YR 5/6). The rock is moderately hard, but brittle, and fractures into small angular pieces which commonly have sub-conchoidal fracture. The mudstone is thinly (less than 0.5 cm) to very thickly (to 5 m) bedded. Where thinly bedded it commonly has small carbonaceous flecks on parting planes and commonly is silty. Thin silty beds typically occur in intervals of several to several hundred beds. These beds are rhythmically bedded, each bed being very silty mudstone to siltstone at the base, sometimes containing indistinct ripple or parallel laminations, and grading upward over a thickness of 0.2 to 2 cm into slightly silty mudstone. This suggests Bouma "cde" layers, or episodic bottom currents. Two silty mudstone samples from outcrops along the Sisquoc River near Alkali Canyon were examined, and the silt grains were found to be angular and composed of the following minerals:

		24-b	24D
Quartz	approximately	52%	45%
Chert		5%	5%
Feldspar		30%	28%
Rock fragments		18%	12%
Biotite and Muscovite		5%	10%

Silt grains are composed predominantly of common (plutonic) quartz and partially weathered feldspar grains. Other grains include a small percentage of recrystallized metamorphic quartz and rock fragments which are composed of either foliated, fine-grained metamorphics or very fine-grained sedimentary rock.

The sandstone is medium light gray (N 6) to light olive gray (5 Y 5/2), or rarely grayish orange-pink (5 YR 7/2), weathering to very pale orange (10 YR 8/2) to medium dark gray (N 4) with small amounts of reddish hematitic stain. Very few sandstone beds of the Unnamed unit have cement, and these have calcite cement, but all are well indurated. All but the thinnest and thickest sandstone beds are graded. Low in the section most sandstone beds contain Bouma turbidite divisions "cde" some have "bcde" and rare beds have "abcde". These beds do not have sole marks; their bases are flat and sharp and have no indication of erosion. Grain size grades from coarse or medium sand to fine sand or silt.

In the middle of the section most sandstone beds still contain Bouma divisions "cde" or "bcde" and beds containing "abcde" are more common. Ripup clasts occur rarely. Bases of some beds are distinctly erosive into underlying mudstone, and tool marks occur rarely, but this small number of sole marks is likely due to the poor quality of exposure common where the middle portion of the section crops out. Grain size at the base of beds is usually coarse to very coarse and thicker beds are pebbly or bouldery at their base.

High in the section Bouma divisions "cde" and "bcde" are still common low in each sandstone package. High in each package beds containing "abcde" and "abe" are common and some beds are amalgamated repetitions of "a" or "ab" commonly with very thin (about 0.5 cm) discontinuous traces of mudstone between repetitions. Ripup clasts are common. Some beds are massive or have poorly developed grading and rare dish structures. Sole marks are common, but flute marks and tool marks indicating flow direction are rare. Grain size at the base of beds is usually pebbly or coarser.

A few of the graded sandstone beds do not grade all the way through Bouma layer "e" or "de". These beds, and ungraded beds, commonly have oscillation and interference ripples on their upper surfaces. Carbonized plant fragments of up to 1 cm in size are also common along the upper surfaces of these beds and within some finer sandstone beds.

For five sandstone specimens examined (Table 4),

Table 4. Composition in percent of thin sections of four sandstone samples and one siltstone sample from the Unnamed shale and sandstone. Sample number 6 and 73 are from outcrops along Sisquoc River near Rattlesnake Creek and number 51 and 137 are from near Manzana Creek. *Represents percent of just Q, F, and R constituents, not whole-rock percentages.

	sandstone				siltstone	
Sample number	137	6	24A	51	73	composite total
Average grain size (mm)	0.35	0.25	0.45	0.3	0.25	0.28
Quartz	25	32	31	24	34	29.2
Chert	5	3	<1	<1	2	2.0
-Q	35*	42*	35*	31*	40*	36.6*
Orthoclase	18	8	16	21	15	15.6
Plagioclase	21	23	27	18	22	22.2
Microcline	--	<1	--	<1	1	<0.6
-F	48*	37*	48*	50*	42*	45.0*
Igneous rock fragments	9	11	12	10	13	11.0
Metamorphic rock fragments	1	5	3	4	2	3.0
Sedimentary rock fragments	2	1	--	<1	1	<1.0
-R	17*	21*	17*	19*	18*	18.4*
Biotite and muscovite	2	3	5	2	2	2.8
Epidote	1	<1	<1	--	--	<0.6
Sphene	--	--	--	--	<1	<0.2
Pyrite	<1	<1	1	3	<1	<1.4
Secondary chlorite	<1	<1	<1	<1	<1	<1
Clay matrix	15	13	5	11	7	10.4
Calcite cement	--	--	--	1	--	0.2
Pore space	--	--	--	5	--	1

grains range in shape from angular to rounded, but generally are subrounded. The samples are immature, being poorly sorted and high in clay matrix. All are lithic arkose. Mineral grains include a high percentage of quartz grains with straight to slightly undulose extinction typical of plutonic quartz, a few composite quartz grains with straight to slightly undulose extinction and straight grain boundaries between composite grains typical of recrystallized metamorphic quartz, and slightly to moderately altered feldspar. Other grains are fine-grained igneous and metamorphic rock fragments. The occurrence of euhedral pyrite rhombs up to 2 mm in size is common.

Conglomeratic sandstone beds grade upward from framework-supported, unstratified conglomerate at their base through matrix-supported, unstratified, parallel-, or cross-stratified, slightly conglomeratic sandstone in the middle of the bed to coarse- or medium-grained sandstone at their top. Conglomerate clasts are subangular to well rounded. An estimation of approximate, overall clast composition based on compilation of several field estimates and one collection examined in the lab is:

Pink and gray rhyolite porphyry	25%
Dark gray and green volcanic porphyry and basalt	25%
Granitic	25%
Dark gray quartzite	10%
Black slate	10%
Light green and bright green chert	<5%
Sandstone, siltstone, conglomerate	<5%
Other metamorphic	Trace

Contacts and Recognition

The lower contact of the Unnamed shale and sandstone within the map area is faulted as was discussed in the Fish Creek conglomerate section.

The upper contact is well exposed in several outcrops along the Sisquoc River. This contact is sharp, the overlying Carrie Creek Formation is slightly scoured into mudstones of the Unnamed unit, and the immediately overlying sandstone beds also contain many clasts of the underlying mudstone. Because the underlying and overlying units have similar attitudes, the contact is a parallel unconformity. This contact is discussed further in the Carrie Creek section.

Age and Fossils

Fossils from the Unnamed shale and sandstone, found at only four localities (Table 5), are in interturbidite mudstone beds. The fossils are whole or nearly whole, but bivalves are disarticulated, and are fairly well preserved as external or internal molds. <u>Inoceramus</u> was an

Table 5. Megafossils from the Unnamed shale and sandstone.

Species	Abundance	Locality number and location
Cephalopoda		
Baculites anceps pacificus Matsumoto and Obata	few	UCLA 6587 and CSUN 643, Sisquoc River near Alkali Canyon
?*Didymoceras* sp.	rare	UCLA 6588, Sisquoc River between Rattlesnake and Alkali Canyons
Bivalvia		
Inoceramus cf. *I. chicoensis* Anderson	rare	CSUN 644, Manzana Creek near Dry Creek

attached byssate bivalve. It is possible that this specimen was rafted out to sea over these deep water mudstones on floating seaweed or a floating log. No breakage or abrasion is apparent, but the specimen is disarticulated.

Burrowing of sandstone beds is common. Both horizontal and vertical burrows were found. These are typically filled with sand of approximately the same grain size as that of the beds within which the burrows occur. Some horizontal burrows, however, are mud filled. The burrows have a diameter of 0.5 to 1.5 cm.

Ten samples were processed for microfossils. All proved to be barren. This is likely due to the same post-depositional processes that dissolved the megafossil shell material.

Ward (1978), in studying rocks of the Nanaimo Group of British Columbia and Washington state, found that *Baculites anceps pacificus* ranges through "some part of the *Metaplacenticeras pacificum* Zone and possibly part of the *Hoplitoplacenticeras vanconverensis* Zone". *B. anceps pacificus* thus represents late to possibly latest Campanian age. Because the cephalopods were found near the top of the Unnamed shale and sandstone and because the underlying Fish Creek conglomerate is probably of Cenomanian and possibly older age, it is likely that the Unnamed shale and sandstone is of Cenomanian or Turonian through

Campanian age. The unit is therefore Late, but not latest, Cretaceous in age.

A baculite from the Debris Dam sandstone of Page, Marks, and Walker (1951) in the Agua Caliente Canyon area was identified as *Baculites rex* by Matsumoto (1960). Matsumoto (1959) stated that *B. rex* ranges from latest Campanian through Maestrichtian. An associated bivalve from that area, *Cucullaea youngi*, suggests Campanian rather than Maestrichtian age for the Debris Dam sandstone (LouElla Saul, per. com., 1979). Because the Debris Dam localities are from near the top of the formation and the formation is more than 700 m thick (Page, Marks, and Walker, 1951), it is possible that the Unnamed shale and sandstone is contemporaneous with the upper portion and at least some lower part of the Debris Dam sandstone of the Agua Caliente Canyon area.

Origin and Geologic History

The Unnamed shale and sandstone probably was deposited in a prograding turbidite fan environment. The lower part of the unit, having a predominance of mudstone over sandstone and having thin, fine-grained sandstone beds that mostly contain Bouma divisions "cde" (and less commonly "bcde", and rarely "abcde") are typical of what Walker and Mutti (1973) and Mutti and Ricci Lucchi (1978), term outer fan deposits.

As deposition continued, more proximal parts of the turbidite fan must have prograded over the outer fan deposits. High in the section the unit becomes predominated by sandstone. Generally, the sandstone beds become progressively thicker and coarser up section and some occur in packages of coarsening- and thickening-upward sequences. This progression is typical of the middle fan association of Walker and Mutti (1973) and Mutti and Ricci Lucchi (1978). In this model, deposition of sandstone on the middle fan is in suprafan depositional lobes which extend seaward from the end of middle-fan braided channels. Deposition causes aggradation and progradation of a depositional lobe, and a thickening- and coarsening-upward sequence results. Periodically, channels suddenly are abandoned, resulting in cessation of sand deposition in the area of one of these lobes. At a later time, lobe deposition may resume at the area and the coarsening- and thickening-upward sequence will be repeated. The outer edge of the suprafan lobes is characterized by classical turbidites with flat bedding surfaces. As the lobe and the fan prograde, sedimentation over the area of the suprafan lobe will change to deposition of the massive and pebbly sandstones with irregular erosive bases of the braided channel portion of the upper fan.

The immature nature of the sandstone and its content of unstable rock fragments, subangular grains, and weathered feldspars indicates a short distance of transportation in a humid climate. A predominantly granitic source terrane is suggested by the high percentage content of plane (granitic) quartz and feldspar and the content of granitic conglomerate clasts. Other components are associated with a partially exposed batholith: metamorphic quartz grains, metamorphic conglomerate clasts, and siliceous volcanic conglomerate clasts. A minor sedimentary source terrane is also indicated by the small percentage of chert and sedimentary clasts.

Paleocurrent measurements (Fig. 4) indicate a generally southward or westward flow. Turbidity current flows probably were derived from submarine canyons along the shores of highlands that were exposed to the east during this time (Ingersoll, 1978; Howell and others, 1977). This represents a reversal in the source direction from the western Franciscan source proposed for the underlying Fish Creek conglomerate and indicates that the previously uplifted western Franciscan highlands had now subsided and been replaced by more normal eastern continental highlands as source rocks.

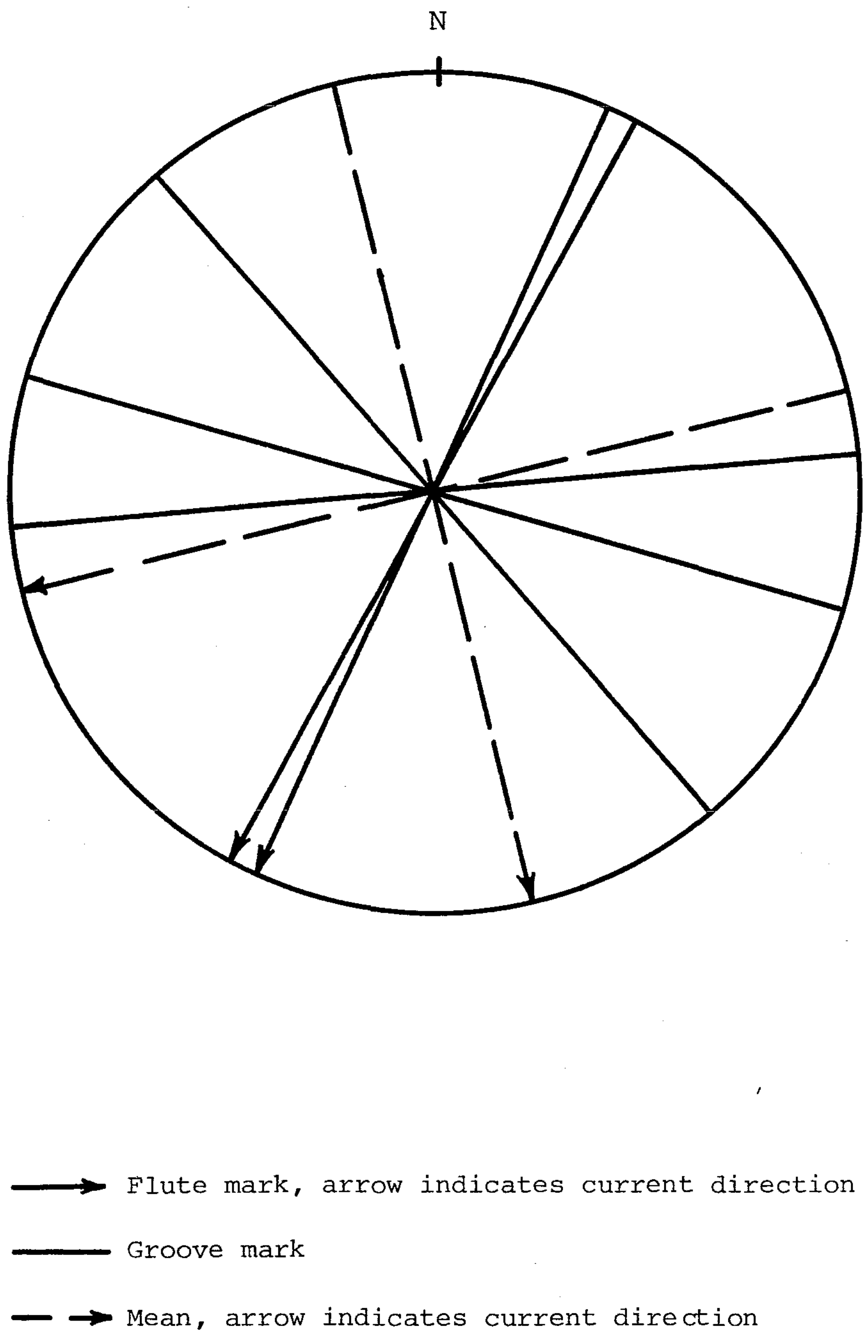


Figure 4. Five paleocurrent measurements from the Unnamed shale and sandstone of the map area. The mean direction is between S 75° W and S 15° E depending on what direction of current is assumed for those sole marks without direction sense.

CARRIE CREEK FORMATION

Nomenclature

The Carrie Creek Formation was named by Hall and Corbató (1967) who designated the type locality as the Carrie Creek area in the eastern part of the Nipomo quadrangle. They described the formation as "more than 5,000 feet of greenish-brown to gray or greenish-gray, fine- to coarse-grained arkosic sandstone, and resistant to nonresistant conglomerate". They further described the sandstone of the formation as containing mostly quartz (50 to 70 percent) with lesser amounts of feldspar (20 to 30 percent) and flakes or books of biotite (5 to 20 percent) and mentioned content of "dark-gray or blue-gray and brown mudstone and siltstone" beds. In the Nipomo quadrangle, the Carrie Creek Formation crops out west of the Nacimiento fault and east of the Huasna fault. Hall and Corbató suggested that equivalent strata extend from there southeast into the San Rafael Mountains.

The Carrie Creek Formation cannot be directly traced from its type area into the Zaca Lake quadrangle 30 km to the southeast, but the lithology described below is sufficiently similar to the type area Carrie Creek to allow correlation.

The informal terms "Buckhorn sandstone" and "Morris formation" used in the area east of Santa Maria are correlative in lithology and age with the Carrie Creek Formation (Oltz and Suchsland, 1975). Crandall (1961) in a study of the "Buckhorn" suggested turbidity current deposition for these rocks based on graded beds and other features.

The Carrie Creek may also be equivalent in age and lithology to the "Atascadero Formation" of Fairbanks (1904, in Hall and Corbató, 1967). The U.S. Geological Survey, however, has abandoned use of the term "Atascadero" (Taliaferro, 1944, p. 472).

In the Zaca Lake quadrangle, Arnold and Anderson (1907) mapped these rocks as "pre-Monterey". Jennings (1959) shows this unit as "Upper Cretaceous marine". Vedder and others (1967) have mapped it merely as Upper Cretaceous and have not named it on their San Rafael Mountains reconnaissance geologic map which adjoins and slightly overlaps the Zaca Lake quadrangle on the east.

Distribution and Thickness

In the map area, the Carrie Creek Formation crops out on the southern limb of the Hurricane Deck Syncline as a narrow band approximately 0.5 km wide extending along the south side of the Sisquoc River from Manzana Creek to the fault near Alkali Canyon. There it is displaced to the north of the Sisquoc River and crops out as a wide band extending from Alkali Canyon west to the edge of the map area. On the north limb of the syncline the formation crops out in the northeastern corner of the map area.

Because the upper contact of the Carrie Creek Formation in the area is everywhere an angular unconformity, only a minimum thickness for the unit of about 800 m can be given, which corresponds to its maximum stratigraphic exposure in the vicinity of Rattlesnake Creek near the western edge of the area.

Lithology

In most of the map area exposure of the Carrie Creek is poor. Good quality exposures occur only at a few locations along the Sisquoc River and at several locations in Tunnel Canyon.

The Carrie Creek Formation in the map area consists of poorly graded to massive, amalgamated turbidite sandstone along with a lesser amount of conglomerate, siltstone, silty mudstone, and mudstone.

The sandstones are light olive gray (5 Y 5/2) to yellowish gray (5 Y 8/4), weathering to mottled moderate orange pink (5 YR 8/4) and light brown (5 YR 6/4) or medium gray (N 5) with a hematitic stain. The rock is only rarely cemented with calcite and varies from hard and compact to porous and friable.

Bed thickness of sandstone averages 1 to 5 m, ranging from 0.2 m to almagamated beds up to 20 m or more thick. Beds commonly have a thickness greater than that exposed.

The thick, graded beds vary from boulder conglomerate to medium-, or rarely, fine-grained sandstone. Bases are sharp and erosional, and they contain flame structures. Rip up clasts and floating pebbles and boulders are common. Cut-and-fill structures suggesting amalgamation are also common. Planar laminae, convolute laminae, and dish structures are rare. The underlying fine-grained beds are commonly deformed due to load. A typical Carrie Creek bed is diagramatically illustrated in Figure 5.

Thin sandstone beds compose only a few percent of the formation. These beds are 5 cm to 3 m thick, rarely amalgamated, and have well defined grading from coarse, or slightly pebbly, to fine grained, locally with floating pebbles. These are classical turbidites and contain Bonma divisions "abcde" or "abc". Small (averaging approximately 1 cm in longest dimension) mudstone rip-up clasts, parallel lamination, and convolute ripple lamination are common. Carbonaceous wood fragments and horizontal burrows are common on bed surfaces. A few escape burrows are present. Burrows are 0.5 - 2 cm in diameter and sand filled.

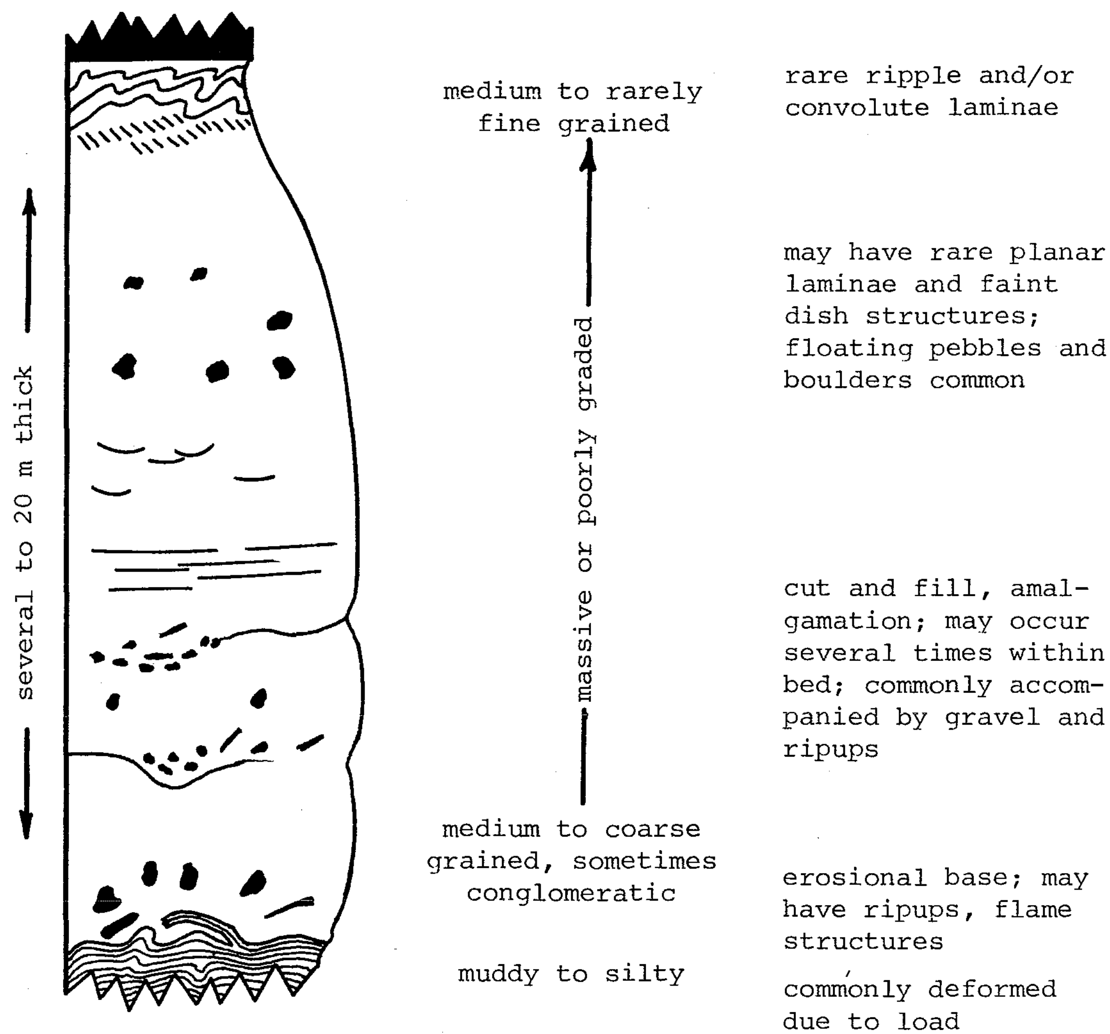


Figure 5. Generalized sequence of structures found in thick sandstone beds of the Carrie Creek Formation of the map area.

Four sandstone samples that were examined (Table 6) are immature, being poorly sorted and high in clay matrix with angular to subangular grains which show little evidence of transportation. Biotite flakes are as large as 5 mm in diameter and commonly 1 to 2 mm thick.

Two of the samples are arkose and two are lithic arkose. Mineral grains include a high percentage of quartz grains which have straight to slightly undulose extinction, typical of common (plutonic) quartz, and composite quartz grains with slightly to highly undulose extinction and straight to crenulated boundaries, typical of recrystallized and stretched metamorphic quartz. Other grains include slightly to moderately altered feldspars and fine-grained igneous and metamorphic rock fragments. All four samples are well indurated, are cemented with calcite, and have no pore space. More commonly, however, the sandstone is uncemented, poorly indurated, and at least moderately porous.

Conglomerate beds compose a few percent of the formation and occur in no particular relative position to the other lithologies. These beds are 1 to 15 m thick, averaging 7 to 10 m. No sedimentary structures were found. Most beds are clast-supported conglomerate, but a few are matrix supported. Matrix is coarse grained and essentially the same composition as the sandstone. Conglomerate

Table 6. Composition in percent of thin sections of four sandstone samples from the Carrie Creek Formation. Sample number 14, 14A, and 260 are from outcrops in Tunnel Canyon and number 45 is from Alkali Canyon. *Represents percent of just Q, F, and R constituents, not whole-rock percentages.

	sandstone				
Sample number	14A	14	45	260	composite total
Average grain size (mm)	0.6	0.35	1.1	0.5	0.64
Quartz	29	25	21	55	32.5
Chert	--	1	1	1	0.75
-Q	43*	52*	49*	60*	51.0*
Ortholase	12	7	6	21	11.5
Plagioclase	11	9	11	13	11.0
Microcline	1	--	1	<1	<0.75
-F	35*	32*	40*	37*	36.0*
Igneous rock fragments	10	2	3	1	4.0
Metamorphic rock fragments	5	1	2	2	2.5
Sedimentary rock fragments	--	5	<1	--	<1.5
-R	22*	16*	11*	3*	13.0*
Biotite and muscovite	7	6	5	5	5.8
Secondary chlorite	<1	--	<1	<1	<0.75
Fossils	--	5	3	--	2.0
Clay matrix	13	25	27	3	17.0
Calcite cement	12	14	20	<1	<11.75

clasts are generally rounded, but vary from subangular to well rounded. They range in size from 2 mm to 0.75 m in longest dimension, averaging 6 to 10 cm. Thin beds have a slightly smaller average clast size. Approximate overall clast composition, based on 5 random conglomerate clast counts in the field, is:

Granitic (fine- to couarse-grained, buff to pink)	75%
Quartzite (gray to dark gray)	15%
Diorite	5%
Sandstone and siltstone	3%
Porphyritic volcanic	2%
Black slate	trace
Schist	trace
White marble	trace

Interbedded with the sandstone and conglomerate are bioturbated claystone to mudstone, laminated siltstone, and mudstone beds. It is difficult to determine the total thickness of these finer grained beds within the formation because they weather easily, forming brush covered slopes. Although these fine-grained beds are exposed in only a few localities they probably constitute several percent of the formation.

Most of the fine-grained beds are highly bioturbated mudstone. Due to the bioturbation, color is mottled, varying from medium gray (N 5) to moderate brown (5 YR 3/4), commonly with powdery, sulfur-yellow splotches. Bed thickness ranges from 0.5 cm to 1 m. Texture is mottled, varying from claystone to silty or sandy mudstone. Small biotite flakes are common and they compose up to 15 percent of the rock in places. Burrows are rarely preserved in these rocks, but where found compose most of the volume of the rock. Where burrows are well preserved they occur in a mottled medium-gray (N 5) claystone and are filled with grayish-orange (10 YR 7/4) micaceous siltstone. The burrows are 0.5 to 1 cm in cross-sectional diameter, continuous, and have no particular orientation.

Laminated siltstone beds are less common. These beds are medium gray (N 5), thinly bedded (0.5 to 3 cm), and contain approximately equal amounts of angular quartz and feldspar grains along with carbonized wood fragments of up to 1 cm in size. In places wood constitutes as much as 30 percent of the rock. Convoluted lamination due to compaction is common.

Mudstone beds are rare. They are moderate brown (5 YR 3/4), weathering to grayish buff (10 YR 6/4). Bedding is thick (about 1 to 3 m) and the rock breaks up into hard, brittle angular chips averaging 1 cm in size. Dark brown calcareous concretions occur rarely.

Contacts and Recognition

The lower contact of the Carrie Creek Formation, as discussed in the Unnamed shale and sandstone section, is a parallel unconformity. The contact was placed between the last occurrence of the underlying greenish mudstone of the Unnamed shale and sandstone and the first occurrence of Carrie Creek sandstone. Poor exposure prevented accurate mapping of the contact except in a few locations. Rocks of these two formations are somewhat similar, but can be differentiated based on several criteria. Carrie Creek sandstone contains a much greater percentage of biotite and muscovite, and usually is more porous than sandstone of the Unnamed unit. Mudstone of the Carrie Creek is gray to brown in color and usually is very bioturbated, whereas the underlying mudstone is greenish in color and rarely is bioturbated.

The upper contact of the Carrie Creek Formation was placed between the last occurrence of mudstone or micaceous sandstone and the first occurrence of "clean" sandstone or conglomerate of the unconformably overlying Branch Canyon Formation. This contact is discussed in detail in the Branch Canyon Formation section.

Age and Fossils

Megafossils in the Carrie Creek Formation were found at three localities (Table 7). The two CSUN localities are in coarse-grained turbidite sandstone. Fossils collected here are unabraded bivalve shell fragments as large as 5 cm in longest dimension and 0.5 cm thick. They were identified in thin section as Inoceramus (?) sp.

Table 7. Megafossils from the Carrie Creek Formation.

Species	Abundance	Locality number and location
Cephalopoda		
Neodesmoceras cf. *N. catarinae* Anderson & Hanna	rare	UCLA 6589, upper Tunnel Canyon
Bivalvia		
Inoceramus ? sp.	common	CSUN 645 and 646, Sisquoc River near Tunnel Canyon and Alkali Canyon

These large byssate bivalves probably were transported from shallow water to deeper water along with the turbidity currents that deposited the sandstone beds in which they are found, perhaps broken by the turbidity current along the way. Surface "rafting" is another possible mode of transportation of these bivalves. Such a mechanism, however, could not explain their common occurrence in a rapidly deposited turbidite sandstone bed.

The UCLA locality is in a massive, brown mudstone bed. A poorly preserved internal and partial external mold of the ammonite *Neodesmoceras* cf. *N. catarinae* was collected. This identification, largely with the help of LouElla Saul of UCLA, is largely based on the whorl profile and suture pattern.

Six mudstone samples were processed for microfossils, but all proved to be barren.

Neodesmoceras catarinae indicates an early Maestrichtian age. The unit is, therefore, very Late, but not latest, Cretaceous.

Because the underlying Unnamed shale and sandstone is considered equivalent in age to the Debris Dam sandstone of Page, Marks, and Walker (1951), superposition suggests that the Carrie Creek of the Zaca Lake area is, at least in part, contemporaneous with the Pendola shale of Page, Marks, and Walker (1951) which overlies the Debris Dam.

Origin and Geologic History

The Carrie Creek Formation, having conglomerate beds lacking sedimentary structures, along with massive or poorly graded, coarse and pebbly sandstone beds, and fine-grained beds, is typical of what Walker and Mutti (1973) term a channelized inner turbidite fan association. An inner turbidite fan is characterized by one large, broad channel which is aggrading with thick, coarse sandstone and conglomerate beds. Finer grained beds are deposited by turbidity currents that overflow the channel banks.

The deposits of the Carrie Creek Formation thus probably resulted from progradation of the same submarine fan which deposited the underlying Unnamed shale and sandstone. However, the expected upsection gradation from the middle-fan deposits of the Unnamed shale and sandstone into upper-fan deposits of the Carrie Creek is missing. This and the erosional nature of the contact between the two formations suggest that the fan channel abruptly shifted into the area from elsewhere and eroded any record of transition as it shifted.

The very immature nature of the sandstone suggests a short distance of transportation followed by deposition in a shoreline environment such as a beach or delta. Deposition was so rapid that shoreline processes had no opportunity to rework the sediment, or else deposition was on a steep slope so that slumping occurred, and the sediment was transported into deep water before waves and currents could rework it.

The content of granitic and diorite conglomerate clasts along with an abundance of common (plutonic) and some metamorphic quartz grains and weathered feldspars suggests erosion of a plutonic source terrane in a humid climate.

UPPER CRETACEOUS OR YOUNGER IGNEOUS INTRUSIVE ROCKS

General

Igneous dikes were not previously recognized in the Zaca Lake quadrangle. The nearest mapped intrusive rocks, other than those within the Franciscan, are basaltic dikes mapped by Dibblee (1966) in Black Canyon near the eastern edge of the San Rafael Mountain quadrangle approximately 35 km southeast of the Zaca Lake quadrangle.

The Zaca Lake area dikes, found at only one locality along the Sisquoc River, occur in a fresh, well exposed outcrop where two dikes intrude the Upper Cretaceous Unnamed shale and sandstone. The dikes are thus considered to be Upper Cretaceous or younger in age.

Lithology

Color of the dikes varies from greenish gray (5 GY 6/1) in the center of the dikes to grayish orange pink (5 YR 7/2) at the margin. The dikes are about 1 m thick, cut the intruded beds approximately normal to bedding, and are exposed over about 15 m of their length. Chill zones occur along the margins of the dikes and mostly are denoted by a color change and a slightly decreasing content and grain size of plagioclase phenocrysts toward the margins. The normally brittle, olive gray mudstone that was intruded is baked to a brick-hard, black slate which has lost all indications of bedding in the baked zone and has developed a closely spaced (2 to 5 mm) cleavage parallel to the dike margins. Cleavage surfaces are stained with an orangish-yellow mineralization, probably limonite.

The dikes are very altered, but relict features indicate they originally were a plagioclase-olivine porphyritic diabase. The rock was holocrystalline with fine- to medium-grained plagioclase and olivine phenocrysts making up a few percent of the rock. The groundmass consists of very fine-grained plagioclase, pyroxene, and olivine. A few calcite-filled vesicles up to 2 mm in diameter occur.

The following original composition was estimated based on original crystal outlines and remaining primary material:

Plagioclase	80-90%
Olivine	5-10%
Pyroxene	2-7%
Ilmenite and magnetite	3%

The only original phase remaining is plagioclase, which mostly is altered to calcite, chlorite, sericite, and other clays. Olivine is altered to iddingsite and some hematite. Pyroxene is altered to chlorite. Ilmenite and magnetite chiefly are altered to hematite.

Calcite veinlets are common. These are very thin

(0.1 to 1 mm in width), comprise a very small percentage of the rock, and have no regular pattern.

BRANCH CANYON FORMATION

Nomenclature

The name Branch Canyon Formation was first used by Hill and others (1958) for beds cropping out in the Cuyama Valley and Sierra Madre area which had previously been called the Bitter Creek Formation (Savage, 1957). The name Bitter Creek was preoccupied so Hill and others redefined the unit and designated the type locality as the west side of Branch Canyon of the Cuyama Valley, Cuyama Ranch quadrangle.

The Branch Canyon Formation of the Cuyama Valley and Sierra Madre is divided into two informal members separated, in places, by a tongue of the Monterey Shale (Hill and others, 1958). Only a slight lithologic difference exists between the two members, however, and where the tongue is missing the contact between the two members is uncertain (Fritsche, 1969). In the Zaca area these members could not be distinguished.

In the San Rafael Mountain quadrangle, just to the southeast of the map area, Dibblee (1966, Pl. 3) mapped as "Temblor" Sandstone a similar, but thinner, sandstone unit which occupies the same stratigraphic position as the lower member of type Branch Canyon Formation (Fritsche, 1969). Vedder and others (1967) mapped several thick sections of Miocene sandstone which Fritsche (1969) suggests probably belong to the lower member of the Branch Canyon. Vedder and others' map adjoins the Zaca area on the east and slightly overlaps it and their Miocene sandstone can be traced directly into the Zaca area.

Although the Branch Canyon cannot be traced from its type locality into the Zaca area, the lithology, stratigraphic position, and fossil content described below are sufficiently similar to the type Branch Canyon to allow correlation.

In the Zaca Lake quadrangle, Arnold and Anderson (1907) mapped these rocks as "Vaqueros, Sespe, and Tejon formations undifferentiated". Jennings (1959) shows the formation as questionably "lower Miocene marine" based on unpublished mapping by Redwine and others in 1953.

Distribution and Thickness

The Branch Canyon Formation is exposed as a narrow band on both limbs of Hurricane Deck Syncline. On the southern limb the formation crops out along either side of the Sisquoc River from the eastern edge of the area to Alkali Canyon where it is faulted to a more northerly position. On the northern limb of the syncline the formation crops out in a discontinuous east-west-trending band which thickens and thins or pinches out.

The formation generally thickens toward the southeast, varying from nearly zero at points along the northern limb of Hurricane Deck Syncline to about 400 m on the southern limb of the syncline near Manzana Creek.

Lithology

Exposure of the Branch Canyon in the map area is fairly good. It tends to be very resistant and forms cliffs along stream banks and ridges. The formation predominantly is sandstone with minor amounts of siltstone, mudstone, a basal conglomerate, and an upper glauconitic sandstone.

The basal conglomerate occurs at the lower contact of the formation at nearly all localities. Overall color is yellowish gray (5 Y 7/2) to grayish orange pink (5 YR 7/2). The rock weathers to olive gray (5 Y 6/1) to grayish orange (10 YR 7/4). Thickness varies from 0.1 to 12 m, averaging approximately 1 m. It is thick enough to show on Plate 1 only near Manzana Creek. The rock is not well indurated, and clasts fall out to form debris slopes which obscure much of the bed. Sedimentary structures were not observed.

Clasts range up to 0.75 m in diameter, averaging approximately 3 cm, and are angular to well rounded. Angular clasts comprise approximately 10 percent of the conglomerate and are composed of pebble conglomerate, sandstone, and mudstone. Rounded clasts comprise approximately 40 percent of the rock and are mostly granitic along with a few percent each of porphyritic volcanic, black slate, and gray to dark gray quartzite.

Matrix, about 50 percent of the rock, is medium to coarse grained and has subangular to subrounded grains. Sand-sized mineral grains include common (plutonic) quartz, moderately weathered feldspar, and fine-grained igneous and sedimentary rock fragments. The matrix is different from the formation's normal sandstone (Table 8) in that it has a much higher percentage of rock fragments and only contains about one half as much quartz. Overall, the conglomerate's composition is very similar to the underlying Carrie Creek conglomerate. Sand grains, however, are more rounded.

The upper contact of the basal conglomerate with the lowermost sandstone bed is gradational over a thickness of about 0.3 m. Both clast content and clast size decrease over this thickness. A few large clasts (0.5 m diameter), however, protrude up through the contact from below.

The sandstone is variegated in color, ranging from light red (5 R 6/6) to dusky yellow (5 Y 6/4) to pale greenish yellow (10 Y 8/2). Yellowish gray (5 Y 7/2) is the most common color. Weathered color is grayish yellow (5 Y 8/4) to moderate reddish orange (10 R 6/6) and commonly is mottled. The rock varies from well cemented with calcite and very hard to uncemented and friable. Cavernous

Table 8. Composition in percent of thin sections of four sandstone samples and one conglomerate matrix sample from the Branch Canyon. Sample number 20 is from an outcrop along the Sisquoc River near Tunnel Ranch, 28 and 80 are from Tunnel Canyon near Tunnel Spring, 170A is from Manzana Creek, and 234 is from the ridge dividing Horse and Tunnel Canyons. *Represents Percent of just Q, F, and R constituents, not whole-rock percentages.

	massive sandstone	cross-strat. sandstone			basal cgl.	glauc. sandstone
Sample number	20	28	80	composite total**	170A	234
Average grain size (mm)	0.5	0.3	0.4	0.4	0.5	0.45
Quartz	49	40	42	43.7	23	14
Chert	--	1	3	1.3	--	--
-Q	60*	56*	60*	58.7*	28*	37*
Orthoclase	16	12	15	17.3	20	9
Plagioclase	12	9	12	11.0	3	6
Microcline	1	1	1	1	2	4
-F	35*	30*	36*	33.7*	31*	50*
Igneous rock fragments	2	5	2	3	17	5
Metamorphic rock fragments	2	4	1	2.3	1	--
Sedimentary rock fragments	--	1	--	0.3	15	--
-R	5*	14*	4*	7.7*	41*	13*
Biotite and muscovite	--	1	<1	<0.7	<1	1
Hematite	3	<1	<1	<1.7	1	2
Glauconite	--	<1	2	<1.0	<1	24
Clay matrix	10	--	1	3.7	6	25
Calcite cement	5	25	20	16.7	12	10

**Composite total is only for samples 20, 28, and 80.

weathering is common. In a few locations, small subspheroidal concretions (about 0.5 cm in diameter) commonly weather out on the outcrop surface.

Thickness of sandstone beds varies from 0.3 to 10 m, averaging approximately 2 m. Except in areas where the formation is thickest, it seldom consists of more than 4 or 5 sandstone beds. Internally most beds are massive; locally some have large-scale cross stratification, and a few have plane stratification.

Massive sandstone beds are up to 10 m thick, but average 2 to 3 m. Although the beds generally are structureless, thin pebbly layers or lenses and thin, irregular mudstone lenses which roughly parallel bedding do occur rarely. A mottled color is common and probably is due to extensive burrowing. Massive sandstone beds are the only beds of the Branch Canyon in which fossils were found. Fossils constitute less than 1 percent of the rock and are most common near the top of the beds, but may occur anywhere within the bed.

Cross stratification was observed only in outcrops in Tunnel Canyon and Alkali Canyon and at one location on the eastern edge of the area at Manzana Creek. Between these locations only massive or planar-stratified sandstone beds were observed. Cross stratification consists of planar and trough-shaped sets. Individual sets vary in thickness from 0.5 to 2 m. Cross stratification is recognized by slight variations in grain size (which generally is medium) and resistance to weathering. Thin pebbly layers are strung out along the foresets in only a few places. Foresets are truncated at the top of each set and tangential at the bottom. A massive or pebbly sandstone bed separates some sets (Fig. 6).

Plane-stratified sandstone beds very rarely occur. They were found only near the top of the formation. The beds range from 0.5 to 0.75 m thick. In most of these beds, plane stratification occurs in the lower one-third and upper one-third of the bed. The middle of the bed is massive.

Texturally, the sandstone is fine to coarse grained or slightly pebbly and submature to mature, having little clay matrix and being fairly well sorted. Massive beds generally are less mature than cross-stratified beds and a few have as much as 10 percent clay matrix.

Three sandstone specimens examined have angular to rounded grains. Two of the specimens are arkose, one is a lithic arkose (Table 8). Mineral grains include a high percentage of quartz that has straight to slightly undulose extinction, typical of common (plutonic) quartz, and slightly to moderately altered feldspar grains. A few composite quartz grains are present and have slightly

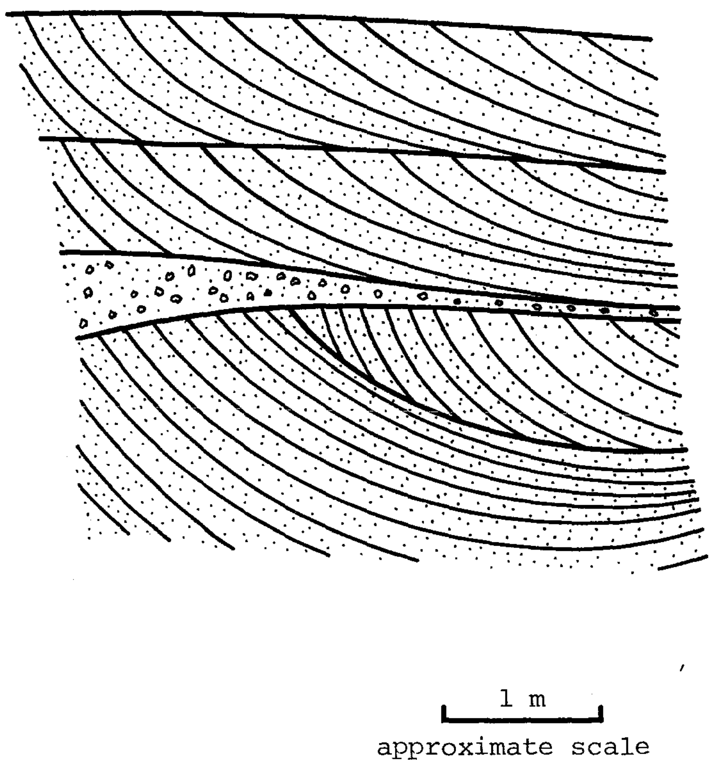


Figure 6. Sketch of cross stratification in an outcrop of the Branch Canyon Formation in Tunnel Canyon near Tunnel Spring. This outcrop is typical of cross stratified Branch Canyon.

to highly undulose extinction and straight to crenulated crystal boundaries typical of recrystallized and stretched metamorphic quartz. An unusual constituent is rare grains that show a graphic intergrowth of quartz and feldspar.

Siltstone beds commonly are interbedded between sandstone beds. These beds are yellowish gray (5 Y 7/2) on fresh and weathered surfaces. They have undulating bedding surfaces so that beds pinch and swell between 5 and 15 cm thick. The rock is massive except for rare, subhorizontal to horizontal, branching burrows that are circular to oval in cross section and 0.5 to 2.5 cm in diameter. Grains are angular and composed of about equal percentages of quartz and feldspar and a few percent of scattered, sand-sized, carbonized wood fragments.

Mudstone composes only a small percentage of the formation. Color is light olive gray (5 Y 5/2) to dark yellowish brown (10 YR 4/2), weathering to pale brown (5 YR 5/2) and pale yellowish brown (10 YR 6/2). The color usually is mottled, probably due to bioturbation. The mudstone occurs as thin, undulatory beds (0.1 to 1 m thick, averaging 0.25 m) between some sandstone beds or as thin lenses and discontinuous stringers within sandstone beds. Internally the mudstone is structureless except for some irregularly shaped sandy patches which are a result of burrowing. The mudstone is composed predominantly of clay-sized grains with a lesser amount of silt. It is rarely sandy. Silt and sand grains are angular and composed of approximately equal percentages of quartz and feldspar. Secondary gypsum is common in the mudstone and in a few locations comprises as much of 50 percent of the rock. Crystals are irregularly shaped and 1 mm to 5 cm in longest dimension. Larger crystals are of very clear selenite. Volume expansion due to growth of these crystals has entirely deformed the mudstone in some places.

At the top of the Branch Canyon Formation is glauconitic sandstone. This unit usually occurs between the Monterey and the Carrie Creek where the rest of the Branch Canyon is absent. It is too thin, however, to show on Plate 1. Fresh color is dusky yellow (5 Y 6/4) and weathered color is yellowish gray (5 Y 7/2). Thickness varies from 0.1 to 3 m, averaging approximately 1 m. The unit is internally massive and poorly to moderately indurated with calcite cement. Grain size varies from clay size to 4 mm, averaging less than 0.2 mm. The typical glauconitic sandstone is an immature muddy sandstone. It contains about 25 percent clay matrix, 20 percent calcite cement, 20 percent angular quartz grains, 20 percent round glauconite grains, 10 percent subangular and moderately altered feldspar grains, and 5 percent angular igneous rock fragments. One sample examined in thin section contains more calcite cement than usual (Table 8).

At a few locations the glauconitic sandstone contains irregularly-shaped, 0.5 to 3 cm, clasts of white to light-brown clay pebbles. The pebbles contain 1 to 30 percent sand-sized grains of glauconite, quartz, and feldspar in the same proportions as the glauconitic sandstone. The percentage of clay pebbles grades from only a few percent near the bottom of the glauconitic sandstone bed to 80 percent near the top of the bed.

Contacts and Recognition

The lower contact of the Branch Canyon Formation is sharp and unconformable, but rarely exposed. The basal conglomerate of the Branch Canyon weathers easily and forms a debris slope that usually covers up the contact at its base. The contact is slightly angular, with a difference of a few degrees of dip between the underlying Cretaceous Carrie Creek and the Miocene Branch Canyon.

The lower contact was placed between the last occurrence of mudstone or micaceous sandstone of the Carrie Creek and the first occurrence of non-micaceous sandstone or conglomerate of the Branch Canyon.

The upper contact of the Branch Canyon is conformable and gradational with the overlying Monterey Shale. The contact was placed at the first occurrence of light-gray tuff of the Monterey or the last occurrence of glauconitic sandstone. This contact is discussed more fully in the Monterey Shale section.

Age and Fossils

Fossils were found at only two localities (Table 9). Both of these are in coarse-grained, massive sandstone. All specimens of pectinids are fragments or molds of single valves. A few valves have traces of original shell material and some valves are nearly whole with fair to well preserved surface sculpture and little evidence of abrasion. The nearly whole specimens probably were transported only a short distance before deposition.

According to Loel and Corey (1932) the marine pectinid *Pecten* (*Amussiopecten* herein) *vanvlecki* is restricted in its occurrence to the upper and uppermost Vaqueros stage and *Chlamys sespeensis* is restricted to early Miocene. The Branch Canyon Formation of the map area is thus early Miocene in age.

The Branch Canyon of the Zaca area probably is correlative with the Rincon Formation of the Venture area which according to Durham (1954, Fig. 2) correlates with the Vaqueros Stage.

Table 9. Megafossils from the Branch Canyon Formation.

Species	Abundance	Locality number and location
Vertebrata		
Isurus sp.	few	CSUN 647, ridge dividing Tunnel and Horse Canyons
unidentified shark teeth	rare	
unidentified vertebrate bones	few	
Vertebrata		
Isurus sp.	few	CSUN 648, ridge dividing Tunnel and Horse Canyons
Echinoidea		
unidentified echinoid spines	common	
Bivalvia		
Leptopecten andersoni Arnold	few	
Chlamys sespeensis Arnold	few	
Amusiopecten vanvlecki Arnold	few	
Brachiopoda		
unidentified terebratulid	few	

Origin and Geologic History

The Branch Canyon Formation represents a transgressive sequence of shoreline to continental shelf deposits. The basal conglomerate's unconformable contact with the underlying Carrie Creek, and its clasts, which are mostly well rounded, hard rock types derived from the underlying Carrie Creek conglomerate, suggest that the basal conglomerate represents a beach gravel formed as the Branch Canyon sea transgressed over what must have been a pre-Branch Canyon-time highland. The occurrence of angular sandstone clasts in the basal Branch Canyon suggests erosion and transgression were rapid and waves did not have time to break up these soft clasts.

The change upsection to cross-stratified and massive sandstone and glauconitic sandstone suggests transgression continued and water depth increased over the area. The cross stratification (Fig. 6), as well as the medium grain size, of the cross-stratified Branch Canyon is similar to that found in modern longshore bars and megaripples formed in rip channels (Reineck and Singh, 1975). The cross stratification is also similar to that formed in megaripples of the shallow-marine sand sheet described in the southern part of the North Sea by McCave (1971).

Paleocurrent measurements in the Zaca area suggest different directions of sediment transportation at the three localities where cross stratification occurs (Fig. 7).

Facies change from cross-stratified sandstone to massive and extensively burrowed sandstone suggests that either the environment which produced the cross stratification occurred in geographically limited areas or bioturbation destroyed most cross stratification. Because Branch Canyon beds contain rare pebbly and muddy layers and lenses suggesting that the beds were deposited over a period of time by a fluctuating current, and because true massive sandstone is thought to form by the very rapid dumping of the sediment as a homogenous mass, burrowing is most likely the reason for why the sediment is massive.

Plane-stratified sandstone is known to form at current velocities of the upper or lower flow regime (Allen, 1970, p. 106). In the Zaca area, plane-stratified sandstone beds are composed of medium sand and, therefore, must have been deposited by currents of the upper flow regime.

The sandstone's large content of subround quartz and slightly to moderately altered feldspar may indicate a moderate distance of transportation in a humid climate.

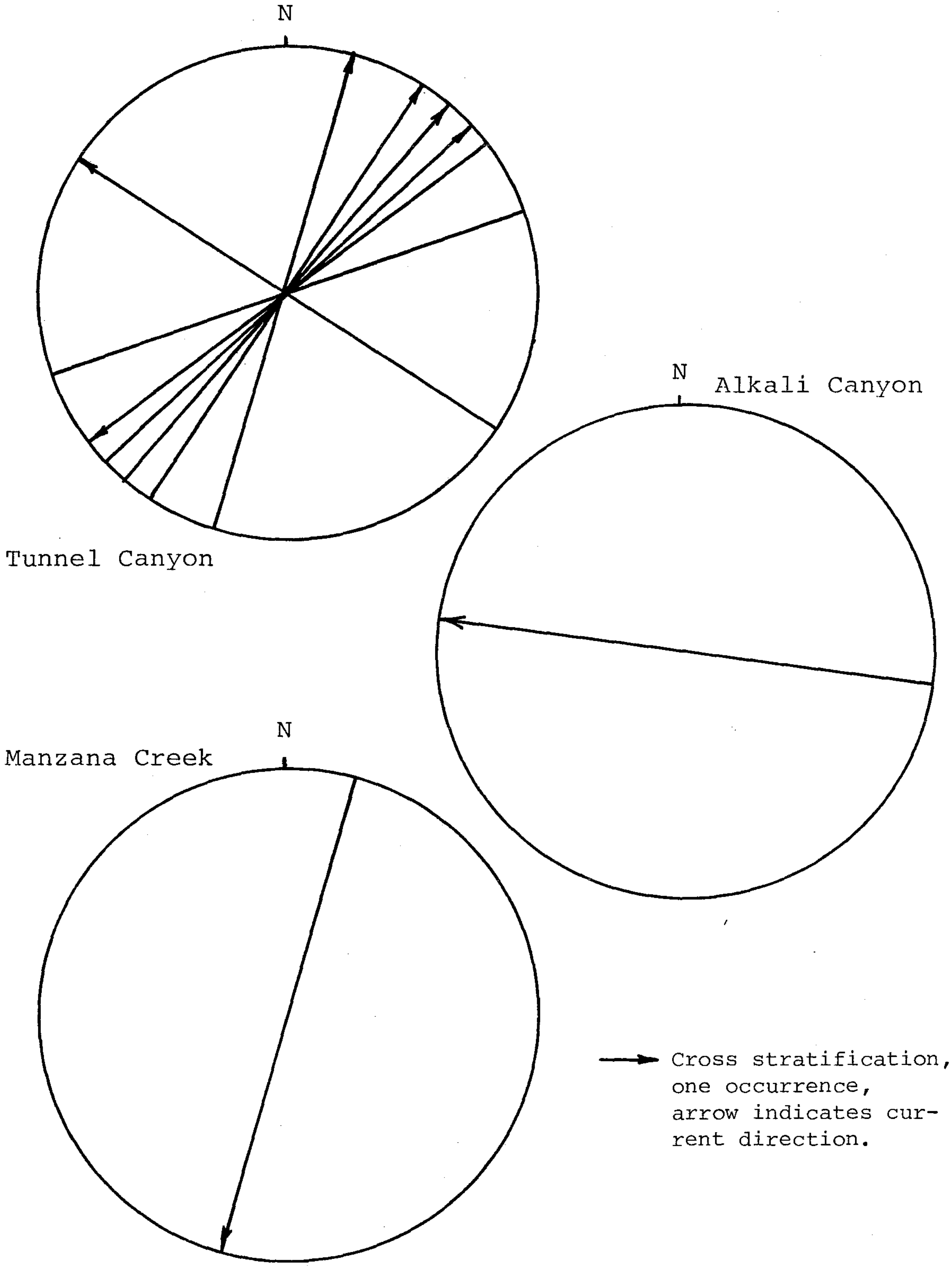


Figure 7. Paleocurrent measurements from the Branch Canyon Formation of the map area.

The content of rare grains showing graphic intergrowth of quartz and feldspar along with the high percentage of common (plutonic) quartz may suggest a predominantly granitic provenance. The small percentage of metamorphic quartz grains may suggest a minor metamorphic source. Reworking of the underlying sedimentary rocks, however, could also supply these constituents.

Thin bioturbated siltstone and mudstone layers that occur interbedded between coarser beds of the formation probably represent times when currents waned so that only finer grained sediments were transported into the area.

The glauconitic sandstone bed at the top of the formation probably was deposited at continental shelf depths. In the modern environment glauconite forms on continental shelves where there is some turbulence, a low rate of sedimentation, and some organic matter (Reineck and Singh, 1975, p. 132).

MONTEREY SHALE

Nomenclature

Blake (1855) unintentionally named the Monterey Shale in his description of strata exposed near Monterey, California. A type section was designated 3 km southeast of central Monterey at a stage coach station. The formation, however, is not exposed as a continuous sequence at the type locality and the complete detailed stratigraphy could not be worked out until the area was mapped in detail by Galliher (1932). On the basis of Galliher's work, Bramlette (1946) described the Monterey at its type section as varying thicknesses of sandstone, sandy shale, and calcareous shale, which are overlain by thin-bedded porcelanite and porcelaneous shale which comprise the greatest part of the formation, and which, in turn, are overlain by diatomite and diatomaceous shale that grade upward into interbedded diatomaceous, cherty, and porcelaneous rocks.

The Monterey occurs over an extensive area from south of Los Angeles to north of San Francisco. Lithology and thickness vary greatly over this extent, but the formation can always be distinguished by its siliceous character (Bramlette, 1949).

The Monterey Shale cannot be traced directly from its type locality into the Zaca Lake quadrangle, but the lithology described below is sufficiently similar to the type Monterey to allow correlation.

In the Zaca area, Arnold and Anderson (1907) mapped these rocks as Monterey Shale. Jennings (1959) shows this unit as "middle Miocene marine" on his geologic map of California, Santa Maria Sheet. Vedder and others (1967), on their reconnaissance geologic map of the San Rafael Mountains which adjoins the Zaca Lake quadrangle on the east, show this unit as Miocene shale and silty claystone, but do not name it.

Distribution and Thickness

The Monterey Shale crops out along the southern edge of the map area and as a wide band in the core of Hurricane Deck syncline just to the north of the Sisquoc River.

Thickness in the area is at least 500 m. The top of the formation is not exposed.

Lithology

The Monterey Shale chiefly consists of a series of interbedded, thin, tabular beds of shale, mudstone, porcelaneous mudstone, and porcelanite in roughly equal percentages. Mudstone and shale dominate low in the formation, porcelanite gradually becomes dominant toward the top of the formation. These rocks commonly are interbedded with very thin beds of bentonite and a very minor number of dolostone and turbidite sandstone beds. A bentonite bed occurs at the base of the formation.

The basal bentonite is very pale orange (10 YR 8/2), weathering to medium gray (N 5). It is massive, friable, and weathers easily to form slopes. Its presence commonly is indicated by a poor, clayey, gray soil that supports little vegetation. Its thickness is about 0.75 m. The bed is fossiliferous, being composed of approximately 5 percent forams.

Mudstone and shale beds are very similar, except that the shale is fissile. Together they comprise nearly one-half of the formation, but their relative percentage could not be determined. Fresh color varies from olive gray (5 Y 3/2) to grayish yellow (5 Y 7/2), weathering to grayish yellow (5 Y 8/4) and pale yellowish orange (10 YR 8/2). The rocks weather easily to form grassy or brush-covered slopes. Thickness of beds is 1 to 20 cm, averaging about 5 cm. They are laminated or internally massive. Laminae are very thin (usually less than 2 mm thick) and distinguished by alternating layers of lighter and darker colors. Most laminated beds are hard, calcareous, light in color (a few are dark), and have abundant fish scales on lamina surfaces. Massive beds are dark to light in color, softer than laminated beds, and only rarely calcareous.

The rock is dominantly composed of unidentified clay and about 1 percent angular, silt-sized quartz and feldspar grains.

Porcelanite and porcelaneous mudstone together comprise nearly one-half of the formation. Porcelanite is a silica-cemented rock that is less hard, dense, and vitreous than chert. It has minute pore spaces that give it the dull luster of unglazed procelain (Bramlette, 1946, p. 15). Porcelanite grades into porcelaneous mudstone by an increase in the amount of clay and silt. Color of porcelanite and porcelaneous mudstone is very pale orange (10 YR 8/2) to grayish orange pink (5 YR 7/2). Upon weathering, the rock develops a light brown (5 YR 5/6) surface stain. The rocks are hard, but brittle, and sometimes break with conchoidal fracture. They are somewhat more resistant to weathering than other Monterey rocks and form ridges where a significant thickness of these rocks occurs. Thickness of beds varies from 1 to 30 cm, averaging about 10 cm. Internally the beds are either massive or laminated. Laminae are distinguished by alternating lighter and darker colors and are less than 3 mm thick. The rock consists mostly of amorphous silica with a varying amount of clay and a few percent of angular, silt-sized quartz, feldspar, muscovite, and biotite grains. Fish scales, fish bones, and diatom frustules occur sparingly in porcelaneous mudstone and rarely in porcelanite.

Bands and nodules of chert commonly occur within porcelanite beds. The chert is brownish gray (5 YR 4/1) to olive gray (5 Y 4/1). The bands and nodules parallel bedding and are 0.2 to 5 cm in thickness. Nodules are up to 1 m in length. The chert is very thinly laminated. Laminations commonly can be traced from chert nodules into the surrounding porcelanite, suggesting the nodules are secondary.

Thin beds of bentonitic clay commonly are interbedded between other rock types of the Monterey. The clay is white (N 9) to medium light gray (N 7), weathering to medium gray (N 5). This very soft rock weathers easily and is poorly exposed. The beds are 0.5 to 1 cm thick and internally massive.

Only 3 dolostone beds were seen. Color is pale yellowish brown (10 YR 6/2), weathering to very pale orange (10 YR 8.2) with a spongy, powdery surface crust. These beds are interbedded with mudstone low in the formation on the hillsides between Tunnel Canyon and Tunnel Ranch. The dolostone is hard and dense and, being more resistant than the surrounding strata, forms small, low outcrops on an otherwise grassy slope. These 10 to 20 cm thick beds are internally massive and contain approximately

10 percent subangular to angular silt and sand grains, 0.05 to 0.5 mm in size. The grains are composed of feldspar and quartz in approximately equal quantities along with a trace of muscovite and apatite. Matrix is finely crystalline spar. A few foraminifera tests and unidentified fossil fragments, probably diatoms and fish bones, occur. These are completely replaced and infilled with very finely crystalline to finely crystalline dolomite, collophane, or opal. Staining of thin sections in alkaline solution with alizarine red-S (Friedman, 1959) confirmed that all carbonate is dolomite.

Two sandstone beds crop out in Tunnel Canyon near Tunnel Spring and a third sandstone bed crops out in West Fork Mill Creek in the southeastern corner of the map area. Color is grayish orange (10 YR 7/4) on fresh surfaces, weathering to light olive gray (5 Y 5/2). The rock is cemented with calcite and moderately well indurated. The three beds are 1.5, 5, and over 10 m thick (the thickest bed is thicker than its exposure). All beds are vaguely graded and the two thinner beds contain parallel laminations in the middle half of the bed. Grain size in the two thinner beds is fine to medium, with a few floating pebbles less than 1 cm in size. The thicker bed is a pebbly sandstone composed of approximately 5 percent pebble clasts of up to 1 cm in size in a medium-grained matrix. Pebbles are gray, well-rounded, fine-grained volcanic rocks.

The sandstone and the pebbly sandstone matrix are submature (Table 10). They contain less than 5 percent clay matrix and are moderately sorted. Fine-grained quartz and feldspars are mostly subangular. Medium-grained quartz and feldspars and all rock fragments are rounded to well rounded. The sandstone is arkose and the pebbly sandstone matrix is lithic arkose. The pebbly sandstone matrix has a higher percentage of rock fragments than the sandstone. These rock fragments predominantly are fine-grained volcanics along with a smaller percentage of fine-grained sedimentary and foliated metamorphics. Quartz grains are of common (plutonic) and recrystallized metamorphic types. Feldspar grains are fresh to very altered. Muscovite and biotite grains are rare, but are large (up to 0.5 mm) and fresh.

Contacts and Recognition

The upper contact of the Monterey Shale is not seen within the map area. In the northern part of the area the lower contact is well exposed at two localities. Here it is conformable and gradational with the underlying glauconitic sandstone of the Branch Canyon Formation. Within the upper 0.5 m of the glauconitic sandstone bed, clay matrix of the sandstone gradually gives way to a

Table 10. Composition in percent of thin sections of one sandstone and one pebbly sandstone matrix sample from the Monterey Shale. Sample number 29 is from an outcrop in Tunnel Canyon near Tunnel Spring and number 117 is from near West Fork Mill Creek. *Represents percent of just Q, F, and R constituents, not whole-rock percentages.

	sandstone	pebbly sandstone	
Sample number	29	117	composite total
Average grain size (mm)	0.2	0.4	0.3
Quartz	43	27	35.0
Chert	<1	1	<1
-Q	54*	32*	43.0 *
Orthoclase	24	18	21.0
Plagioclase	10	12	11.0
Microcline	1	1	1
-F	45*	35*	40.0 *
Igneous rock fragments	--	26	13.0
Metamorphic rock fragments	1	1	1
Sedimentary rock fragments	--	1	0.5
-R	1*	33*	17.0 *
Biotite and muscovite	<1	<1	<0.5
Secondary chlorite	--	<1	<0.5
Apatite	<1	--	<0.5
Zircon	<1	--	<1
Epidote	<1	<1	<1
Hematite	1	1	1
Clay matrix	3	<1	<2.0
Calcite cement	15	10	12.5
Pore Space	2	--	1.0

bentonitic matrix and the framework of sand-sized glauconite, quartz, and feldspar gradually becomes less abundant, until the unit is all bentonite.

At most localities the contact was placed between the last occurrence of Branch Canyon sandstone and the first occurrence of buff shale, mudstone, or porcelanite of the Monterey. The poor, clayey gray soil that develops over the Monterey basal bentonite is easily recognized, and at many places is useful in locating the contact.

In the southern part of the area the Monterey is in fault contact with the Franciscan Complex as discussed in the Franciscan Complex section.

Age and Fossils

Several megafossils were found in the Monterey Shale (Table 11). Fragmented and nearly whole unidentified fish skeletons, as well as fish scales, are rare to common, but never abundant, on parting planes at many localities. The bivalve *Delectopecten peckhami* is rare to abundant at numerous localities.

At one locality the basal bentonite contains a diverse assemblage of foraminifers. Table 12 lists these foraminifers and shows the stage and zone Kleinpell (1938, 1940, 1946) indicated for those species which are age diagnostic. The fauna suggests the lower Luisian Stage for the base of the formation. Monterey rocks in the map area

Table 11. Megafossils from the Monterey Shale.

Species	Abundance	Locality number and location
Vertebrata		
unidentified vertebrate bones	rare	CSUN 649, lower Horse Canyon
unidentified fish bones	rare to abundant	numerous localities
Bivalvia		
Delectopecten peckhami (Gabb)	common	numerous localities
Bryozoa		
unidentified fennestellid bryozoan	rare	CSUN 650, ridge dividing Tunnel and Horse Canyons

Table 12. Foraminifers from the basal bentonite of the Monterey Shale at locality CSUN 651. This locality is near the ridge dividing Tunnel and Horse Canyons. Age range following Kleinpell (1938, 1940, 1946) is given for age diagnostic species. C = common, F = few, R = rare.

SPECIES	FREQUENCY	STAGE AND ZONE							
		Saucesian	Relizian		Luisian			Mohnian	Delmont.
			Siphogenerina hughesi	*Siphogenerina branneri*	*Siphogenerina reedi*	*Siphogenerina nuciformis*	*Siphogenerina collomi*		
Bolivina advena Cushman	C		—	—	—	—	—	—	
Bolivina marginata Cushman	F	—	—	—	—	—	—	—	—
Bulimina corrugata Cushman and Siegfus	R								
Cibicides altamerensis Kleinpell	C								
Cristellaria articulata (Reuss)	R								
Dentalina obliqua (Linne)	F			—	—	—	—		
Globigerina bulloides d'Orbigny	C	—	—	—	—	—	—	—	—
Hemicristella beali (Cushman)	F		—	—	—	—	—		
Lagena marginata (Walker and Boys)	F								
Lagena strumosa Reuss	F								
Lagena sp.	R								
Nodogerina advena Cushman and Laiming	C		—	—	—	—	—	—	—
Nodosaria cf. *N. boffalorae* Martinotti	F								
Nodosaria cf. *N. longiscata* d'Orbigny	C	—	—	—	—				
Nodosaria sp.	R								
Planulina cf. *P. ariminensis* d'Orbigny	F								
Robulus miocenicus (Chapman)	F				—	—	—		
Siphogenerina branneri (Bagg)	F	—	—	—	—				
Siphogenerina reedi Kleinpell	C				—	—	—		
Uvigerina joaquinensis Kleinpell	F								

are thus middle Miocene to possibly younger.

Samples from several other localities were processed for microfossils but were found to be barren.

Origin and Geologic History

Three of the foraminifers from the basal Monterey, *Bolivina advena*, *B. marginata*, and *Cassidulina crassa*, are indicative of a marine upper-bathyal biofacies that has a water depth of between 100 and 500 m (Arnal and Vedder, 1976). *Delectopecten peckhami* is found higher in the formation. Living species of *Delectopecten* are found only in depths greater than 20 m and are more common in depths greater than 200 m (Moore, 1963, p. 19). Hence, the Monterey Shale represents deposition in an upper bathyal sea. The transition from the glauconitic bed at the top of the Branch Canyon to the conformably overlying bathyal-depth beds of the Monterey occurs over a stratigraphic thickness of only about 1 m, which suggests subsidence was rapid or sedimentation during subsidence was slow.

The very fine-grained, commonly laminated, nature of most Monterey rocks suggests deposition by a slow rain of terrigneous clays and dead organisms in deep water. There were few currents and few organisms capable of disturbing the sediment. Varying supply of terriginous clay, calcareous microfossils, and siliceous microfossils controlled the type of sediment deposited.

The mudstone and shale beds were deposited during times when terrigneous source dominated over biologic, perhaps due to periods of high runoff on land or periods of low microorganism productivity. The sand and silt in these rocks may have been transported by wind or strong storm seas which were capable of suspending these grains long enough to carry them out to deep water.

Calcareous mudstone, dominant low in the formation, indicates deposition above the calcium carbonate compensation depth. Siliceous porcelaneous beds which become dominant higher in the formation may indicate deposition below this depth.

Monterey chert, porcelanite, and porcelaneous mudstone are probably the result of alteration of diatom rich sediments in which the relatively unstable opaline shells were dissolved and reprecipitated either to form the cement of these rocks (Bramlette, 1946) or as a microcrystalline siliceous ooze.

The replacement of calcite shell material by finely crystalline dolomite shows that the dolostone beds probably are diagenetic. Dolostone beds probably were deposited as calcareous oozes above the carbonate compensation depth during times of high calcareous microorganism productivity and low siliceous supply. Later, the calcite was completely replaced by finely crystalline dolomite.

The formation's sandstone beds are graded and have parallel laminations, which suggests deposition by turbidity currents. The submature nature of the sandstone, angularity of its fine-grained constituents, rounding of its larger constituents, and content of weathered feldspar may suggest a moderate distance of transportation in a humid environment. The content of common (plutonic) and recrystallized metamorphic quartz, and metamorphic and volcanic rock fragments may indicate a mixed granitic, metamorphic, and volcanic source terrane and/or a reworked sedimentary source.

Bentonite, which occurs at the base of the formation and interbedded throughout the formation, generally is thought to be derived from the alteration of volcanic ash (Bramlette, 1946, p. 26).

The basin in which the Monterey of the Zaca area was deposited, as well as other late Tertiary basins of California, is temporally and spatially related to the San Andreas fault system (Blake and others, 1978) and the plate tectonic movements that resulted in the development of the fault. Discussion of the basin's development is beyond the scope of this paper, but reviews based on regional syntheses can be found in Atwater (1970), Atwater and Molnar (1973), Blake and others (1978), and Luyendyk and others (1980).

QUATERNARY DEPOSITS

Stream and terrace alluvium in the Zaca area are essentially identical; both were deposited by streams which were eroding the same terrain as the modern Sisquoc River drainage system. Alluvium forms the beds of all streams in the Zaca area, but only in larger stream valleys such as those of the Sisquoc River, Manzana Creek, and Horse Canyon is it extensive enough to be shown on Plate 1. Terrace alluvium occurs mainly along the Sisquoc River and Manzana Creek where it forms elevated remnants of formerly more extensive alluvial deposits that have been eroded through during recent times. Terrace alluvium presumably is Pleistocene in age. These deposits unconformably overlie all older units. The terraces are up to 10 m thick and average about 2 m.

Color is grayish yellow (5 Y 9/4). The alluvium ranges from unconsolidated to semiconsolidated with calcite cement. A typical braided stream deposit, the alluvium contains irregularly shaped lenses of varying grain size. A few lenses have large-scale, low-angle cross stratification in 0.5 to 1 m thick sets. The alluvium is mostly a poorly sorted, pebble to boulder conglomerate or gravel, but has minor lenses of sand and silt. Matrix is coarse grained and porous. Several lenses of black-stained gravel were observed. These probably were stained by decaying aquatic vegetation which grew in a temporarily stable pond or channel.

Clasts are derived from nearby units and are composed of both hard and soft rock types. Hard rock clasts are reworked from older conglomerates. The average alluvium deposit contains clasts that range up to 1.5 m in diameter, averaging 2 cm, and are angular to well rounded. Soft rock types are more angular than reworked hard rock types. Monterey Shale clasts are very abundant and tend to be very angular due to their tendancy to fracture.

STRUCTURE

General Features

The major structural features of the Zaca area are the Hurricane Deck syncline and three northwest-southeast-trending faults and their related folds along Catway Ridge (Fig. 8). Other structural features include a small fault near Alkali Canyon, one near Rattlesnake Canyon, and one between Tunnel and Horse Canyons, two folds near Manzana Creek, one in Horse Canyon, and numerous small folds in the Monterey Shale.

Evidence for four other regional structural events has already been described in the stratigraphic parts of this thesis. Included are events before and after deposition of the Fish Creek conglomerate, as shown by its drastic change in provenance, and events during the hiatuses between the Unnamed shale and sandstone, the Carrie Creek Formation, and the Branch Canyon Formation.

Faults

Northwest-southeast-trending faults - Three faults which are roughly parallel and which trend approximately N. 70° W. occur along the steep brush-covered slopes north of Catway ridge. These faults are nowhere well exposed. Outcrop pattern suggests that all three of these faults dip steeply toward the north. Evidence for the existence

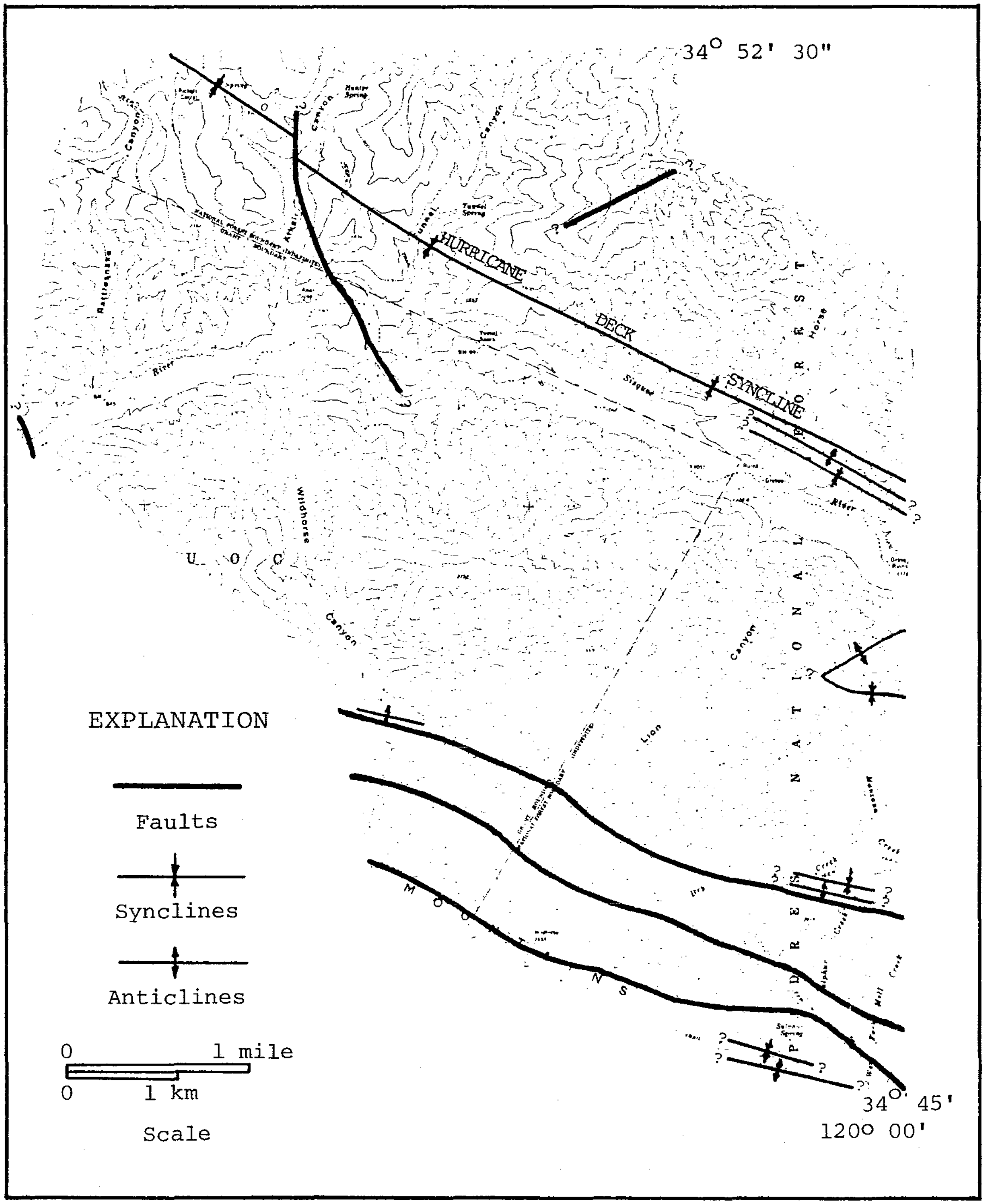


Figure 8. Folds and faults of part of the Zaca Lake quadrangle. Topography reduced from USGS Zaca Lake quadrangle (1:24,000).

of these faults is discussed in sections on the individual formations which they divide.

The southernmost of these faults divides Monterey rocks on the south from Franciscan rocks on the north. Direct evidence of the nature and amount of displacement on this fault is lacking in the map area. Exposure of Franciscan basement rocks on the north side of the fault and its steep northerly dip suggest that it is a reverse fault.

The central fault separates Franciscan rocks on the south from Espada rocks on the north. Direct evidence for the nature of this fault is lacking also, but exposure of Fransiscan basement on the south and its steep northerly dip suggest it is a normal fault. Franciscan and Great Valley (e.g. Espada) rocks are almost always in fault contact and these faults are thought to represent faults along which the Franciscan was subducted and deformed (Bailey and others, 1964) and/or uplifted and accreted against the continent (Ingersoll, 1978).

The northernmost of these three faults separates the Fish Creek conglomerate on the south from the Unnamed shale and sandstone on the north. This fault continues southeastward until it merges with the Big Pine fault in the vicinity of Grapevine Creek, San Rafael Mountain quadrangle (Vedder and others, 1967) 25 km from the map area. Exposure of the younger rocks on the north suggests normal faulting, but strike-slip faulting could also produce this apparent movement.

Other Faults - A small fault in the Sisquoc River canyon near Rattlesnake Creek trends approximately N. 15° W. The fault forms the axis of a small gully and is not exposed. It is recongized primarily by an abrupt change in attitude in Unnamed shale and sandstone strata on its two sides and by the juxtaposition of mudstone and sandstone beds on opposite sides of the gully. The nature and movement of the fault could not be determined.

A fault trending about N. 20° W. cuts across the Sisquoc River near Alkali Canyon in the north-central part of the map area and displaces Cretaceous and Miocene strata and the trough of the Hurricane Deck syncline. The fault dips very steeply to the west and is a right-reverse-slip fault with a strike slip of approximately 200 m measured between offset troughs of the Hurricane Deck syncline. Despite this small displacement, the fault contains a breccia zone approximately 15 m wide which is well exposed in the Sisquoc River canyon. Breccia clasts are as large as 0.5 m in diameter and composed of sandstone and mudstone clasts derived from the adjacent units. The zone is mineralized and has gypsum and quartz veins of up to 1 cm wide. Caliche coats the surface of the breccia zone's outcrop. Much of the crushed rock contains very thin (less than 0.5 mm) stretched and deformed carbonized wood flakes. This fault is older than Pleistocene terrace deposits which it does not disturb and younger than the Hurricane Deck syncline which it offsets.

A small fault occurs along the ridge dividing the drainages of Tunnel and Horse Canyons. It is not exposed, but evidence for this fault is the abrupt truncation and offset of Branch Canyon outcrops. Right separation is approximately 100 m.

Folds

Hurricane Deck Syncline - The Hurricane Deck syncline trends about N. 65° W. across the northern part of the map area and plunges very slightly toward the southeast. Near the eastern edge of the area limbs dip moderately between 35° and 45°. In the northwestern part of the area limbs dip more gently between 20° and 30°. The fold is symmetrical, approximately cylindrical, and upright. The Hurricane Deck Syncline is older than Pleistocene terrace deposits which it does not fold, older than the Alkali Canyon fault which displaces its trough, and younger than the Monterey Shale which it folds.

Other folds - A small syncline and anticline occur in Unnamed shale and sandstone rocks at the northeastern corner of the map area. These folds are very similar to the Hurricane Deck Syncline and have a trough and crest which trend in the same direction as the trough of the Hurricane Deck Syncline. The folds are symmetrical, cylindrical, and upright. Beds on the southern limb of the anticline dip between 30° and 50°. Limbs of the syncline dip between 20° and 30°. These folds fold the Unnamed shale and sandstone, do not affect Pleistocene terrace deposits, and are probably of the same age as the Hurricane Deck syncline.

Another syncline and anticline related to the Hurricane Deck syncline occurs in the vicinity of Manzana Creek. The anticline trends northeast-southwest and the syncline trends generally east-west. They merge and die out about 1 km west of Manzana Creek. About 3 km eastward of the edge of the quadrangle they merge with the Hurricane Deck syncline (Vedder and others, 1967). These folds are symmetrical, approximately cylindrical, and upright. Limbs dip steeply at approximately 65°. Because these folds fold the Unnamed unit, the Carrie Creek, and the Branch Canyon, but do not affect Pleistocene terrace deposits, their age is probably the same as that of the Hurricane Deck syncline.

Near Sulfur Creek, rocks just to the north of the most northerly northwest-southeast-trending fault are abruptly folded near the fault. The folds are symmetrical, cylindrical, and range from upright to steeply inclined. Limbs dip steeply at between 55^{o} and 85^{o}. North of these folds the rocks are undisturbed for approximately 2 km. The folding probably is related to drag during faulting.

The Monterey Shale commonly is deformed into small, closely spaced, generally steep-limbed folds that trend northwest-southeast. With a few exceptions, these folds are too small to show on Plate 1. The folding is most prevalent in the Monterey along Catway Ridge and near the base of the formation north of the Sisquoc River. In order for folding to have occurred along the base of the formation, some slippage must have taken place along bedding faults to permit deformation of Monterey beds without similar distortion of the more rigid underlying sandstone. North of Catway Ridge these folds trend parallel to the Hurricane Deck syncline and probably are related to it in origin.

Development of Structural Features

Other than the subduction related structures of the Franciscan Complex, the oldest structural event for which there is evidence in the map area is a major uplift to the west which resulted in a drastic change from the westerly "continental" provenance of the Espada to the easterly Franciscan melange provenance of the Fish Creek. At the end of Fish Creek deposition, provenance changed back to a westerly "continental" source for the Unnamed unit, suggesting subsidence of the Franciscan terrane.

The next younger structural feature in the map area is the Late Cretaceous parallel unconformity between the Unnamed shale and sandstone and the Carrie Creek. This unconformity apparently resulted from migration, along with erosion, of a submarine-fan channel.

A slightly angular unconformity separates Late Cretaceous Carrie Creek and Miocene Branch Canyon rocks. This unconformity is the result of uplift, regional folding which caused tilting of Zaca area Cretaceous strata, and erosion, subsequently followed by submergence. Plate interactions during the early Tertiary are thought to have resulted in strike-slip faulting which produced a "borderland" topography of uplands and marine basins in this region (Nilsen, 1977b). The Zaca area presumably was one of the uplands during the formation of this unconformity.

Because the Hurricane Deck syncline and its related folds north of the Sisquoc River, the synclines and anticlines along Manzana Creek and Catway Ridge, the fault near Alkali Canyon, and the fault between Alkali and Horse Canyons deform the Monterey and Branch Canyon equally and have not deformed the Pleistocene terraces, it is apparent that these folds and faults are related to the same episode of deformation which is post-Monterey and pre-Pleistocene in age. The southernmost of the northwest-southeast-trending faults cuts the Monterey and also likely is related to this event. Compression from the northeast and southwest caused the rocks to yield to produce the generally northwest-southeast-trending folding. Compression continued until the brittle failure point of the rocks was exceeded and the rocks broke to produce the faults.

Post-Miocene compressional events in this region are thought to be related to right-lateral translational shear on the San Andreas fault (Page, 1977). A review of the plate-tectonic events that might have brought about the post-Miocene compression and deformation can be found in Page (1977).

Continuing compression resulted in uplift of the area, followed by erosion and development of the pre-terrace unconformities. The fact that the Sisquoc River is incised into the most recent Pleistocene terraces indicates uplift is probably continuing today.

Because the northernmost of the northwest-southeast-trending faults merges with the Big Pine Fault, it is probably related to the Big Pine Fault in origin. The Big Pine Fault is a left-slip fault of probable Miocene through Recent age (Hill and Dibblee, 1953). The folds adjacent to the northernmost northwest-southeast-trending fault in Sulfur Creek and Wildhorse Canyon seem to be the result of drag during faulting and they thus suggest some movement on the fault was vertical.

GEOMORPHOLOGY

The Zaca area has a late youthful topography. The hillsides of the Sisquoc River canyon are marked by four terrace levels in a stairstep fashion. Some larger terraces have undulatory topography. The undulations are characteristic of old meander bends.

The surfaces of the modern alluvial beds of the Sisquoc River and Manzana Creek are marked by old meander scars and partially stabilized (by vegetation) flood-stage bars. The present channels of both streams are typical of near-source, braided streams. They consist of anastamosing channels divided by longitudinally arranged bars.

In places, the course of the Sisquoc River bends around resistant exposures of sandstone and exploits mud-stone strata. The dominant control on the river's course, however, is the attitude of the strata through which it has eroded. In the eastern part of the area, the generally northwesterly course parallels the northwesterly strike of strata in this area. West of the fault near Alkali Canyon both the strike of the rock units and the stream's course change to southwesterly. The stream apparently is cutting down and slipping northeastward and northwestward. Its efforts to erode the bottom of its channel are being deflected northerly by hard sandstone strata dipping in that direction. Steep canyon walls immediately south of the stream are northward-dipping flatirons of resistant sandstone strata.

The map area is wholly within the Sisquoc River drainage system and smaller streams generally flow northerly or southerly to reach the Sisquoc. The pattern of these streams is a dendritic one, dominated by the shortest distance to the Sisquoc. A less important, local control is the strata through which the individual streams flow. Many diversions and bends occur where stream courses bend around, or for short distances flow parallel to, resistant strata and take advantage of less resistant strata.

All smaller streams and parts of the Sisquoc River are intermittent. During more than 6 months of the year, parts of the Sisquoc with wide, deep alluvium are dry and the water table is entirely below the surface. Areas of the canyon with narrow, shallow alluvium, however, have perennial flow because the constricted water table reaches the surface.

SUMMARY OF GEOLOGIC HISTORY

Table 13 lists events in the geologic history of the Zaca area and summarizes data and conclusions discussed in greater detail in sections on individual formations and "Structure".

Table 13. Summary of the geologic history of a part of the Zaca Lake quadrangle.

Period	Epoch	Event	Geologic record or evidence
QUATERNARY	Recent	Nonmarine deposition.	Alluvium.
QUATERNARY	Pleistocene and Recent (?)	Regional uplift or lowering of base level.	Pleistocene terraces along major streams.
		Nonmarine deposition.	Pleistocene terraces.
Miocene to Pleistocene		Development of fault separating Fish Creek and Unnamed shale and sandstone.	Fault merges with Big Pine fault to the southwest.
		Uplift and erosion; compression.	Lack of any upper Miocene or Pliocene rocks; unconformities at base of Pleistocene terraces; folding and faulting of Miocene rocks.
TERTIARY	Miocene	Continued subsidence.	Deep marine aspect of Monterey Shale fossils.
		Volcanic activity nearby during Monterey deposition.	Bentonite beds at base of, and interbedded with, the Monterey Shale strata.
		Transgression of sea; resumption of marine deposition.	Shallow-marine to continental shelf facies of Branch Canyon Formation; marine fossils.

Table 13. *(Continued).*

Period and epoch	Event	Geologic record or evidence
JURASSIC AND CRETACEOUS	Marine deposition in distal turbidite fan or on continental slope by turbidity currents derived from a land mass to the east.	Thin turbidite beds in Espada Formation representing Bouma divisions "de" or "cde" and a high predominance of mudstone over sandstone; sandstone contains a high percentage of common (plutonic) quartz.
	Marine deposition on, and emplacement of igneous bodies in, oceanic crust; subduction and tectonic mixing.	Franciscan complex consists of chaotic blocks of mafic igneous and sedimentary rock types "floating" in a ductily deformed and sheared mudstone matrix; fossils are marine.

Table 13. *(Continued)*.

Period and epoch		Event	Geologic record or evidence
Upper Cretaceous to lower Miocene		Uplift and erosion; tilting.	Lack of any lower Tertiary rocks; slightly angular unconformity between Carrie Creek and Branch Canyon Formations.
Upper Cretaceous or younger		Intrusive volcanic activity.	Dikes intruding Unnamed shale and sandstone.
CRETACEOUS	Upper Cretaceous	Migration of turbidite fan channel causing, initially, erosion of fan; deposition of inner fan sediments.	Erosional surface at top of Unnamed shale and sandstone; change to a more proximal turbidite fan facies of the Carrie Creek.
		Probable subsidence of Franciscan terrane; return to turbidite fan deposition by turbidity currents derived from the east.	Unnamed shale and sandstone contains classical turbidite sandstones, marine fossils, granitic conglomerate clasts and common (plutonic) quartz grains, and westward directed paleocurrents.
		Uplift of Franciscan terrane west of area resulting in marine deposition of inner to middle fan channel-fill conglomerates.	Disorganized conglomerate and probable Franciscan clasts of the Fish Creek conglomerate.

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