UNITED STATES

DEPARTMENT OF THE INTERIOR

Geological Survey

SEDIMENTOLOGY OF THE SIMMLER AND VAQUEROS FORMATIONS IN THE CALIENTE RANGE-CARRIZO PLAIN AREA, CALIFORNIA

By

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Open-file Report 74-338

Menlo Park, California

1974

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ABSTRACT

The Simmler and Vaqueros Formations in the Caliente Range-Carrizo Plain area make up a large part of the thick Tertiary sedimentary sequence that was deposited in a basin which lay along the southwest side of the present-day San Andreas fault. The evolution of this basin during Oligocene and early Miocene time and the relationship of its sedimentary record to the tectonic history is an important chapter in the Tertiary history of California.

The Simmler Formation, of provincial Oligocene to early Miocene age, unconformably overlies basement rocks and an Upper Cretaceous-lower Tertiary marine sequence. It consists of a sandstone facies, which is mostly a variegated sequence of sandstone and mudstone occurring in fining-upward cycles, and a conglomerate facies, which occurs around the southwest and southeast margins of the basin.

The conformably overlying Vaqueros Formation, of provincial early to middle Miocene age, is subdivided from base upward into the Quail Canyon Sandstone, Soda Lake Shale, and Painted Rock Sandstone Members. The Vaqueros intertongues eastward, southeastward, and northward with the continental Caliente Formation and is conformably overlain by the Monterey Shale. In the Caliente Range, northeast of major thrust faults, the Vaqueros may reach a thickness of 8,700 feet (2,650 m). Around the margin of the basin, the formation is much thinner--locally only 200 feet (60 m) thick--and is generally undivided. The Quail Canyon Sandstone Member is composed of cross-bedded or planar-stratified sandstone. The Soda Lake Shale Member consists mostly of siltstone and platy shale with

a few thin sandstone interbeds. The Painted Rock Sandstone Member, the thickest and coarsest member, consists mostly of large lenticular bodies of thick-bedded coarse-grained sandstone and thinner units of siltstone.

Petrology and paleocurrent studies indicate that, in a given subarea, the Simmler and Vaqueros Formations were derived from the same source terrane and that the sediments were usually transported in the same general direction. Crystalline basement terranes to the north and south were the primary sources, but the Upper Cretaceous-lower Tertiary marine sequence made substantial contributions along the southwest side of the basin.

The sandstone facies of the Simmler Formation is interpreted as an alluvial plain depositional complex formed by through-flowing low-sinuosity streams, and the conglomerate facies is interpreted as alluvial fan deposits. The Vaqueros Formation in the Caliente Range forms a transgressive-regressive sequence. The Quail Canyon Sandstone and lowermost Soda Lake Shale Members represent the transgressive phase, are interpreted as beach-nearshore and offshore deposits, and are locally the marine equivalents of the upper part of the Simmler conglomerate facies. The remainder of the Soda Lake Shale Member and the Painted Rock Sandstone Member represent the regressive phase and are interpreted as a complex of deltaic and shelf-slope deposits that prograded over basinal shales and turbidites.

The reconstructed basin history began in the Oligocene with alluvial plain sedimentation in an area of relatively low relief. This was interrupted in the early Miocene (ca. 25 m.y. B.P.) by the beginning of a period of crustal extension, probably related to the first interaction of the Pacific and North American plates, resulting in the formation of a rapidly subsiding marine basin. This crustal extension was followed by a period of north-south compression in the Pliocene and Pleistocene, which caused the thick accumulation of sediments in the basin to be folded and thrust over the thinner basin-margin section. The Red Hills-Chimineas-Russell fault trend, along which Cretaceous granitic and Precambrian(?) gneissic rocks had been juxtaposed in Cretaceous time, was reactivated in the Pliocene, when 8 to 9 miles (13-14.5 km) of additional right-lateral slip occurred. The pattern of north-south thrusting and right-lateral shear within the Caliente Range-Carrizo Plain area during the late Tertiary is related to simultaneous large-scale right-lateral movements on the San Andreas fault system.

INTRODUCTION

Geologic Setting and Purpose

The Caliente Range-Carrizo Plain area lies along the southwest side of the San Andreas fault in the southern Coast Ranges of California (fig. 1), just north of the Transverse Ranges structural province. This area contains an unusually thick accumulation of Tertiary sedimentary rocks that were deposited in a basin developed adjacent to the present San Andreas fault. The Simmler and Vaqueros Formations, which make up a large part of this accumulation, provide an unbroken record of the Oligocene and early Miocene history of the basin and the transition from continental to marine sedimentation in the early Miocene. It was during this period of time that the Pacific lithospheric plate first encountered the North American plate (Atwater and Molnar, 1973), setting off a sequence of tectonic events, including the evolution of the modern San Andreas fault system, that continues to the present. The complete sedimentary record in the Caliente Range-Carrizo Plain area, with its well displayed variety of sedimentary environments, is an ideal place to study the evolution of a Tertiary sedimentary basin and the relationship of its sedimentary record to the tectonic history.

The purpose of this study was to determine the Oligocene and early Miocene history of the Caliente Range-Carrizo Plain basin and to reconstruct the paleogeography and paleogeology. This reconstruction may contribute to the understanding of the Tertiary history of the region, and serve as a model for other similar Tertiary basins in California.

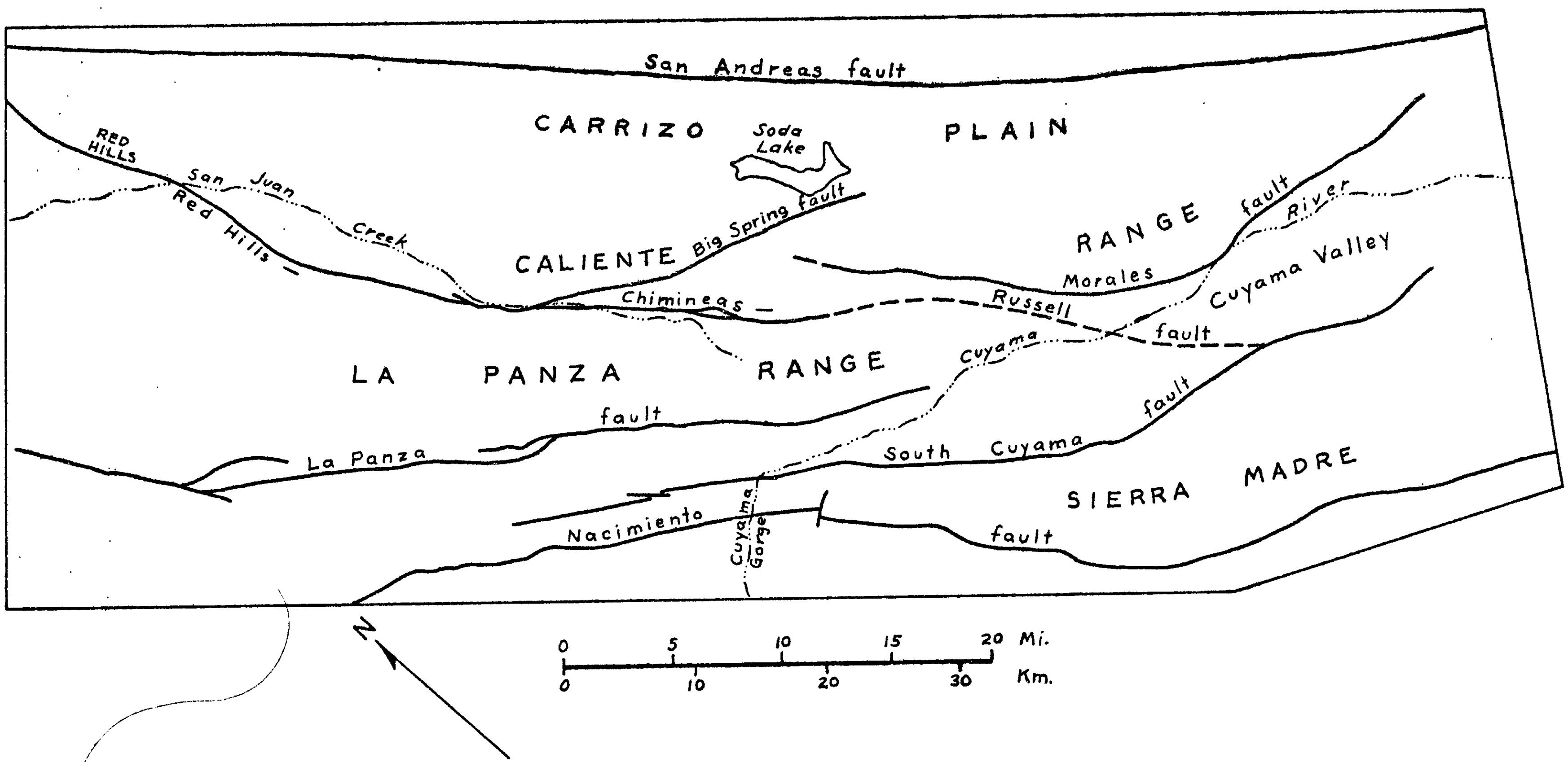

Figure 1.--Index map showing pertinent geographic names and major faults in area of plate 1.

Methods

The method of approach to this problem was basically sedimentological. The aim was to determine paleogeography from an understanding of sediment provenance and dispersal systems, changes in depositional environments with basin evolution, and the inter-relationships of sedimentation and tectonics.

Existing geologic maps were used to a large extent. Plate 1 is a geologic map of the region which includes the study area. It was compiled, with slight modification, from a preliminary version of Dibblee's (1974) regional map at the same scale, Vedder and Repenning's (1965) map of the southeastern Caliente Range, and my own mapping of the northwestern Caliente Range.*

Approximately 50 localities in the continental Simmler Formation and 140 localities in the marine Vaqueros Formation were visited to make systematic observations of lithology and sedimentary structures, and to make measurements of paleocurrent indicators. At a number of localities rock samples were collected for petrologic study and fossils were collected where encountered, but no special effort was made to look for fossils. The localities were spaced as evenly as possible within the study area, but spacing was largely determined by distribution of outcrops.

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*The unnamed range of hills west and northwest of Soda Lake, which is separated from the La Panza Range by San Juan Creek and includes Hubbard Hill and Freeborn Mountain, will be referred to informally in this report as the northwestern Caliente Range.

Laboratory studies consisted mainly of modal analysis of sandstone samples by point-counting of thin-sections and statistical treatment of paleocurrent data. The sandstones proved to be nearly impossible to disaggregate without breaking larger grains and thus biasing the results toward the finer grain sizes. Therefore, grain size estimates were made by visual comparison, and no grain size analyses were made.

Acknowledgements

This report is an outgrowth of a U.S. Geological Survey subsurface study of the Carrizo Plain and Caliente, Temblor, and La Panza Ranges and vicinity conducted by H.C. Wagner, myself, and the late R.L. Pierce within the area of Dibblee's (1974) regional map. Well logs, core descriptions, and paleontologic reports used in that study, as well as in the subsurface portion of my work, were obtained through the cooperation of most of the oil companies that have operated in the study area, of several well log and service companies, and of the California Division of Oil and Gas. I would like to express my sincere appreciation to the officials of these organizations. Many of the ideas embodied in this report evolved from the subsurface work with Wagner and Pierce, to whom I am grateful.

T.W. Dibblee generously provided unpublished quadrangle mapping in the area, and D.C. Ross furnished mapping and other information on basement rock exposures. W.O. Addicott provided invaluable assistance in the form of identification and age assignment of megafossil collections; J.G. Vedder provided additional paleontologic and stratigraphic information from the southeastern Caliente Range. Ann Tipton Donnelly (of the University of California, Santa Barbara) and Jay Phillips (of the University of California, Berkeley) identified foraminiferal collections, and Jay Phillips generously provided additional stratigraphic information from his own study of the Caliente Mountain area. I would like to express my appreciation to Professors W.R. Dickinson, N.J. Silberling, and J.C. Ingle of Stanford University, and to my colleagues at the U.S. Geological Survey for the help and encouragement they have provided through innumerable discussions about various aspects of my study. I would also like to thank Professors Dickinson, Silberling, and Ingle for reading and commenting on the manuscript.

The U.S. Geological Survey has provided financial support and laboratory facilities, for which I am grateful. The preparation of thin-sections was financed, in part, by a grant from the Shell Companies Foundation, and the Stanford Geology Department provided funds for computer operations.

STRATIGRAPHY AND LITHOLOGY

General Considerations

Previous Work

Because of the nearly complete marine early Miocene through middle Miocene section in the Caliente Range and the variety of biofacies represented, much of the work to date has been on the biostratigraphy. The earliest significant contributions to the geology of the Caliente Range area were by Anderson and Martin (1914) and English (1916). Anderson and Martin mapped and briefly described the lower Miocene rocks of the "San Juan District" (the area along San Juan Creek and the northeast flank of the La Panza Range), which they correlated with the Temblor Group of the Temblor Range and the Kern River area east of Bakersfield. English mapped the areas around the west and south sides of Cuyama Valley and introduced some of the stratigraphic names that are in use today (e.g., Santa Margarita, Whiterock Bluff, Vaqueros).

The earliest biostratigraphic studies leading to attempts at zonation of the Miocene section using invertebrate megafossils were made by Loel and Corey (1932) and Eaton and others (1941). Loel and Corey made fairly extensive collections in the northwestern Caliente Range and the adjacent east flank of the La Panza Range. The work of Eaton and others centered on Caliente Mountain proper with additional collections from the areas around the Cuyama Valley. Dougherty (1940) made the first attempts at correlating mammalian faunas with the marine section by using the basalt flows in the middle Miocene on the north side of the Caliente Range for horizon markers.

Increased interest in the Cuyama Valley area, following the discovery of oil there in 1948, led to papers by Hill and others (1958) and Schwade and others (1958). Hill and others proposed stratigraphic names that are, with only slight revision, in use today (see next section). Schwade and others (1958) made regional correlations between the Caliente Range-Cuyama Valley area and the Salinas Valley, including the type area of the Vaqueros Formation, to the northwest.

J.G. Vedder and C.A. Repenning have made detailed maps and stratigraphic studies in the southeastern Caliente Range where there is a well exposed lateral transition in the Miocene section from continental facies through nearshore to offshore marine facies. Their work has resulted in a number of publications (Repenning and Vedder, 1961; Vedder and Repenning, 1965; Vedder, 1970, 1973) which have made valuable contributions to Miocene stratigraphy and have provided an excellent framework on which to base sedimentologic studies. In addition, Vedder (1968) provided detailed mapping of some of the Teritary rocks on the south side of Cuyama Valley, and Vedder and Brown (1968) discussed the Oligocene red beds exposed in the Cuyama Gorge. The most recent work was by Dibblee (1973, 1974), who provided a regional geologic map including the Carrizo Plain-Caliente Range-Cuyama Valley area, and a summary of regional stratigraphy.

Nomenclature

The units considered in this study were the middle Tertiary Simmler and Vaqueros Formations (fig. 2). The name Simmler was first proposed by Hill and others (1958) for the red to gray continental conglomerate, sandstone, and siltstone that unconformably overlies the Upper Cretaceous-lower Tertiary marine sequence of the Caliente and La Panza Ranges and Cuyama Valley area. The name was formally adopted by Dibblee (1973). A conglomerate facies of the Simmler Formation in the Cuyama Gorge was mapped as the Redrock Canyon Member of the Santa Margarita Formation by English (1916); as continental Vaqueros Formation by Eaton and others

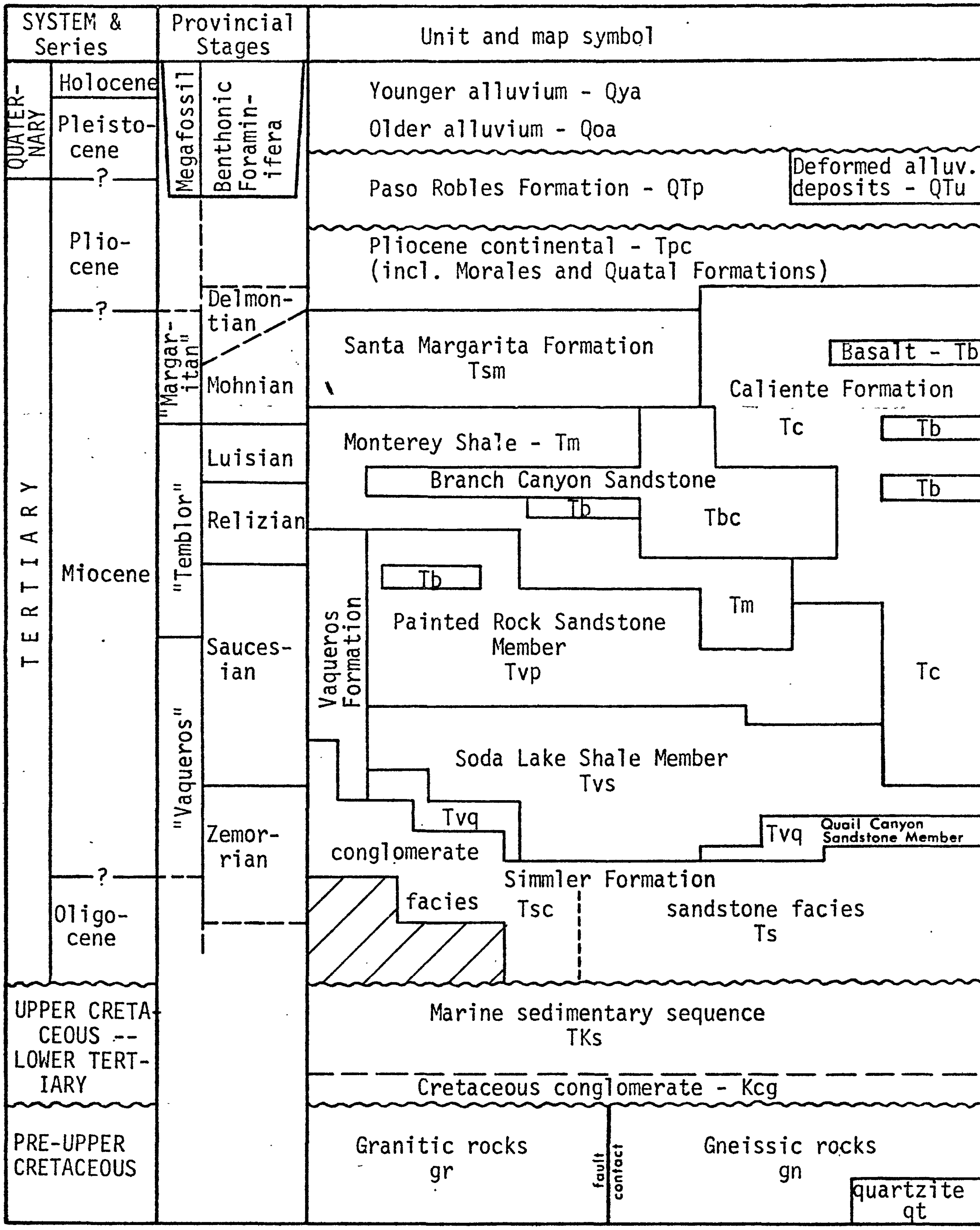


Figure 2.--Generalized chart of stratigraphic units in Caliente Range-Carrizo Plain area. Correlation of provincial megafaunal and foraminiferal stages after Addicott (1972) and Vedder (1973). Letter symbols same as symbols on plate 1 (geologic map).

(1941); as Sespe Formation by Clements (1950); and as Oligocene(?) red beds by Vedder and Brown (1968). It was referred to as the Simmler Formation by Hill and others (1958) and by Dibblee (1973, 1974).

The name Vaqueros was first used by Hamlin (1904) for sandstones along Vaqueros Creek on the west side of Salinas Valley near King City. The name was applied to strata in the Caliente Range-Cuyama Valley area by English (1916). Meanwhile, the name Temblor had been applied to marine lower Miocene rocks in the northwestern Caliente Range by Anderson and Martin (1914), and through the years both names have been used--generally in a time-stratigraphic sense by the earlier workers. Dibblee (1973) thoroughly reviews the usage of these names. Dickinson (1966, p. 711), in considering the Miocene nomenclature problem for the southern Diablo Range, proposed that "the best resolution of the dual usage now appears to be the recognition of a joint regional name, Vaqueros-Temblor, while freely mapping local members to develop stratigraphic details." Dibblee (1973, p. 16) proposed "that in all areas southwest of the San Andreas fault the name Vaqueros Formation be applied to this whole stratigraphic unit and that in areas northeast of this fault the name Temblor Formation be applied." Despite the arbitrary nature of the Dibblee proposal, it has practical advantages, and the use of the name Vaqueros in the Caliente Range area is consistent with recent practice (Hill and others, 1958; Vedder and Repenning, 1965; Vedder, 1970, Dibblee, 1973, 1974). Hill and others (1958) divided the Vaqueros Formation of the Caliente Range area into three members--a local basal sandstone called the Soda Lake Sandstone Member, the Soda Lake Shale Member, and the Painted Rock Sandstone Member. Dibblee (1973) renamed the basal sandstone the Quail Canyon Sandstone Member and formally adopted the other two names.

The names Vaqueros and Temblor, in addition to being formation names, are also applied to stages in the Pacific Coast megainvertebrate chronology (Weaver and others, 1944; Durham, 1954). As these megafaunal stages have been based on strata representing sublittoral environments, whereas the microfaunal stages of Kleinpell (1938) were based on bathyal facies, disagreement continues as to the exact correlation of the two chronologies. Similarly, there is disagreement on the assignment of Pacific Coast provincial stages to the standard European series. The Tertiary series, as used here, are defined in terms of the provincial megafaunal chronology. The megafaunal stages have never been formally defined, but in present usage the "Vaqueros Stage" is generally correlated with the upper part of the Zemorrian and lower part of the Saucesian Stages of Kleinpell (1938) and is considered to be early Miocene in age (Addicott, 1972; Vedder, 1973). The "Temblor Stage" is generally correlated with the upper part of the Saucesian, the Relizian, and the Luisian Stages and is considered to be middle Miocene in age (Addicott, 1972; Vedder, 1973).

Basement Complex

The Salinian block, the area of the California Coast Ranges bounded by the San Andreas and Nacimiento fault zones, is characterized by its basement complex of crystalline plutonic and metamorphic rocks. A recent reconnaissance study of the crystalline basement rocks of the Coast and Transverse Ranges by Ross (1972b) gives petrologic and chemical data on these rocks. The crystalline basement rocks of the study area are of two basic types--the granitic rocks of the La Panza Range, and the gneissic rocks of Red Hills and Barrett Ridge. The Red Hills-Chimineas-Russell fault trend forms the boundary between these two basement types (Ross, 1972b).

The large area of granitic rocks exposed at the northwest end of the La Panza Range is a homogeneous intrusive body of granodiorite to quartz monzonite (Ross, 1972b). This body is probably Early Cretaceous in age; a K-Ar date of about 80 m.y. may reflect a later event. The petrologically similar granitic rocks of the Gabilan Range, which may be comagmatic with the La Panza Range rocks (Ross, 1972b), have been dated by the Rb-Sr method at 109 ± 5 m.y. (Ross, 1972a). Small exposures of granitic rocks are located along San Juan Creek about midway between the large area of exposure in the La Panza Range to the northwest and the Barrett Ridge gneissic rocks to the southeast. These rocks are quartz monzonite similar to the La Panza Range rocks, but more felsic and with a higher proportion of K-feldspar. The La Panza Range and San Juan Creek rocks are probably part of the same granitic mass (Ross, 1972b).

The Barrett Ridge exposure of gneissic rocks lies along the northeast side of the Chimineas fault about 7 miles (11 km) west of Soda Lake. This exposure is dominantly gneiss with a small amount of quartzite (quartz schist) and an alaskite intrusive body at the southeastern end. The foliation in the gneiss strikes northwest to west and is truncated by the Chimineas fault, but a basement high extending eastward from the outcrop is approximately parallel to the foliation. Fault horses of marble are strung out along the Chimineas fault. The alaskite intrudes the gneiss, but much of it may have been sweated out of the granitic gneiss more or less in situ (Ross, 1972b). The basement exposures at Red Hills are mostly of a gneissic rock having a quartz diorite composition. Augen gneiss, biotite-rich gneiss, amphibolite, and very minor marble are also present, and the gneiss is intruded by pegmatite dikes and sills with abundant salmon-colored K-feldspar. The gneissic layering is not as well defined as at Barrett Ridge, and the gneiss grades into homogeneous granitic-looking rocks (Ross, 1972b). In the past, these gneissic rocks have not usually been differentiated from the La Panza granitic rocks and have been assigned the same general age. However, recent work by Kistler and others (1973) indicates quite high strontium isotope ratios in the gneissic rocks, which suggests correlation with similar gneissic terranes of Precambrian age in the Transverse Ranges.

Upper Cretaceous and Lower Tertiary Marine Sedimentary Sequence

The granitic and gneissic basement rocks are overlain by the Upper Cretaceous and lower Tertiary marine sedimentary sequence of Dibblee (1973). This thick, lithologically monotonous sequence is exposed over large areas of the La Panza Range and Sierra Madre. With the exception of a conglomerate unit at the base of the sequence in the La Panza Range, the sequence is not differentiated into lithostratigraphic units. It is composed of interbedded sandstone, shale or siltstone, and conglomerate. Chipping (1972a) has described most of these rocks as flysch and interpreted them as being composed principally of turbidites and fluxoturbidites; Dibblee (1973) interpreted parts as deltaic deposits. Fossils ranging in age from Late Cretaceous (Campanian to Maestrichtian) to middle Eocene have been found in various parts of the sequence. The Upper Cretaceous fossils occur mostly in the lowest part of the sequence in the northern La Panza Range, and where the sequence overlies the gneissic rocks of Barrett Ridge. Although several unnamed lithologic units were described by Chipping (1972a), their relative age remains uncertain. The exposure of this sequence in the southeastern Caliente Range was named the Pattiway Formation (Hill and others, 1958; Dibblee, 1973), and its age there has been established as Paleocene (Vedder and Repenning, 1965). This marine sequence is unconformably overlain by the continental Simmler Formation.

Simmler Formation

Lithology and Distribution

The continental Simmler Formation occupies a transitional position between lower Tertiary and upper Tertiary marine sequences. It consists of a sandstone facies and a conglomerate facies. The sandstone facies of the Simmler is exposed in the southeastern Caliente Range, the type area, and in the northwestern Caliente Range west of Soda Lake. The conglomerate facies of the Simmler is exposed at the southeastern end of the La Panza Range and in the Cuyama Gorge area at the west end of the Cuyama Valley. A lithologically similar unit, the Caliente Formation of Hill and others (1958) and Vedder (1968), occurs in the Santa Barbara Canyon area south of the Cuyama Valley. This unit was originally named the Pato Red Member of the Vaqueros Formation by English (1916), but it may be correlative with the Simmler Formation. The conglomerate facies also crops out in small isolated patches on the gneissic rocks northwest of the Chimineas fault and on the granodiorite on the northeast flank of the La Panza Range. Red beds referred to the conglomerate facies of the Simmler crop out at the north end of the La Panza Range (Dibblee, 1974) and in the Cuyama Badlands (southeast of the area shown on plate 1) (Hill and others, 1958).

Southeastern Caliente Range

A complete section of the sandstone facies of the Simmler Formation in the southeastern Caliente Range was designated as the type area by Hill and others (1958). The formation is about 3,100 feet (950 m) thick in this area. No type section was given, but Vedder and Repenning (1965) subdivided the Simmler in the type area into four lithologic units. Unit 1 (the lowest) is about 500 feet (185 m) thick and is mostly thin-to medium-bedded* fine- to medium-grained sandstone with some thin mudstone interbeds. It contains pebbly sandstone lenses near the base. Unit 2, which is estimated to be about 150 feet (45 m) thick, is composed of thin- to medium-bedded claystone, siltstone, and mudstone with thin fine-grained sandstone interbeds. It is generally poorly exposed because of the predominance of fine-grained strata. Unit 3 is composed of about 1,000 feet (305 m) of medium- to thick-bedded fine- to coarse-grained sandstone with thin claystone and mudstone interbeds. Unit 4, which is about 1,350 feet (410 m) thick in the type area, is the most extensive areally and is also the best exposed. It consists of interbedded thin to medium beds of claystone, siltstone and fine-grained sandstone, with subordinate amounts of thin- to thick-bedded fine- to very coarse-grained, locally pebbly sandstone. Sandstone beds throughout the formation are commonly lenticular.

Although the four units are recognizable in the field, the differences are often slight--especially between units 3 and 4--and there is much interfingering between units. Overall, the formation has the appearance of a monotonous sequence of interbedded sandstone and fine-grained rocks; the lithologic units differ primarily in relative proportion of coarser and finer material.

The coarsest sediment occurs near the base of unit 1 and in unit 4. In unit 4 the coarsest sediment occurs near the top, but there appears to be a trend toward coarser-grained sediment southeastward. Coarse sand and pebbles occur at scattered horizons throughout unit 4 in the easternmost exposures, but are restricted to the uppermost 125 feet (38 m)

*The bed thickness classification used here is: very thin, 1-10 cm; thin, 10-50 cm; medium, 50-150 cm; thick, 150-300 cm; very thick, >300 cm.

in the western area of exposure (plate 2). Bed thickness seems to be largely a function of grain size and no independent trends were observed.

Grain size differences are reflected in the colors. The sandstone is yellowish gray to pale olive to greenish gray. The fine-grained rocks are mostly grayish red or grayish olive to olive gray. The westernmost exposures of the Simmler (unit 4) are generally darker and of different hue. The sandstones are medium gray to dusky yellow green, and red hues (pale red to dusky red) are more common in the finer-grained rocks. From a distance, these rocks have an overall gray color.

Lithologic characters of the sandstone facies of the Simmler Formation are summarized in table 1. The number of features shown for each unit is largely a function of relative exposure, but some generalizations can be made. Planar stratification was the most commonly observed sedimentary structure in the Simmler Formation, although cross-bedding is locally abundant. Planar stratification (or flat-bedding) in sandstone is an upper flow regime structure and is generally associated with parting lineation (Allen, 1964a). The Simmler sandstone, however, is usually not flaggy, and bedding plane exposures are rare. Molds of desiccation cracks occur on the base of a few sandstone beds where they overlie claystone or mudstone (figs. 3 and 4). I found dish structures in one very thick medium-grained sandstone bed (fig. 5). This structure has previously been reported principally from turbidite and grain flow deposits (Wentworth, 1967; Stauffer, 1967; Chipping, 1972b). Medium-scale cross-bedding is mostly trough type; some apparently tabular planar sets are also present. Small-scale cross-bedding (ripple-drift lamination) is present in the finer sandstones (fig. 6). The rare trace fossils are mainly trails on bedding surfaces (fig. 7), but a few small

Table 1.--*Ltihologic characters of the Simmler Formation*

[C=common, X=present, R=rare]

	Southeastern Caliente Range				Northwestern Caliente Range
	Unit 1	Unit 2	Unit 3	Unit 4	
Cross-bedding* small scale (ripples)		X	R	X	R
medium scale	R	R	X	X	X-C
Planar stratification	X	C	C	C	C
Parting lineation	?	R	R	X	R
Channels			R	R	
Claystone clasts	X	R	X	X-C	X
Desiccation cracks				R	
Convolute lamination		R	R	R	R
Soft-sediment deformation				R	R
Dish structure				R	
Trace fossils			R	R	R
Carbonate concretions	R	R	R	R	X

*Magnitude of cross-bedding is based on set thickness--small scale, <5 cm; medium scale, 5-50 cm; large scale, >50 cm.

Figure 3.--Mold of desiccation cracks on base of sandstone. Simmler Formation, southeastern Caliente Range.

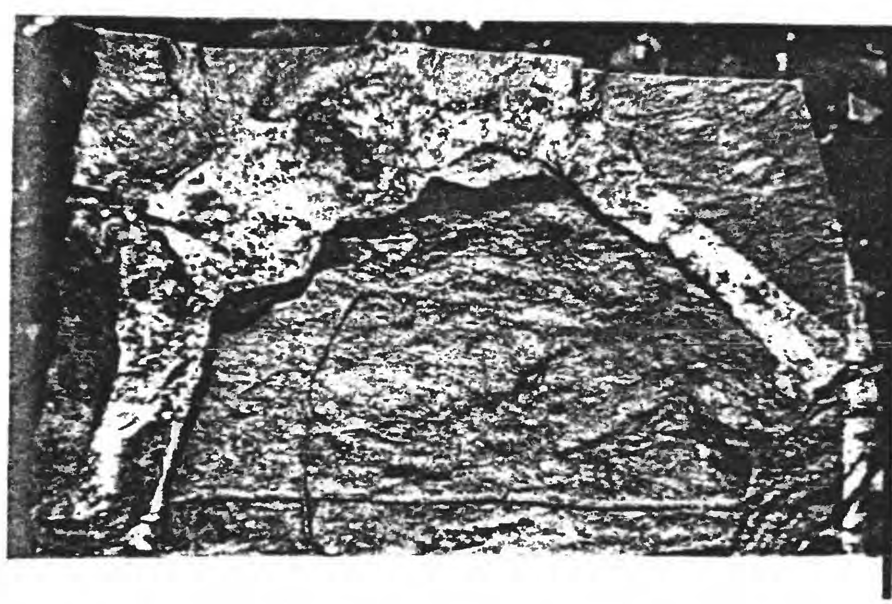


Figure 4.--Mold of desiccation polygon on base of sandstone. Note thin film of grayish-red mudstone adhering to sandstone with plant(?) impressions, and mudstone chips in sandstone filling of desiccation cracks. Simmler Formation, southeastern Caliente Range. Scale in millimeters.

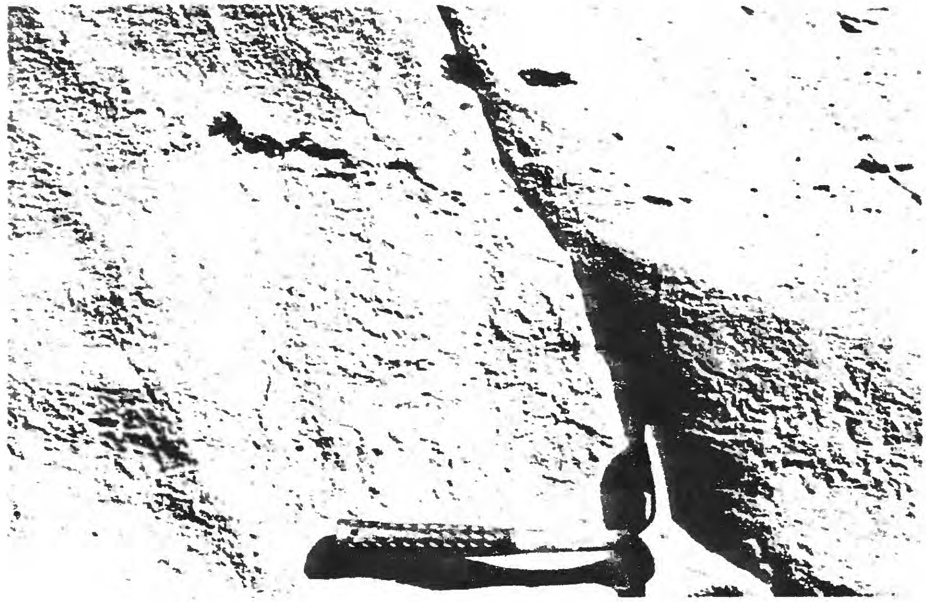


Figure 5.--Dish structures in lower part of very thick medium-grained sandstone bed. Simmler Formation, southeastern Caliente Range.

Figure 6.--Ripple-drift lamination in fine-grained sandstone overlain by medium-grained sandstone; thin layer of claystone at top. Simmler Formation, southeastern Caliente Range. Scale in millimeters.

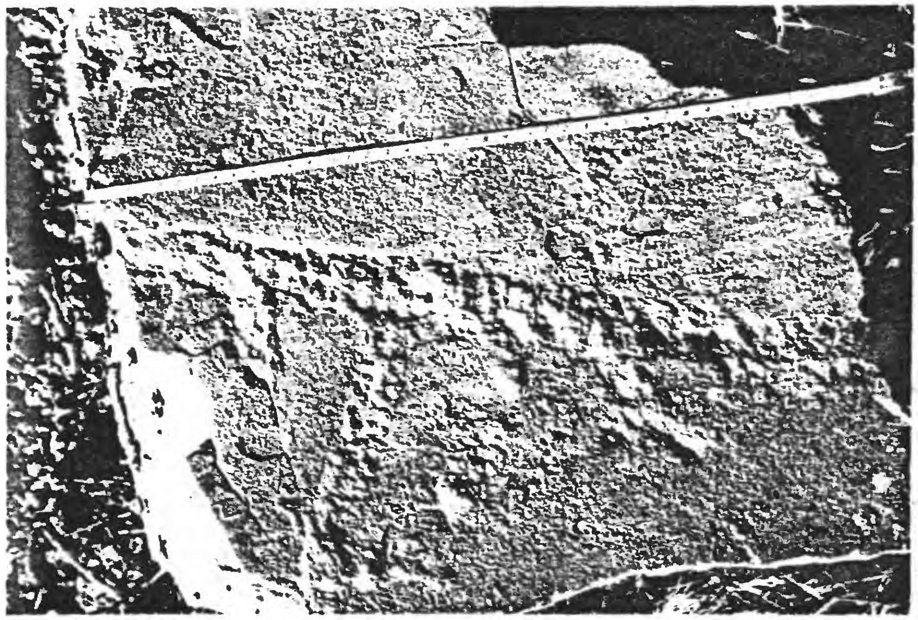


Figure 7.--Trail and vague parting lineation on bedding plane. Simmler Formation, southeastern Caliente Range. Numbered divisions on scale are centimeters.

Figure 9.--Thin laterally persistent concretionary layers in sandstone, at top of fining-upward cycle. Simmler Formation, northwestern Caliente Range.

vertical tubes probably represent invertebrate burrows.

Channel forms are rare (fig. 8), but nearly planar scoured surfaces at the base of sandstone beds are very common. These laterally persistent surfaces, which generally have only a few centimeters of relief, are usually overlain by sandstone containing reddish claystone or siltstone clasts and mark the base of fining-upward cycles. The cycles in the measured section of the upper part of unit 4 in the westernmost exposures (plate 2) average about 7.2 feet (2.2 m) thick for the most part, but increase in thickness near the top. The typical sequence begins with a scoured surface followed by sandstone grading up into siltstone or claystone, locally containing small carbonate concretions.

Northwestern Caliente Range

The Simmler Formation exposed in the core of an anticline west of Soda Lake is lithologically similar to the Simmler in the type area. The base is not exposed, but subsurface evidence (plate 3) suggests that the thickness is more than 3,000 feet (900 m) and may be more than 3,400 feet (1,050 m). Exposures are generally poor except for an erosional scarp about 2 miles (3.2 km) west of the north end of Soda Lake, where about half of the total thickness is continuously exposed.

The Simmler Formation at this exposure is composed of thin- to medium-bedded fine- to medium-grained sandstone with a few thin siltstone or claystone interbeds. The sandstone is generally light to medium gray or locally yellowish gray, and the siltstone is medium gray to light olive gray or grayish red. The average grain size of the sandstone in this area seems to be slightly less than the sandier parts of the section in the type area, but for sections of roughly equivalent grain size and bed thickness (plate 2), the sand-shale ratio is higher in the northwestern Caliente Range.

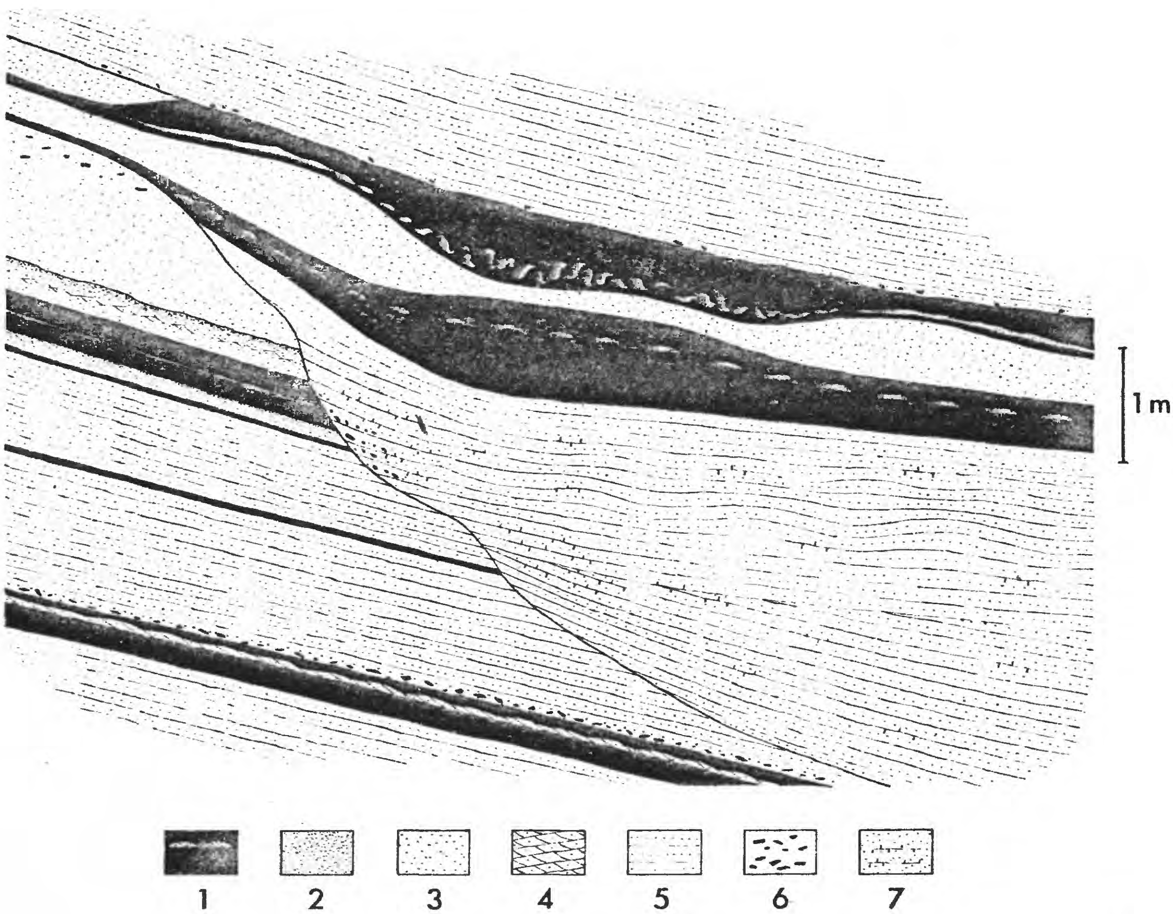


Figure 8.--Possible channel-fill deposit in Simmler Formation, southeastern Caliente Range. Lower part of channel filled with sand bar of bed-load material; upper part filled mainly with overbank material after channel was abandoned. Drawn from a photograph. Lithology: 1=claystone or mudstone with very fine-grained sandstone ripple forms; 2=very fine-grained silty sandstone to sandy siltstone; 3=fine- to medium-grained sandstone; 4=ripple-laminated sandstone; 5=flat-bedded sandstone; 6=claystone-mudstone pebbles; 7=calcareous sandstone.

The lithologic characters of the Simmler Formation in the northwestern Caliente Range are included in table 1. Both cross-bedding, mostly medium scale, and planar stratification are more common in the northwestern Caliente Range are as described for the type area.

The Simmler Formation of the northwestern Caliente Range was also deposited in fining-upward cycles like those of the type area. A measured section of a representative portion of the Simmler (plate 2) shows that, in addition to the higher sand-shale ratio, the cycles average about 8.9 feet (2.7 m) thick. Another difference is that small carbonate concretions at the top of the cycles occur in the siltstone or claystone in the southeastern Caliente Range, but form zones of thin concretionary layers in the sandstone in the northwestern Caliente Range. These concretionary zones at the top of the cycles are locally quite conspicuous in outcrop (fig. 9).

La Panza Range and Cuyama Gorge

The conglomerate facies of the Simmler Formation crops out in a long northwest-trending belt just northeast of the Nacimiento fault in the lower Cuyama Valley and Cuyama Gorge area. Another extensive exposure of this facies is several miles to the east in the southeastern end of the La Panza Range. In the Cuyama Gorge area the Simmler is up to 3,400 feet (1,050 m) thick (Dibblee, 1973). It appears to thin northward or northeastward in the La Panza Range, partly by intertonguing with the overlying Vaqueros Formation. It pinches out against a local high of Upper Cretaceous-lower Tertiary sequence at the south end of the La Panza Range and is overlapped by Vaqueros. Both Simmler and Vaqueros are absent at a small inlier of Tertiary rocks in the western Cuyama Valley.

The small isolated patches of conglomerate facies overlying basement rocks in the La Panza Range vary from zero to a few hundred feet thick within very short distances along strike. The exposure overlying the gneiss of the Barrett Ridge area thins from a maximum of 650 feet (200 m) to zero within 2,000 feet (610 m) laterally and is overlapped by the Vaqueros Formation.

The conglomerate facies of the Simmler Formation in the La Panza Range and Cuyama Gorge area consists of pale-red-brown to grayish-red or dark-reddish-brown conglomerate, muddy conglomerate and pebbly to sandy mudstone with interbedded lenses of yellowish-gray to pale-yellowish-brown fine- to coarse-grained sandstone and pebbly sandstone (fig. 10). Adjacent to the Nacimiento fault in the vicinity of the Cuyama Gorge, the Simmler is principally a breccia of large sandstone clasts and lesser amounts of reworked pebbles and cobbles (Vedder and Brown, 1968). The bedding is lenticular throughout the area and channels are present locally; the conglomerate is generally thick bedded, the sandstone thin to medium bedded, and the mudstone thin bedded. There is no noticeable trend in bed thickness independent of grain size, but there is a northeasterly decrease in clast size (principally in sandstone clasts), amount of coarse material, content of sandstone clasts, and degree of angularity of sandstone clasts (Vedder and Brown, 1968).

The conglomerate of the Simmler Formation commonly exhibits a striking pebble imbrication due to the abundant tabular-shaped sandstone clasts. Planar stratification is common in the sandstone, and some thin sandstone or muddy sandstone beds are graded. Desiccation cracks are presently locally on the top of mudstone beds.

The two small, isolated patches of the conglomerate facies of the

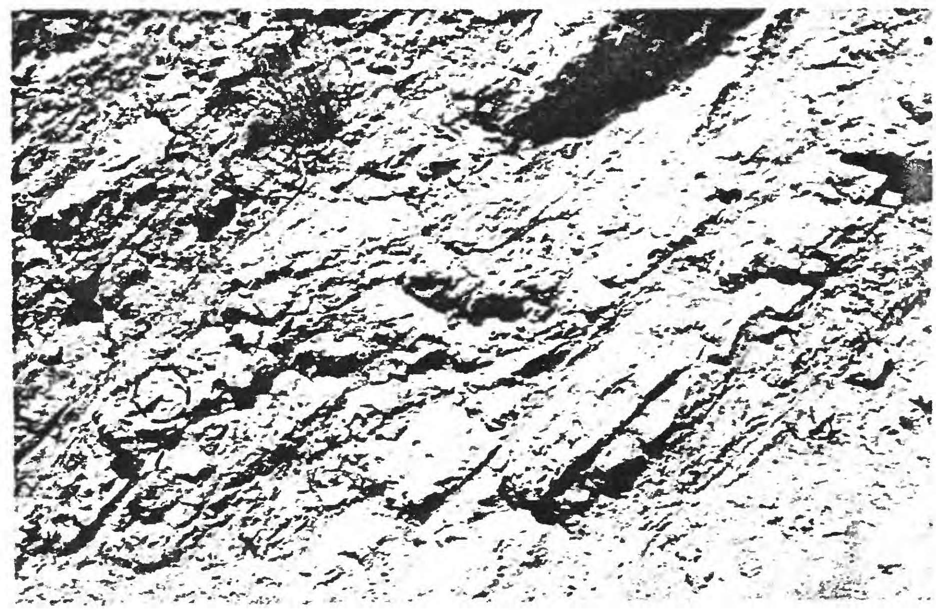


Figure 10.--Interbedded grayish-red pebbly mudstone, pebbly sandstone, and muddy conglomerate. Conglomerate facies of Simmler Formation, Cuyama Gorge. Hammer (in circle) for scale.

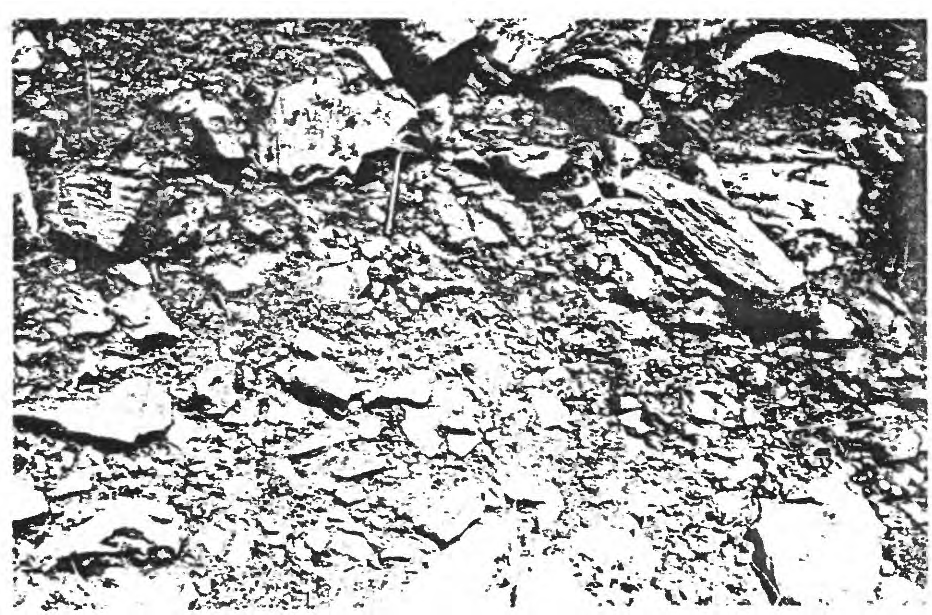


Figure 11.--Very poorly sorted rubble of angular gneiss clasts in red-brown muddy matrix. Conglomerate facies of Simmler Formation, Barrett Ridge.

Simmler Formation overlying the basement rocks of the La Panza Range are composed mostly of red-brown to grayish-red muddy breccia. The material is very poorly sorted and poorly bedded, and grades down into a rubble zone near the base (fig. 11). Lenses of light-gray pebbly sandstone to sandy breccia are present locally.

Cuyama Badlands area

Red beds referred to the conglomerate facies of the Simmler Formation are also exposed in the Cuyama Badlands and the upper Santiago Creek drainage southeast of the area shown on plate 1 (Hill and others, 1958). These red beds consist of interbedded medium- to coarse-grained sandstone and pebble to boulder conglomerate (fig. 12). A minor amount of mudstone is also present, but much of the conglomerate has a muddy matrix. The sandstone and conglomerate with a sandy matrix is generally light gray or yellowish gray; mudstone and muddy conglomerate are red brown. Both sandstone and conglomerate are poorly sorted. The bedding, particularly of the conglomerate, is lenticular and channels are present locally. Pebble imbrication is present in the conglomerates, but it is not as obvious as in the conglomerates of the Cuyama Gorge area. There is a westward decrease in clast size and degree of angularity (Frakes, 1959).

The Caliente Formation of the Santa Barbara Canyon area south of the Cuyama Valley most closely resembles the Simmler Formation of the Cuyama Gorge area, rather than either Caliente or Simmler in the Cuyama Badlands. Like the Simmler of the Cuyama Gorge area, it becomes coarser southwestward and adjacent to the Ozena fault is essentially a breccia and conglomerate of large sandstone clasts derived from the underlying Eocene strata (Vedder, 1968).

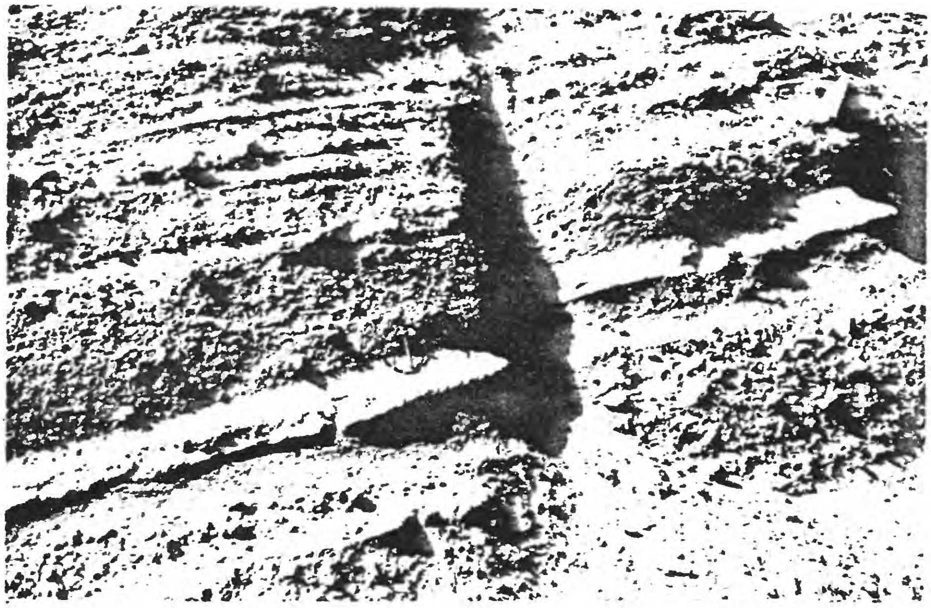


Figure 12.--Interbedded sandy to muddy conglomerate, sandstone, and red-brown mudstone. Conglomerate facies of Simmler Formation, Cuyama Badlands. Hammer (in circle) for scale.

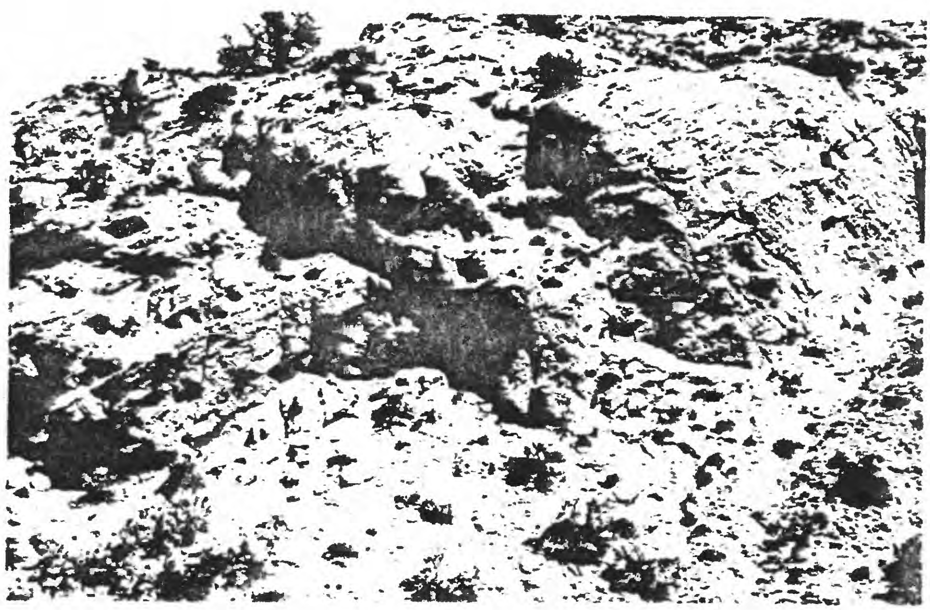


Figure 13.--Type locality of Quail Canyon Sandstone Member of Vaqueros Formation. Medium- to thick-bedded fine- to medium-grained sandstone with medium- and large-scale cross-bedding.

Subsurface

Many wells have been drilled for oil in the area extending from the western Cuyama Valley into the northwestern Caliente Range. These wells provide additional information on the distribution of the Simmler Formation. Correlation sections (plate 3) through Simmler and Vaqueros Formations northeast and southwest of the Morales and Big Spring thrust faults, using both subsurface and outcrop information, show striking differences of thickness and facies for the Simmler and Vaqueros Formations. The sandstone facies of the Simmler is restricted to the area northeast of these major faults, and the conglomerate facies is apparently restricted to the area southwest of the faults, with the exception of a few tongues of breccia in the lower part of the Simmler in a well just east of Freeborn Mountain (plate 3, well 7).

Thickness control is limited, but the thickness seems to be fairly uniform throughout the area. The 3,100 feet (950 m) in the type area is probably a minimum; a maximum for the southeastern Caliente Range may be about 3,800 feet (1,150 m) (Vedder, 1973). The thickness in the northwestern Caliente Range is 3,400 feet (1,050 m) or more. By contrast, the conglomerate facies southwest of the thrust faults shows a discontinuous distribution with thicknesses ranging from zero to over 600 feet (180 m). A subcrop map under the Vaqueros Formation (plate 4) shows that the apparent patchy distribution of the conglomerate facies in outcrop (plate 1) and in longitudinal section (plate 3, B-B') is misleading. These occurrences are, in reality, accumulations in re-entrants in the older terrain, as was suggested by Cross (1962).

The lithology in the subsurface seems to be essentially the same as in outcrop. The Simmler conglomerate is recognized by its muddy matrix and reddish color, although greens and grays are present. The sandy facies is composed of interbedded light-gray sandstone, red-brown or green siltstone and red-brown or green claystone.

Age and Correlation

Fossil remains are very rare in the Simmler Formation. Some smooth-shelled ostracods were reported from the lower part of the formation in a well near the south end of Soda Lake (plate 3, well 12), and rare plant remains and very rare bone fragments have been found in outcrop. The age assignment of the formation, therefore, must be based on its relationship to overlying and underlying formations.

In the southeastern Caliente Range and in the Cuyama Badlands, the Simmler Formation overlies the Paleocene Pattiway Formation of Hill and others (1958) with slight angular unconformity. The base of the Simmler is not exposed in the northwestern Caliente Range, but subsurface evidence indicates that it overlies granitic or gneissic basement. In the Cuyama Gorge and La Panza Range area, the conglomerate facies of the Simmler unconformably overlies the Upper Cretaceous-lower Tertiary sequence. There is an angular discordance of up to 75° between the Simmler and the underlying strata along the Nacimiento fault. This discordance decreases away from the fault, and the units are approximately concordant a short distance northeastward (Vedder and Brown, 1968). The discordance between the two units in the La Panza Range varies from near zero to about 40°. Lower to middle Eocene fossils occur in the Upper Cretaceous-lower Tertiary sequence about 4,500 feet (1,350 m) stratigraphically below the base of the Simmler in the Sierra Madre (Vedder and Brown, 1968).

The Simmler Formation is conformably overlain by the Vaqueros

Formation throughout the study area. As the base of the Vaqueros marks the beginning of a marine transgression, the age of the Simmler-Vaqueros contact is evidently time transgressive. Indeed, in the La Panza Range there is an observable intertonguing of Simmler and Vaqueros. The Vaqueros also overlaps Simmler onto the underlying Upper Cretaceous-lower Tertiary sequence or onto basement rocks. The evidence bearing on the age of the Vaqueros will be discussed later on, but the base of the formation is considered to be within the provincial early Miocene. The possible age range for the Simmler, then, is late Eocene to early Miocene, and it is assigned a tentative age of Oligocene to early Miocene.

The exact relationship of the sandstone and conglomerate facies of the Simmler Formation cannot be seen, but the stratigraphic position of both facies--conformably below the Vaqueros Formation--suggests that they are lateral equivalents. The situation is complicated by subsequent fault displacements which have separated formerly contiguous areas and juxtaposed others. However, the intertonguing of Simmler and Vaqueros in the southeastern La Panza Range, and the presence of conglomeratic material in the Quail Canyon Sandstone Member of the Vaqueros Formation in the subsurface of the Morales and Taylor Canyon Oil Field area indicates that part of the Simmler conglomerate facies is equivalent to part of the Vaqueros. The apparent correlation of the relatively thin Vaqueros in the southeastern La Panza Range with the upper part of the Painted Rock Sandstone Member in the central Caliente Range, discussed in a later section, suggests that the conglomerate facies of the Simmler in the La Panza Range is equivalent to a large part of the Vaqueros Formation in the Caliente Range.

The Caliente Formation of the Santa Barbara Canyon area occurs in the same stratigraphic position as the Simmler Formation elsewhere, but contains sparse vertebrate fossils of Arikareean age (early Miocene of the North American land mammal chronology), which suggests correlation with the lower part of the Caliente Formation of the southeastern Caliente Range (Vedder, 1968). The Caliente of the Santa Barbara Canyon area is conformably overlain by Vaqueros Formation containing megafossils of provincial early Miocene age (Vedder, 1968). Because of its stratigraphic position below the Vaqueros, which makes it "pre-transgression" in age, it will be included with the Simmler for the purposes of this study. It is probably equivalent to the Simmler conglomerate facies of the Cuyama Gorge area, and its Arikareean age further supports the apparent "younger" age of the Simmler conglomerate facies.

The Simmler Formation can be correlated with other red-bed units in California that occupy transitional positions between lower Tertiary and upper Tertiary marine sequences. Such red-bed units are present throughout southern California. In areas where red beds are not present, unconformities in the equivalent stratigraphic position provide further evidence of a widespread regression. The Plush Ranch Formation of the Lockwood Valley area is shown by Carman (1964) to be of late Eocene through early Miocene age on the basis of its stratigraphic relations. Although outcrops of the Plush Ranch and the Simmler Formation in the Cuyama Badlands are separated by only a few miles, they are lithologically dissimilar and are probably correlative units deposited in separate basins. The Simmler Formation is probably correlative with the Sespe Formation of the Ventura basin, Pine Mountain area, and Santa Ynez Mountains where that unit overlies upper Eocene strata and is overlain by the lower Miocene Vaqueros Formation (Bailey, 1947). The Simmler is probably also correlative with the Berry Formation of the Salinas Valley which underlies the type Vaqueros Formation (Thorup, 1943), and may be in part correlative with the Lospe Formation of the Santa Maria basin and the Vasquez Formation of the Soledad basin (Oakeshott and others, 1954).

Probably correlative rocks in the Temblor Range immediately northeast of the San Andreas fault are included in the lower part of the marine Temblor Formation of late Oligocene to middle Miocene age (Addicott, 1972). Lower Oligocene rocks are missing. Farther southeast, the Eocene Tejon Formation is overlain by the Oligocene San Emigdio and Pleito Formations. These marine units intertongue eastward with the continental Tecuya Formation (Nilsen and others, 1973), but close to the San Andreas fault they are entirely marine.

Vaqueros Formation

Lithology and Distribution

The Vaqueros Formation is extensively exposed throughout the Caliente Range where it has been subdivided into the Quail Canyon Sandstone, Soda Lake Shale and Painted Rock Sandstone Members (Hill and others, 1958; Dibblee, 1973). It ranges in thickness from about 1,000 feet (300 m) at the extreme southeast end of the range to more than 7,000 feet (2,150 m), and possibly as much as 8,700 feet (2,650 m), in the northwestern part of the range (plate 3). In the La Panza Range the Vaqueros is much thinner, is mostly sandstone, and is therefore not differentiated into members. It probably correlates with the Painted Rock Sandstone Member, but it is lithologically distinct and will be described separately. Thin undivided Vaqueros is also present in the Sierra Madre south of the Cuyama Valley, but the Vaqueros is absent in the southwestern Cuyama Valley. A marine unit about 800 feet (250 m) thick, which was referred to the Soda Lake Shale Member by Hill and others (1958), is exposed in the Cuyama Badlands southeast of the area shown on plate 1. This unit is reported to unconformably overlie the conglomerate facies of the Simmler Formation (Sierveld, 1957; Frakes, 1959) and grades up into the continental Caliente Formation. Thin tongues of marine sandstone in the Caliente Formation encountered in a well about 4.5 miles (7 km) east of the Red Hills is tentatively correlated with the Vaqueros Formation. The presence of Vaqueros strata in these two areas gives some indication of the extent of the basin.

As with the two facies of the Simmler Formation, the Big Spring and Morales thrust faults separate Vaqueros sections that are strikingly different.

Subsurface studies show that the Vaqueros southwest of the thrust faults can be subdivided into members, down-dip from the La Panza Range outcrops, but it is very much thinner than the Vaqueros northeast of the faults (plate 3). The Vaqueros Formation is conformably overlain by the Monterey Shale except in the southeasternmost Caliente Range, where the upper part intertongues eastward into the Caliente Formation.

Quail Canyon Sandstone Member

The lowest member of the Vaqueros Formation is the Quail Canyon Sandstone Member. This unit is exposed only in the southeastern Caliente Range, but it is more widespread in the subsurface. The type section of the Quail Canyon Sandstone Member is in the southeastern Caliente Range (plate 3, locality 23), where it is about 300 feet (91 m) thick (Hill and others, 1958). The member thins westward and is 70 feet (21 m) thick (plate 2) about 3 miles (5 km) west of the type section; it is about 450 feet (135 m) thick 2 miles (3.2 km) east of the type section.

The contact with the underlying Simmler Formation is conformable; there is no angular discordance and no evidence of erosion at the contact. A measured section across the contact is shown on plate 2. A marked color change at the contact helps to differentiate the two units.

The Quail Canyon Sandstone Member is composed of light-gray to grayish-yellow or yellowish-gray fine- to medium-grained thick-bedded sandstone (fig. 13). It locally contains thin pebbly sandstone or conglomerate lenses or thin lenses of coarse sandstone with abundant megafossil fragments. It also commonly contains medium- and large-scale cross-bedding--mostly tabular planar sets, although medium-scale trough sets are also present (fig. 14). Planar stratification is locally very common.

Figure 14.--Large-scale cross-bedding in fine- to medium-grained sandstone. Quail Canyon Sandstone Member of Vaqueros Formation.

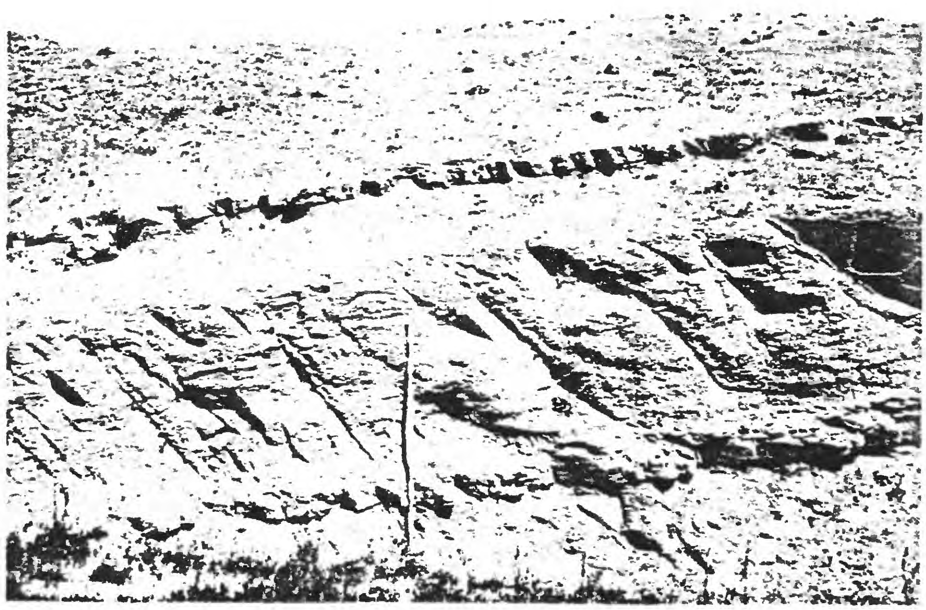


Figure 15.--Thin fine-grained sandstone beds in siltstone of Soda Lake Shale Member of Vaqueros Formation, northwestern Caliente Range. Rod is 150 cm long.

In the subsurface, the Quail Canyon Sandstone Member is fairly widespread, although it is absent in what were apparently the deepest parts of the basin and over the basement high east of the Barrett Ridge gneiss outcrops. The member is thicker and more widespread south of the basement high, however, than north of the high. In the area southwest of the Morales-Big Spring thrust faults (plate 3, B-B'), in the vicinity of the Taylor Canyon Oil Field, it reaches a thickness of 300 to 350 feet (91-105 m). It is apparently absent under much of the Cuyama Valley, except in the vicinity of the South Cuyama Oil Field. The member is thin or absent north of the Barrett Ridge basement high. Northeast of the thrust faults (plate 3, A-A'), the Quail Canyon Sandstone Member is present at the northwest and southeast ends of the basin and on the south side of the basement high, where it reaches its maximum known thickness of about 760 feet (230 m).

The lithology of the Quail Canyon Sandstone Member in the subsurface is similar to the outcrop lithology. It is generally composed of light-gray to greenish-gray fine- to medium-grained calcareous sandstone and locally contains thin interbeds of dark-gray or dark-brown siltstone similar to the siltstone of the Soda Lake Shale Member (see below). Pebble conglomerate to pebbly medium- to coarse-grained sandstone associated with abundant glauconite occurs, usually in the lower part of the member, just south of the basement high and through the area of the Taylor Canyon and Morales Oil Fields (plate 3, B-B'). The Quail Canyon Sandstone Member, locally called the "Colgrove Sand," is the oil sand of these fields.

Soda Lake Shale Member

The Soda Lake Shale Member of the Vaqueros Formation is exposed in the northwestern and southeastern Caliente Range and in a small area on the lower slopes of Caliente Mountain. At its type section in the northwestern Caliente Range, where it directly overlies the Simmler Formation, it is 1,230 feet (375 m) thick (plate 3, locality 20). It is over 2,200 feet (670 m) thick in a well 10 miles (16 km) northwest of the type section (plate 3, well 3), and about 900 feet (285 m) thick a few miles southeast of the type section. The member has a maximum thickness of about 2,000 feet (600 m) in the southeastern Caliente Range. It thins eastward, partly by intertonguing with the overlying Painted Rock Sandstone Member, and grades laterally into sandstone at its easternmost exposure in the Caliente Range.

Subsurface evidence shows that the member is generally between 1,800 and 2,000 feet (550 and 610 m) thick northeast of the Big Spring and Morales thrust faults (plate 3, A-A') and between zero and about 650 feet (200 m) thick southwest of the faults (plate 3, B-B'). It apparently thins over the basement high northeast of the thrusts and is overlapped by the Painted Rock Sandstone Member where it pinches out against the basement high southwest of the thrusts. The Soda Lake Shale Member in the Cuyama Badlands, like that in the southeastern Caliente Range, grades laterally into sandstone--southward or southeastward in this case.

The area of exposure of the Soda Lake Shale Member in the northwestern Caliente Range is one of generally subdued topography, but creek and gully bottoms afford good outcrops (fig. 15). The member in the type section consists mostly of hard dark-gray to grayish-brown siltstone and platy shale with thin and very thin sandstone interbeds. The shale contains some layers of carbonate concretions (mostly dolomite) 30 to

100 cm thick. The fine- to very fine-grained sandstone beds range from 3 to 30 cm thick. They are not obviously graded, but have sharp bases, and the top grades into the overlying siltstone. Some beds have planar lamination in the upper part or throughout; small-scale cross-bedding is very rare. For beds that can be described by the Bouma sequence; AE, BE, and ABE are the most common sequences. Horizontal burrows or casts of trails are very common on the base of the beds; the only other sole markings are rare load casts. Bioturbation may account for many of the beds that have apparently massive ungraded lower parts.

Parting lineation occurs at places on weathered outcrops, but the sandstone is generally too well cemented to part along the lamination. There is also a minor amount of medium- to thick-bedded medium- to coarse-grained sandstone in lenticular bodies up to 60 feet (18 m) thick. The member includes a 40-foot- (12-m-)thick unit of thin-bedded cherty shale and chert with siliceous shale partings which occurs 380 feet (116 m) above the base in the type section. It is dark gray or black, but is usually weathered to yellowish gray or grayish yellow. This unit may be as much as 150 to 200 feet (45 to 60 m) thick a few miles west of the type section. About 50 feet (15 m) of platy siliceous shale occurs 520 feet (159 m) above the cherty shale unit in the type section. The typical lithology of shale with thin sandstone interbeds is present a few feet above the Simmler Formation, although the proportion of sandstone is higher near the base. There is no basal sandstone in the area of the type section, except for local thin very poorly sorted calcareous sandstone beds.

The Soda Lake Shale Member grades up into the Painted Rock Sandstone Member, and coarser sandstone increases in amount near the top of the

Soda Lake Shale Member. One sandstone body near the top of the member a few miles west of the type section (fig. 16) consists of very coarse-grained sandstone containing large angular clasts of siltstone, which is overlain by a "chaotic" bed about 13 feet (4 m) thick composed of clasts of siltstone and sandstone up to several feet long in a coarse sandy matrix. The top of the "chaotic" bed is marked by large contorted clasts and slabs of interbedded fine-grained sandstone and siltstone.

In the southeastern Caliente Range, the Soda Lake Shale Member is mostly brownish-gray to dark greenish-gray clayey to sandy siltstone with thin fine-grained sandstone interbeds. The thin sandstone beds are like those described from the type section. The member includes two tongues of platy concretionary clayey siltstone and silty shale which thin eastward from a maximum exposed thickness of 150 to 200 feet (45 to 60 m) and pinch out a few miles east of the westernmost exposures (Vedder and Repenning, 1965). The lower of the two tongues includes a thin lens of cherty shale ("chert unit" of Hill and others, 1958). The middle part of the Soda Lake Shale Member, between the two tongues of platy shale, contains a considerable amount of fine-grained sandstone and lenticular bodies of coarser-grained sandstone. The sandy middle part and the upper part of the member grade southeastward into the Painted Rock Sandstone Member.

These sandstone lenses in the middle part of the member have their maximum development a few miles east of Padrones Canyon (Vedder and Repenning, 1965), where one or more of them have maximum thicknesses of about 100 feet (30 m). In the area of their maximum development, the lenses are composed of thin- to very thick-bedded fine- to coarse-grained sandstone, commonly in graded beds. The grain size and bed thickness

Figure 16.--Submarine debris-flow deposit near top of Soda Lake Shale Member of Vaqueros Formation, northwestern Caliente Range. "Chaotic" bed (A) of siltstone and sandstone clasts in sandy matrix with large slab of interbedded sandstone and siltstone at top (B). Note bedding at right end of large slab is bent upward. Rod is 150 cm long.

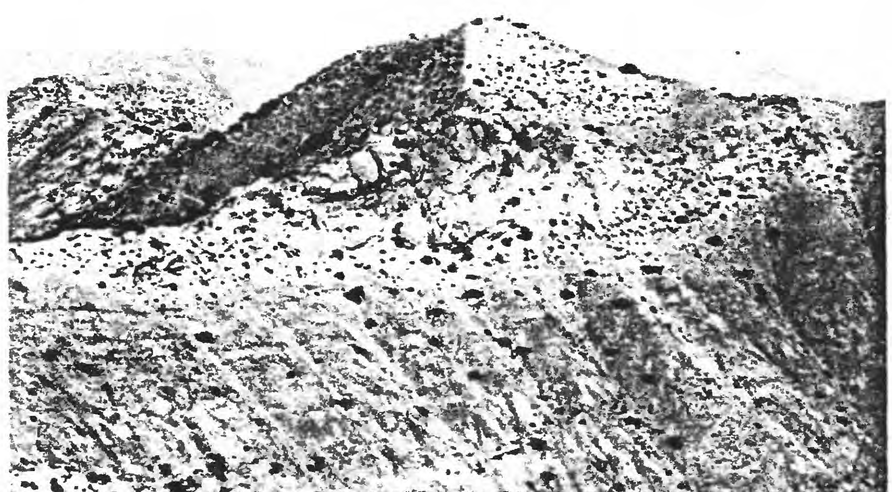


Figure 17.--Giant foreset bedding in sandstone lens in Soda Lake Shale Member of Vaqueros Formation. Lens is 50 to 60 feet (15-18 m) thick at thickest point.

generally increases upward and one lens is composed essentially of an amalgamated sequence of graded beds which are medium- to coarse-grained and 5 to 25 cm thick at the base of the lens, and coarse-grained to pebbly and several meters thick at the top of the lens. The bedding within this sandstone lens is inclined relative to the base of the lens and to bedding in the enclosing siltstones, forming giant foresets (fig. 17). The lenses thin eastward and westward. In the Padrones Canyon area (plate 3, locality 22), sandstone bodies in the equivalent stratigraphic position fill small channels in the interbedded siltstone and fine-grained sandstone. The channel fill is generally structureless thick-bedded fine- to coarse-grained poorly sorted sandstone containing large and small siltstone clasts. The sandstone bodies at places have a disrupted or deformed internal structure resulting from penecontemporaneous soft-sediment deformation.

The Soda Lake Shale Member in the subsurface is very similar to the type section. It is usually described as hard dark-brown to black siltstone or shale with a few thin well-cemented sandstone beds. Fish scales or other fish remains are locally common. The sandy middle part of the member in the southeastern Caliente Range may be unique, although there seems to be more sandstone than normal in the very thick section at the northwest end of the basin (plate 3, well 3).

The Soda Lake Shale Member in the Cuyama Badlands area is mostly light-gray to light-brown sandy siltstone with scattered carbonate concretions. Southward, the siltstone grades into sandstone, and there is up to 250 feet (75 m) of medium- to coarse-grained sandstone at the base and 150 feet (45 m) of fine- to coarse-grained sandstone at the top (Frakes, 1959).

Painted Rock Sandstone Member

The Painted Rock Sandstone Member of the Vaqueros Formation is exposed in three principal areas--the southeastern Caliente Range, the central Caliente Range, and the northwestern Caliente Range. At the type section on Caliente Mountain (plate 3, locality 21), it is about 5,400 feet (1,650 m) thick (Hill and others, 1958). It thins eastward, partly by intertonguing with the overlying Caliente Formation, to 500 feet (150 m) or less at the southeastern end of the Caliente Range. Subsurface evidence indicates that the member thins northwestward to about 3,900 feet (1,200 m) several miles northwest of Caliente Mountain and then thickens again to 6,500 feet (2,000 m) or more near Hubbard Hill in the northwestern Caliente Range (plate 3, well 5). Subsurface information also serves to contrast the thickness of the Painted Rock Sandstone Member southwest of the Morales-Big Spring thrust faults with the juxtaposed section northeast of the faults. The most direct contrast can be made in the northwestern Caliente Range where the section northeast of (or above) the Big Spring thrust fault is nearly 4½ times thicker than the section southwest of (or below) the thrust (plate 3). Southwest of the thrusts, the member thins southeastward to only about 330 feet (100 m) over the basement high east of the Barrett Ridge gneiss outcrops. The Quail Canyon Sandstone and Soda Lake Shale Members are absent over the high, and the Painted Rock Sandstone Member directly overlies basement rocks. Farther southeast, the member thins from about 950 feet (290 m) in the Morales Oil Field area to about 530 feet (160 m) in the South Cuyama Oil Field area. There is a strong contrast here also between the section in the oil field areas southwest of the Morales thrust fault and that in the vicinity of Caliente Mountain northeast of the fault.

The Painted Rock Sandstone Member in the southeastern Caliente Range consists of large lenticular bodies of medium- to very thick-bedded fine- to coarse-grained pale-greenish-gray to yellowish-gray sandstone alternating with poorly exposed thinner units of poorly bedded greenish-gray to brownish-gray siltstone, sandy siltstone, and silty very fine-grained sandstone. Sandstone in the lowest few hundred feet of the member in the Padrones Canyon area (plate 3, locality 22) is mostly medium-bedded with siltstone interbeds (fig. 18); the sandstone beds are commonly graded. In most of the remainder of the member in this area, thick- to very thick-bedded sandstone is more common, siltstone partings or interbeds are usually absent, and the sandstone beds locally seem to be amalgamated but are less commonly graded. The coarser-grained sandstones commonly contain dispersed, poorly sorted pebbles and cobbles (fig. 19). Cut-and-fill structures are common at the base of thick conglomeratic sandstone beds (fig. 20), and larger channel-fill deposits similar to those in the underlying Soda Lake Shale Member occur near the base of the member.

The sandstone in the uppermost few hundred feet of the Painted Rock Sandstone Member in the Padrones Canyon area is commonly laminated and well sorted. The sandstone is less pebbly than the underlying beds, and the pebbles are segregated into lenses or laterally continuous bands, rather than being dispersed (fig. 21). At places these sandstone beds display low-angle medium-scale wedge(?) planar sets, or isolated sets of medium-scale trough cross-bedding; cut-and-fill structures also occur locally. Thin tongues of dusky-red and greenish-olive claystone occur in the uppermost part of the member in the Padrones Canyon area.

Figure 18.--Thin- to medium-bedded sandstone with thin siltstone interbeds in lower part of Painted Rock Sandstone Member, southeastern Caliente Range. Note penecontemporaneous slump block.

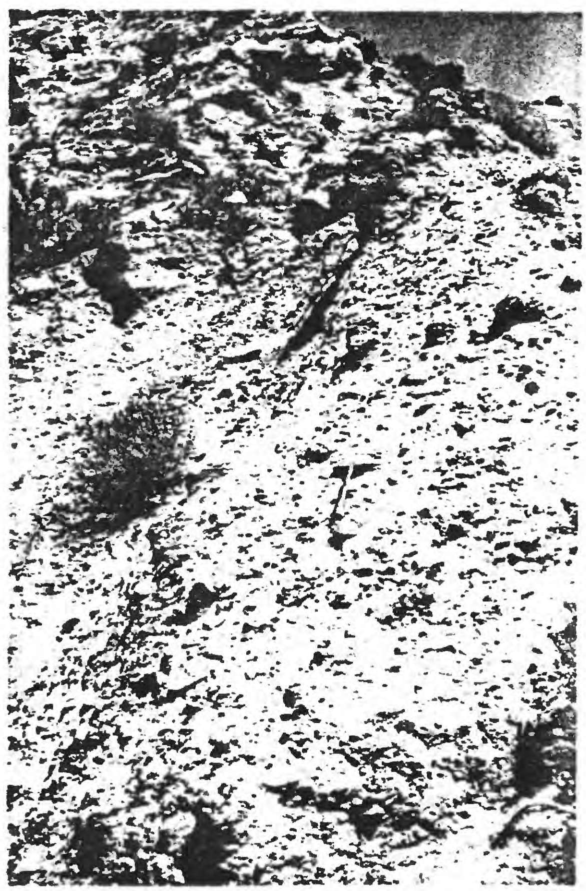


Figure 19.--Very thick disorganized conglomeratic sandstone bed overlain by sequence of thin graded beds. Note dispersed nature of pebbles and cobbles in sandstone and lack of stratification or fabric. Painted Rock Sandstone Member of Vaqueros Formation, southeastern Caliente Range.

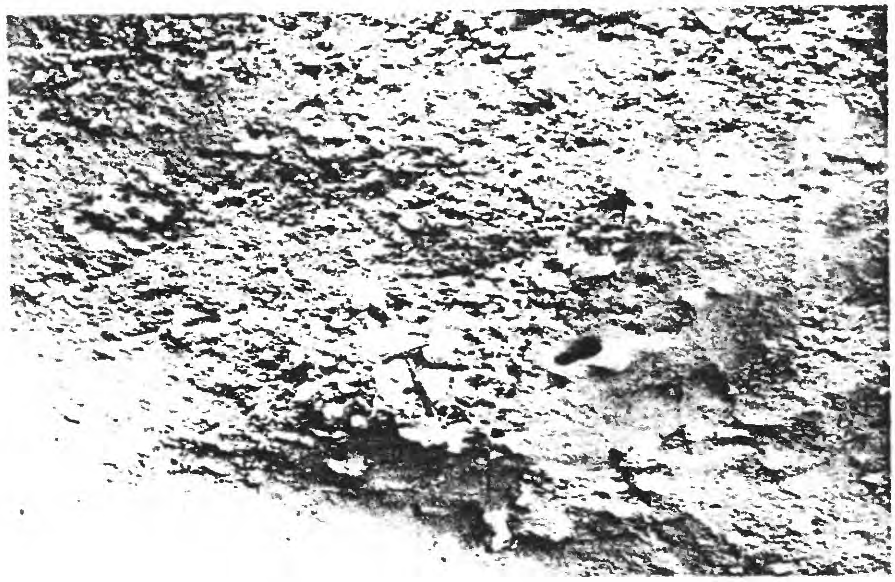


Figure 20.--Cut-and-fill structure at base of very thick graded conglomeratic sandstone bed. Note vague stratification. Painted Rock Sandstone Member of Vaqueros Formation, southeastern Caliente Range.

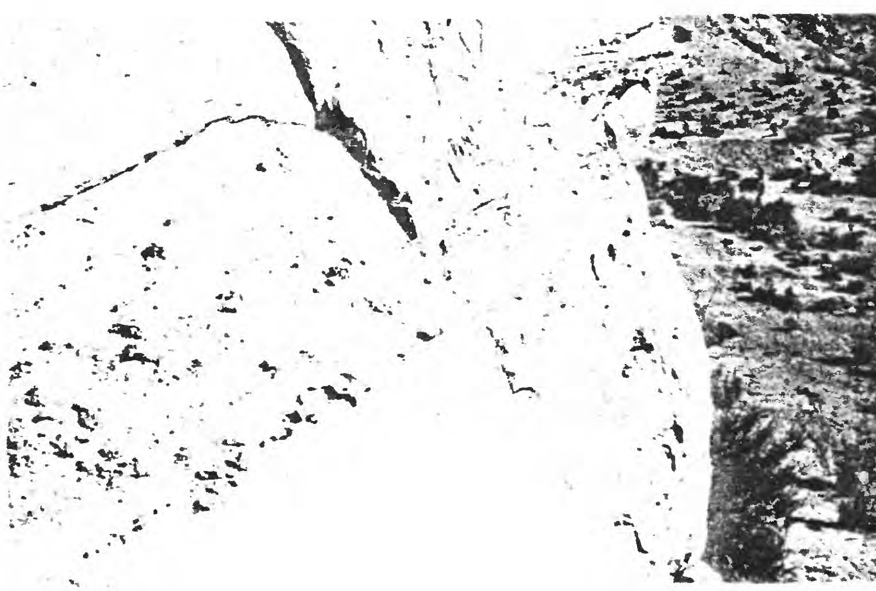


Figure 21.--Medium-grained planar-stratified sandstone overlain by pebbly coarse-grained sandstone with pebbles segregated into thin laterally persistent bands. Note low-angle inclined-bedding at top-right. Uppermost part of Painted Rock Sandstone Member of Vaqueros Formation, southeastern Caliente Range.

These claystones tongue out westward and grade eastward into the lower part of the continental Caliente Formation (Vedder, 1970).

A few miles east of Padrones Canyon, the Painted Rock Sandstone Member is lithologically most like the uppermost few hundred feet in the Padrones Canyon area. A few graded beds are present near the base, but the very thick-bedded conglomeratic structureless sandstone common in Padrones Canyon is not present. Farther east in the vicinity of Quail Canyon (plate 3, locality 23), the lithology seems to be much like the uppermost part in Padrones Canyon except that mollusks are locally common. Fossils are very sparse in the Padrones Canyon area and are present mainly in the siltstone between sandstone bodies.

The Painted Rock Sandstone Member in the central Caliente Range differs significantly from that in the southeastern Caliente Range. The whole section is finer grained. Some coarse-grained pebbly sandstone occurs in the lower part, but the sandstone is predominantly fine to medium grained, and there is a higher proportion of siltstone to silty very fine-grained sandstone. As in the southeastern Caliente Range, bodies of medium- to very thick-bedded sandstone alternate with units of siltstone to silty sandstone, but the bedding is more even and laterally persistent, and sandstone units can be traced for miles (fig. 22; and figs. 5 and 6 of Eaton and others, 1941). The upper part of the member in the central Caliente Range intertongues southwestward with the lower part of the Monterey Shale, and the member is finer grained and thinner bedded on the southwest side of the range. Megafossils (mollusks and echinoids) are locally common throughout the member in this area.

The Painted Rock Sandstone Member in the northwestern Caliente

Figure 22.--Part of type section of Painted Rock Sandstone Member of Vaqueros Formation on south side of Caliente Mountain. Looking southeast over southeastern Caliente Range.

Figure 23.--Very thick bed of conglomeratic very coarse-grained sandstone with dispersed poorly-sorted pebbles and cobbles. Dark concretion at top-right is elongated paralled to bedding, but no other indication of internal organization. Painted Rock Sandstone Member of Vaqueros Formation, northwestern Caliente Range.

Range is lithologically more similar to that in the southeastern Caliente Range than to that in the central Caliente Range, but again there are significant differences. It is composed principally of medium- to very thick-bedded medium- to very coarse-grained pale-greenish-yellow to yellowish-gray or very pale-orange to grayish-orange sandstone. The coarse- to very coarse-grained sandstone commonly contains dispersed pebbles, cobbles or, rarely, small boulders (fig. 23). The bedding is lenticular and small channels or cut-and-fill structures are common (fig. 24). The sandstone seems to occur in larger lenticular bodies, as in the southeastern Caliente Range, but the alternation of coarse and fine units is not as obvious because of the extreme lenticularity. Subsurface evidence indicates that the finer-grained interbeds make up 15-20% of the member and range from a few feet up to 75 to 100 feet (23-30 m) thick. They are composed chiefly of sandy siltstone and silty fine- to very fine-grained sandstone. The bedding in the uppermost 1,000 to 1,500 feet (300 to 460 m) is thinner and more regular, and thin concretionary layers with abundant megafossils are more common. Fossils are generally rare but occur at scattered localities throughout the member in this area. Large pieces of silicified wood or plant impressions (fig. 25) occur at a few places in the upper part of the member. One silicified log measured 9 m long by 30 cm in diameter.

Table 2 shows some of the lithologic characters of the Painted Rock Sandstone Member in its three areas of exposure, and points up some of the differences and similarities between areas. Medium- and large-scale cross-bedding in the southeastern Caliente Range is restricted to solitary medium-scale sets. In a few places these occur

Table 2.--*Lithologic characters of the Painted Rock Member of the Vaqueros Formation*

[C=common, X-present, R=rare, vR=very rare]

	Southeastern Caliente Range	Central Caliente Range	Northwestern Caliente Range
Cross-bedding* small scale (ripples)	vR	R	vR
large and medium scale	vR	X	C
Planar stratification	C	X	C
Graded bedding	X		
Cut-and-fill structures	C	vR	C
Irregular or lenticular bedding	C	R	C
Amalgamated beds	R		vR
Shale clasts	R		R
Trace fossils	vR	X	R
Invertebrate megafossils	R	X	X
Silicified wood or plant material		vR	vR

*Magnitude of cross-bedding is based on set thickness--small scale, <5 cm; medium scale, 5-50 cm; large scale, >50 cm.

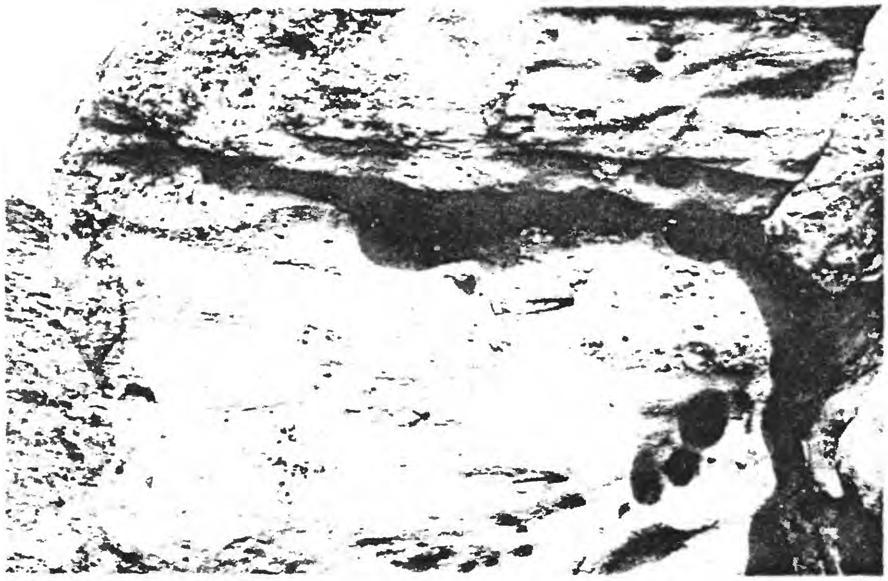


Figure 24.--Cut-and-fill structure in coarse- to very coarse-grained sandstone; pebbles concentrated in lower part of fill. Note planar stratification in underlying sandstone. Painted Rock Sandstone Member of Vaqueros Formation, northwestern Caliente Range.

Figure 25.--Impression of tree bark(?) (about 1 m long) on base of very thick coarse-grained sandstone bed. Note burrows to left of bark impression. Painted Rock Sandstone Member of Vaqueros Formation, northwestern Caliente Range.

at the base of graded beds. Cross-bedding is more common in the central Caliente Range and a few large-scale solitary sets are present. Most medium- and large-scale cross-bedding is in tabular(?) planar sets, but medium-scale trough sets are present. In the northwestern Caliente Range, cross-bedding is common and large scale is more abundant than medium scale. The large-scale cross-bedding is in solitary, apparently tabular planar sets (figs. 26, 27); the medium-scale cross-bedding is mostly trough type, solitary and grouped sets, although some solitary tabular planar sets are present. Small-scale cross-bedding (ripple lamination) occurs principally in the poorly exposed fine-grained parts of the member throughout the Caliente Range and consequently may be more abundant than indicated in the table.

An unusual example of cross-bedding is exposed at "The Painted Rock," the isolated outcrop of Painted Rock Sandstone Member on the Carrizo Plain 5 miles (8 km) south of Soda Lake that derives its name from Indian pictographs and from which the member derives its name. The outcrop, which is more than 30 feet (9 m) high, is largely composed of one giant set of cross-beds in coarse-grained sandstone (fig. 28). The overlying beds have been removed by erosion so that the shape of the set cannot be determined, but the base is approximately planar.

Planar stratification is the most common sedimentary structure in the Painted Rock Sandstone Member. There are two basic types represented. In the most common type, the stratification is defined by simple textural or compositional differences. In very fine- to medium-grained sandstone, the difference is primarily compositional; quartz-feldspar sand laminae alternate with very thin even mica-rich laminae. Where this is associated with parting lineation, it probably represents upper flow regime conditions.

Figure 26.--Large-scale cross-bedding (2 sets) overlain by vaguely stratified conglomeratic sandstone. Painted Rock Sandstone Member of Vaqueros Formation, northwestern Caliente Range.

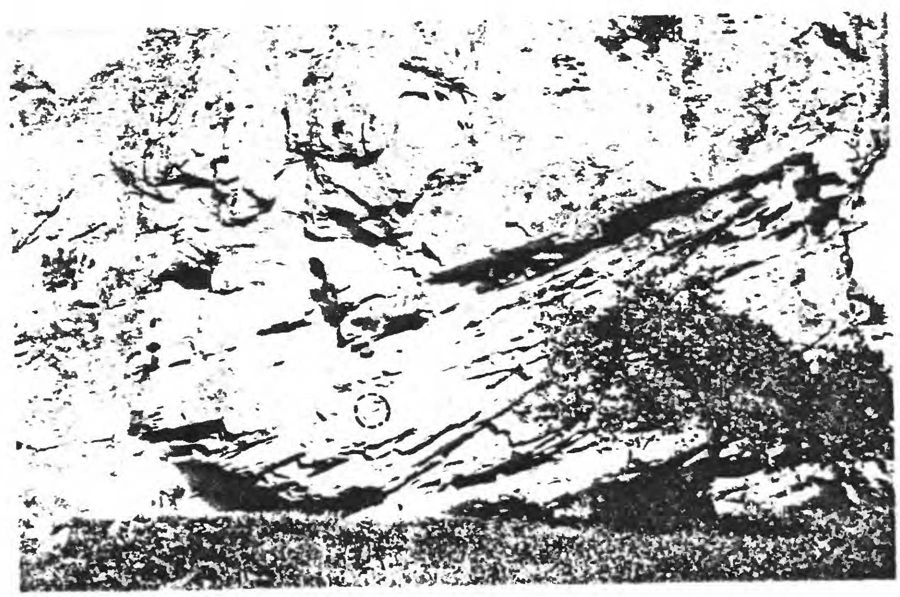


Figure 27.--Large-scale cross-bedding in medium-grained sandstone (set about 150 cm thick). Upper part of outcrop is very coarse-grained pebbly sandstone channeled into well-bedded medium-grained sandstone. Channel axis is approximately parallel to near face of outcrop. Painted Rock Sandstone Member of Vaqueros Formation, northwestern Caliente Range.

Figure 28.--Very large-scale cross-bedding at "The Painted Rock" on the Carrizo Plain. Dashed line indicates base of set and is parallel to bedding at base of outcrop. Everything above line is part of cross-bedding set. Painted Rock Sandstone Member Vaqueros Formation.

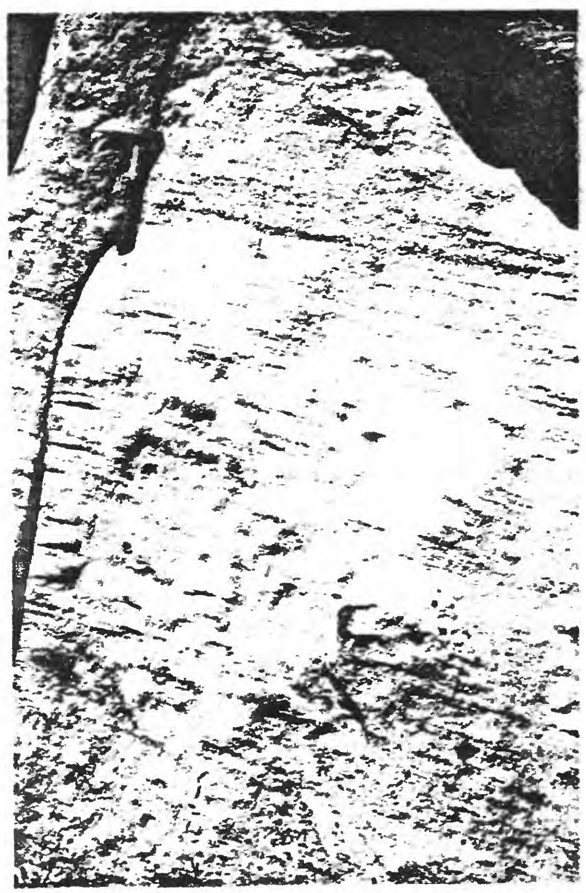


Figure 29.--Planar-stratified coarse- to very coarse-grained sandstone. Laminae defined entirely by textural differences. Painted Rock Sandstone Member of Vaqueros Formation, northwestern Caliente Range.

In coarse- to very coarse-grained sandstone, the difference is primarily textural; coarse sand layers alternate with very coarse sand (fig. 29). Sandstone with this rather crude lamination or bedding shows little tendency to part along the bedding. It may represent lower flow regime plane-bed conditions (Allen, 1970a, fig. 2.6). The other basic type is characterized by reverse grading--fine at the base and coarse at the top. The fine layer may be enriched in heavy mineral content. This latter type is restricted to the uppermost part of the member in the southeastern Caliente Range.

Most of the graded beds in the southeastern Caliente Range can be described by the Bouma sequence. AB sequences are most common; ABC or ABCD sequences are also present but are very rare. Many of the thicker conglomeratic sandstone beds are also graded but are structureless. These beds appear to exhibit the coarse-tail grading of Middleton (1967), in which only the coarsest percentiles (the pebbles and cobbles) show the grading. A few of the thick conglomeratic sandstone beds also have a thin reverse-graded division at the base.

The most common trace fossils in the Painted Rock Sandstone Member are vertical cylindrical burrows 2 to 3 cm in diameter and about 15-20 cm long that occur in fine- or medium-grained sandstone. There are also a very few U-shaped burrows. Another interesting but very rare type of burrow consists of many closely spaced and intertwined tubes in fine-grained sandstone. The tubes, about 3 to 4 mm in diameter, are outlined by mica (fig. 30).

Undivided Vaqueros Formation

Relatively thin undivided Vaqueros Formation crops out along the northeast flank of the La Panza Range, at the southeast end of the

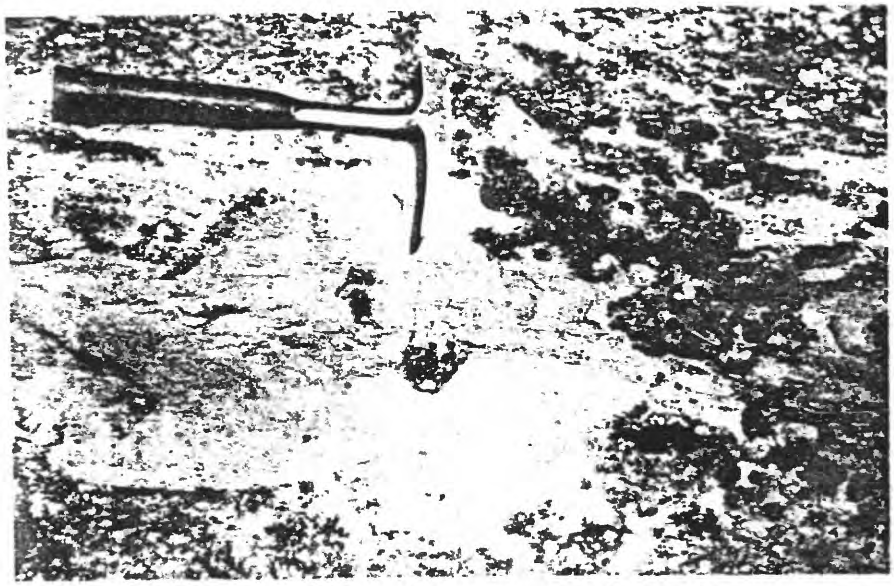


Figure 30.--Closely spaced small burrows in laminated fine-grained sandstone. Painted Rock Sandstone Member of Vaqueros Formation, northwestern Caliente Range.

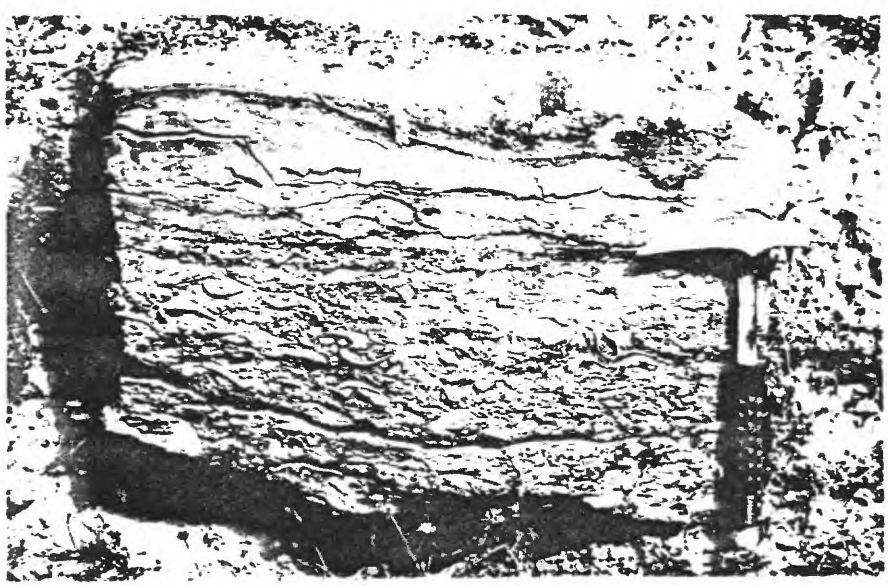


Figure 31.--Concentration of mollusks in thin concretionary layer. Vaqueros Formation, La Panza Range.

La Panza Range, and in the Sierra Madre south of the Cuyama Valley. The Vaqueros in the La Panza Range varies in thickness along strike from about 200 to 1,600 feet (60 to 490 m); this variation reflects the topography of the underlying surface prior to the transgression. The section overlying the gneiss northeast of the Chimineas fault thins southeastward from a maximum of 1,620 feet (494 m) to about 400 feet (120 m) in a distance of about 7 miles (11 km). This is the surface expression of the thinning over the basement high in the subsurface just to the east (plate 3).

At the southeast end of the La Panza Range, where the Vaqueros Formation conformably overlies the conglomerate facies of the Simmler Formation, the Vaqueros varies from zero to about 250 feet (75 m) thick. The lowest part of the Vaqueros intertongues with the upper part of the Simmler, and the Vaqueros is locally overlapped by the Monterey Shale. From zero to 600 feet (185 m) of Vaqueros is exposed in the Sierra Madre (Vedder, 1968).

The Vaqueros Formation on the northeast flank of the La Panza Range is composed chiefly of medium-bedded or indistinctly-bedded, grayish-yellow to yellowish-gray fine- and medium-grained sandstone. In general, the formation in this area is coarse grained and pebbly at the base and gets fine upward, with increasing amounts of interbedded siltstone. There is, however, considerable variation along strike depending on the nature of the underlying surface. The Vaqueros tends to be coarsest where it is overlying granitic or gneissic basement rocks, and in such places it may have a few meters of sandy conglomerate at the base. The Vaqueros overlying the Upper Cretaceous-lower Tertiary sequence is generally finer grained with only a few pebbles or scattered cobbles at the base.

Megafossils are commonly concentrated in well-cemented layers, which in very fine-grained sandstone and siltstone form darker colored concretionary layers (fig. 31). Barnacles, ostreids, and pectinids preferentially occur in coarse-grained or pebbly sand, and layers of coarse- to very coarse-grained sandstone with abundant barnacle plates are common in the Vaqueros overlying granitic or gneissic basement rocks. Overlying the Barrett Ridge gneiss exposure, the lower part of the Vaqueros locally becomes a sandy to pebbly fossiliferous limestone composed mostly of barnacle fragments.

The Vaqueros Formation has a thin claystone unit at the base where it overlies the patch of Simmler Formation about 6 miles (10 km) northwest of Hubbard Hill. This very poorly exposed claystone is up to 120 feet (37 m) thick and is marked by a deep clayey soil and thin platy crystalline limestone beds. A similar and possibly correlative unit occurs about 42 feet (13 m) above the base of the Vaqueros overlying the Simmler at the northwest end of the Barrett Ridge gneiss exposure. In the Barrett Ridge area, the formation also includes a thin lens of volcanic rocks which does not crop out but is marked by a band of reddish soil containing fragments of vesicular basaltic rocks.

The Vaqueros Formation overlying the patch of Simmler Formation at the northwest end of the Barrett Ridge gneiss exposure is the thickest undivided Vaqueros in the area (1,620 feet or 494 m). It has many features in common with the Painted Rock Sandstone Member north of the nearby Big Spring thrust fault, notably thick-bedded medium- to coarse-grained sandstone beds with large-scale cross-bedding and "partings" of intensively burrowed fine-grained silty sandstone (fig. 32). Lithologically,

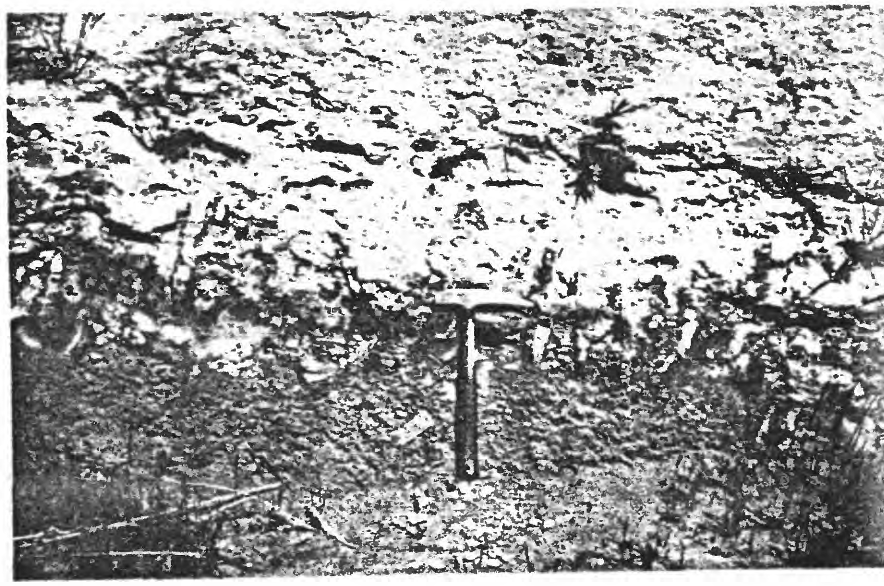


Figure 32.--Burrows in upper part of medium-grained muddy sandstone. Overlain by medium- to coarse-grained sandstone. Vaqueros Formation, La Panza Range.

Figure 33.--Large-scale cross-bedding in medium- to coarse-grained sandstone. Hammer (in circle) for scale. Vaqueros Formation, southeastern La Panza Range.

this exposure seems to be intermediate between the very thin undivided Vaqueros in the La Panza Range and the very thick Vaqueros of the Hubbard Hill-Freeborn Mountain area.

The Vaqueros Formation at the southeast end of the La Panza Range is similar to the exposures along the northeast flank. It is predominantly composed of indistinctly-bedded or medium-bedded fine-grained sandstone and locally contains pebbles and cobbles reworked from the underlying conglomerate facies of the Simmler Formation. At one exposure, coarse-grained fossiliferous sandstone at the base of the Vaqueros can be traced laterally into red conglomerate and sandstone of the underlying Simmler Formation.

The cross-bedding in the Vaqueros Formation of the La Panza Range (table 3) is mostly medium-scale trough and tabular planar types, usually in grouped sets. Large-scale cross-bedding is also present locally in grouped trough sets or solitary tabular(?) planar sets (fig. 33). The same type of trace fossils described for the Painted Rock Sandstone Member also occur in the undivided Vaqueros (figs. 30, 32), but they are more common because of the predominant fine grain size. In addition, there are a few invertebrate escape structures in laminated fine-grained sandstone. A few outcrops of apparently massive sandstone with a knobby appearance to the weathered surface may also represent a type of intensive burrowing. The abundance of structureless sandstone in this part of the formation suggests that bioturbation may have been an important process.

The Vaqueros Formation of the Santa Barbara Canyon area in the Sierra Madre is described by Vedder (1968). It consists of thick-bedded fine- to very coarse-grained and locally pebbly sandstone with some

Table 3.--*Lithologic characters of the undivided Vaqueros Formation*

[C=common, X=present, R=rare, vR=very rare]

	West flank La Panza Range	Southern La Panza Range
Cross-bedding*		
small scale (ripples)	vR	vR
large and medium scale	X	X
Planar stratification	X	R
Cut-and-fill structures	vR	vR
Irregular or lenticular bedding	R	R
Trace fossils	C	R
Plant material	vR	
Invertebrate megafossils	C	R

*Magnitude of cross-bedding is based on set thickness--small scale, <5 cm; medium scale, 5-50 cm; large scale, >50 cm.

cross-bedding. It contains lenses of pebble-cobble conglomerate, beds of concretionary silty fine-grained sandstone, and local interbeds of clayey to sandy siltstone. Tongues of red and greenish-gray mudstone and claystone containing irregular very thin white cherty limestone beds are also present. The base is locally marked by a water-laid tuff.

Age and Correlation

The best information on the age of the Vaqueros Formation in the study area comes from the southeastern Caliente Range. Repenning and Vedder (1961) and Vedder (1973) show that the Miocene marine section in the vicinity of Caliente Mountain intertongues southeastward into the continental Caliente Formation in such a way that foraminiferal and invertebrate megafossil assemblages in the marine rocks and vertebrate assemblages in the continental rocks can be fairly precisely correlated. The correlation of foraminiferal, molluscan, and mammalian sequences based on the stratigraphic relations in the southeastern Caliente Range is shown by Vedder (1973). In the Vaqueros Formation, the Quail Canyon Sandstone and Painted Rock Sandstone Members contain mollusks indicative of the "Vaqueros Stage," provincial lower Miocene, and the Soda Lake Shale Member contains Zemorrian and Saucesian foraminiferal assemblages and "Vaqueros age" mollusks (Repenning and Vedder, 1961; Vedder and Repenning, 1965). The coeval portion of the Caliente Formation contains vertebrate remains of Arikareean age in the North American provincial mammalian chronology (Repenning and Vedder, 1961; Vedder and Repenning, 1965).

Eaton and others (1941) originally placed the upper part of what is now the Painted Rock Sandstone Member of the Vaqueros Formation in the vicinity of Caliente Mountain in the "Temblor Stage." The entire

Vaqueros Formation in the southeastern Caliente Range, including the Caliente Mountain area, is now considered to be within the "Vaqueros Stage" (Repenning and Vedder, 1961; Vedder, 1973).

No stratigraphic studies have been made in the northwestern Caliente Range and La Panza Range since that of Loel and Corey (1932). They reported both "Vaqueros" and "Temblor" faunas (="Vaqueros" and "Temblor" Stages) from what is now mapped as Vaqueros Formation. Their "Vaqueros-Temblor transition zones" occur principally in the uppermost part of the Painted Rock Sandstone Member of the Vaqueros Formation north of Hubbard Hill; they considered most of what is now Vaqueros Formation to be "Vaqueros age." My own meager collections from this area, identified and given age assignments by W.O. Addicott, are in general agreement with their age assignments. The uppermost part of the Painted Rock Sandstone Member northeast of the Big Spring thrust fault contains "Temblor age" (provincial middle Miocene) mollusks and the lower part contains "Vaqueros age" mollusks, but the position of the "Vaqueros-Temblor" stage boundary remains uncertain because the middle part of the formation is only sparsely fossiliferous. The thinner Vaqueros Formation on the northeast flank of the La Panza Range locally contains "Vaqueros age" mollusks at the base, but it is almost entirely "Temblor age" and therefore correlative with the upper part of the Painted Rock Sandstone Member to the northeast. The Soda Lake Shale Member in the northwestern Caliente Range contains late Zemorrian foraminiferal assemblages below the cherty shale unit and early Saucesian foraminiferal assemblages above the cherty shale (R.L. Pierce, oral commun., 1970, in Dibblee, 1973).

The Vaqueros Formation overlying the conglomerate facies of the Simmler Formation at the southeast end of the La Panza Range is only sparsely fossiliferous. Eaton and others (1941), however, report a "Vaqueros age" molluscan assemblage from these rocks. The Vaqueros Formation of the Sierra Madre also contains mollusks diagnostic of the "Vaqueros Stage" (Vedder, 1968) and Zemorrian and Saucesian Foraminifera (Vedder and others, 1967). The Soda Lake Shale Member in the Cuyama Badlands contains Foraminifera of Saucesian or Zemorrian age.

It is apparent, then, that the Soda Lake Shale Member is approximately the same age in both the southeastern and northwestern Caliente Range, but the upper part of the Painted Rock Sandstone Member is younger in the northwestern Caliente Range. Plate 3 shows that the top of the Painted Rock Sandstone Member becomes progressively younger northwestward; this was demonstrated by Cross (1962) for a more limited area. As the Painted Rock Sandstone Member is nearly barren of age diagnostic Foraminifera, these correlations are based primarily on subsurface micropaleontologic evidence for the age of the overlying Monterey Shale and will be discussed further in the section on the Monterey. On the basis of the same evidence, the Vaqueros Formation of the northeast flank of the La Panza Range is considered equivalent to the uppermost part of the Painted Rock Sandstone Member in the northwestern Caliente Range, and the Vaqueros of the southeastern La Panza Range is considered equivalent to the uppermost part of the Painted Rock Sandstone Member in the central Caliente Range. The age discrepancy between the Vaqueros on the northeast flank of the La Panza Range and that at the southeast end of the La Panza Range has some significance in the history of the Chimineas fault and will be discussed in a later section. In summary (fig. 2), the Quail Canyon Sandstone Member is "Vaqueros age" (provincial early Miocene), the Soda Lake Shale Member is late Zemorrian to early

Saucesian (provincial early Miocene), and the Painted Rock Sandstone Member is "Vaqueros age" in the southeastern Caliente Range and "Vaqueros age" to "Temblor age" (provincial early to middle Miocene) in the northwestern Caliente Range.

The Vaqueros Formation can be traced, in outcrop and subsurface, around the north end of the La Panza Range into the Salinas Valley and to the type section of the formation west of King City. The type section contains mollusks diagnostic of the "Vaqueros Stage," provincial lower Miocene (Loel and Corey, 1932), but there was probably no connection between the Caliente Range area and the Salinas Valley area until provincial middle Miocene time. The type section is overlain by the Sandholdt Shale Member of the Monterey Formation of late Saucesian age (Durham, 1963). In the Salinas Valley, Durham (1968) has recognized the Tierra Redonda Formation of probable middle Miocene age conformably overlying the Vaqueros Formation. This sandstone unit, which was originally included in the Vaqueros, may correlate with part of the Vaqueros Formation on the northeast flank of the La Panza Range.

The Vaqueros Formation is also present in the Santa Ynez Mountains and Ventura basin, where it contains "Vaqueros age" mollusks (Loel and Corey, 1932; Dibblee, 1966). The Vaqueros in this area is overlain by the Rincon Shale, which contains Foraminifera of late Zemorrian age in the lower part (Dibblee, 1966). This suggests that the Vaqueros of this area correlates with the Quail Canyon Sandstone Member in the Caliente Range and that the Rincon correlates with the Soda Lake Shale Member. The Soda Lake is lithologically similar to the Rincon but contains more and thicker sandstone interbeds. The foraminiferal faunas of the Soda Lake Shale Member are also similar to those of the Rincon (R.L. Pierce, oral commun., 1970, in Dibblee, 1973). Loel and Corey (1932) and Cross (1962) have suggested that there was a connection between the Cuyama area and the Ventura basin in early Miocene time.

Noble (1954) recognized small patches of a marine lower Miocene unit on the north side of the San Andreas fault in the vicinity of Cajon Pass. On the basis of the "Vaqueros age" mollusks which occur in the lower part (Woodring, 1942), he referred the unit to the Vaqueros Formation. The area has more recently been mapped in some detail by Woodburne and Golz (1972), who also report "Vaqueros age" mollusks. The lower part of the formation consists of light-gray coarse-grained sandstone and thin-bedded yellowish-brown concretionary siltstone and sandstone. This grades up into interbedded reddish-brown siltstone to sandy mudstone and light-gray fine- to medium-grained sandstone. According to Woodburne and Golz, the formation has a maximum thickness of about 500 feet (150 m) and pinches out northward. As Noble (1954) points out, the nearest marine lower Miocene strata northeast of the San Andreas fault are in the southern San Joaquin Valley, 90 miles (145 km) northwest, and the nearest marine lower Miocene strata southwest of the fault are in the Santa Ana Mountains, 40 miles (64 km) southwest. A more likely correlation, however, is with the Vaqueros Formation of the Caliente Range-Carrizo Plain area between the Red Hills in the northwest and the marine lower Miocene in the Cuyama Badlands. This area lies between 108 and 185 miles (175 and 300 km) northwest along the San Andreas fault from the Cajon Pass area.

Strata in the Temblor Range, northeast of the San Andreas fault, that are equivalent in age to the Vaqueros Formation of the Caliente Range-Carrizo Plain area are included in the Temblor Formation of

Zemorrian to Relizian age. The Temblor consists of several members, alternately sandstone and shale. It is predominantly shale, especially in the subsurface of the San Joaquin Valley, but sandstone is dominant locally. Much of the shale was deposited at bathyal to abyssal depths (Bandy and Arnal, 1969), whereas subsurface evidence suggests that the Vaqueros grades into continental strata toward the San Andreas fault. As pointed out previously, the foraminiferal faunas of the Soda Lake Shale Member of the Vaqueros are more similar to faunas of equivalent age in the Ventura-Santa Barbara coastal area than to faunas in the San Joaquin basin. Indeed, there is no evidence, faunal or lithologic, that there was a connection between the two basins in early Miocene time.

Monterey Shale

The Monterey Shale in the Caliente Range area has been subdivided into two members (not shown in plate 1)--the Saltos Shale Member and the Whiterock Bluff Shale Member (Hill and others, 1958; Dibblee, 1973). The Saltos Shale Member, of Saucesian and Relizian age, is composed of shale, siltstone, and siliceous shale and locally contains layers of dolomite concretions. In the southeastern Caliente Range, it is composed of concretionary siltstone and fine-grained sandstone and ranges in age from Saucesian to Luisian(?) (Vedder, 1970). The Whiterock Bluff Shale Member, mainly Luisian in age, is composed of platy siliceous shale, cherty shale, and diatomaceous shale. In the Sierra Madre and southeastern Caliente Range, the Monterey Shale intertongues eastward into the marine Branch Canyon Sandstone. Subsurface evidence suggests that the Branch Canyon also underlies much of the Carrizo Plain and intertongues southwestward into the Monterey (Dibblee, 1973).

The Monterey Shale conformably overlies the Vaqueros Formation and in many places is in gradational or intertonguing contact with it. Because the Monterey generally contains a microfauna, it can provide important age control on the top of the Vaqueros. Plate 3, which shows diagramatically the intertonguing between the Monterey and Vaqueros, was constructed using the boundary between the Saucesian and Relizian Stages as a datum. This point for each of the well sections was determined by using oil company paleontologic reports. The reliability of the reports varies, quite naturally, for a variety of reasons, and the position of the stage boundary must be considered only an approximation.

The lowest Monterey Shale in the central Caliente Range is Saucesian in age--probably lower Saucesian, according to Jay Phillips (oral commun., 1973). The Monterey overlying the Vaqueros at the southeast end of the La Panza Range also contains lower(?) Saucesian Foraminifera (R.L. Pierce, oral commun., 1967, in Dibblee, 1973). The lowest Monterey in the southeastern Caliente Range is Saucesian, but foraminiferal assemblages are too poor to be more precise. The Monterey overlying the Vaqueros of the Santa Barbara Canyon area of the Sierra Madre contains Saucesian(?) Foraminifera (Vedder, 1968). As shown on plate 3, the thickness of Saucesian age Monterey decreases northwestward in the Caliente Range. As the top of the Vaqueros approaches the Saucesian-Relizian boundary, Saucesian assemblages become increasingly difficult to recognize in the subsurface. The lowest Monterey overlying the Painted Rock Sandstone Member north of Hubbard Hill in the northwestern Caliente Range is Relizian in age (Welby, 1949), and the thin Vaqueros of the northeast flank of the La Panza Range is also overlain by Relizian age Monterey.

Caliente Formation

The Caliente Formation in the southeastern Caliente Range is a thick sequence of variegated continental claystone, mudstone, sandstone and conglomerate with interbedded basaltic flows (Dibblee, 1973; Vedder, 1970). It contains vertebrate remains diagnostic of the Arikareean, Hemingfordian, Barstovian, and Hemphillian ages in the North American provincial mammalian chronology (Repenning and Vedder, 1961). That portion which intertongues westward with marine strata of the Vaqueros Formation contains Arikareean age vertebrates.

The gneissic basement of the Red Hills is overlain by coarse reddish boulder-cobble conglomerate, which was questionably referred to the Caliente Formation by Dibblee (1973). Its age is indeterminate, but it is overlain by the marine late Miocene Santa Margarita Formation and may be in part coeval with the Vaqueros Formation. According to Dibblee (1973), the Caliente may underlie much of the northeast margin of the Carrizo Plain. Subsurface studies show that the Vaqueros Formation thins northeastward, at least in part by intertonguing with the continental Caliente Formation.

PETROLOGY

Methods

About 120 representative samples of the Simmler and Vaqueros Formations were collected from the study area. Thin-sections were prepared from most of the samples and 54 sandstones were point-counted--21 from the Simmler and 33 from the Vaqueros. The thin-sections chosen for point-counting give as even a coverage of the study area as possible, with the coarsest sandstone sample available from each subarea. This resulted in using mostly fine- and medium-grained sandstone from the Simmler Formation and mostly medium- to coarse-grained sandstone from the Vaqueros Formation. A few additional samples from contiguous formations were also counted.

According to Galehouse (1971, p. 396), 300 points is an optimum number to count for general purposes. More than 300 points requires a large investment of time to gain only a small decrease in the probable error. In this study, 300 points served fairly well to characterize the detrital composition of the sandstones.

The identification and classification of detrital grain types in this study follows that of Dickinson (1970), and applies the commonly used parameters Q (quartz and chalcedony grains), F (feldspar), and L (aphanitic polycrystalline lithic grains). It is important to note, however, that sand-sized crystals in polycrystalline lithic grains or sand grains in clastic sedimentary rock fragments are counted with the individual mineral species rather than with the lithic grains.

Detrital Components

Conglomerate Clasts

Cuyama Gorge and southeastern La Panza Range.--The clasts of the conglomerate facies of the Simmler Formation give direct evidence of provenance. In the Cuyama Gorge and southeastern La Panza Range, the clasts may be divided into two groups. Pebbles of clastic sedimentary rocks, mostly subangular to rounded sandstone, are most abundant. The second group includes a variety of rounded to well-rounded crystalline rocks, mostly felsic granitic rocks and silicic to intermediate volcanic rocks. The volcanic rocks include fine-grained porphyritic rocks and recrystallized tuffs of the type that are ubiquitous in upper Mesozoic and lower Tertiary conglomerates of the Coast Ranges. A few metamorphic rocks, mostly quartzite, are also present.

The clasts in the Vaqueros Formation of the southeastern La Panza Range include virtually the same types as those in the underlying Simmler Formation; only the proportions are different. Quartzite and silicic to intermediate volcanic rocks are most abundant, with lesser amounts of granitic rocks. Clastic sedimentary rocks are present but are much less common than in the Simmler.

Cuyama badlands.--The clasts in the conglomerate facies of the Simmler Formation in the Cuyama Badlands are chiefly crystalline rocks. The most common clasts are subangular to subrounded gneissic rocks, mostly biotite gneiss. Nearly as abundant, however, are subangular to subrounded clasts of felsic granitic rocks including alaskite, quartz monzonite, and granodiorite. Siliceous volcanic rocks are another distinctive but less common clast type. The volcanic clasts are subrounded to well rounded and are usually reddish or purplish. In thin-section (fig. 34) most of the volcanic clasts appear to be silicified vitric tuffs of rhyolitic(?) composition with phenocrysts of K-feldspar (including sanidine) and quartz. They are similar to siliceous tuff clasts described from the Poway Conglomerate and Sespe Formation in southern California (Woodford and others, 1968).

Southeastern Caliente Range.--The Simmler Formation in the southeastern Caliente Range is locally pebbly. The most common clasts are granitic rocks and gneiss in about equal proportions, but the red and purple siliceous volcanic clasts are also conspicuous, and some quartzite clasts are present.

Although conglomerate is rare in the Vaqueros Formation, pebbles and cobbles are locally abundant in the sandstone. The assmeblage of clasts in the Vaqueros is very similar to that in the underlying Simmler. The principal differences are more abundant quartzite in the Vaqueros and the almost total absence of the red and purple siliceous tuffs that are so conspicuous in the Simmler.

Northwestern Caliente Range.--Granitic rocks (mostly granodiorite) make up more than half of the clasts in the Vaqueros Formation in the northwestern Caliente Range. Quartzite is the second most abundant clast type composing up to 30% of the clasts at places. There are lesser amounts of volcanic rocks, schist, pegmatite, and gneiss. The volcanic rocks are mostly silicic to intermediate porphyries. The pegmatite consists principally of pink to salmon-colored K-feldspar and quartz. The Simmler Formation in this area is not pebbly.

Northeastern La Panza Range.--The types of clasts in the undivided Vaqueros Formation on the northeast flank of the La Panza Range is strongly dependent on the lithology of the underlying unit. Granitic

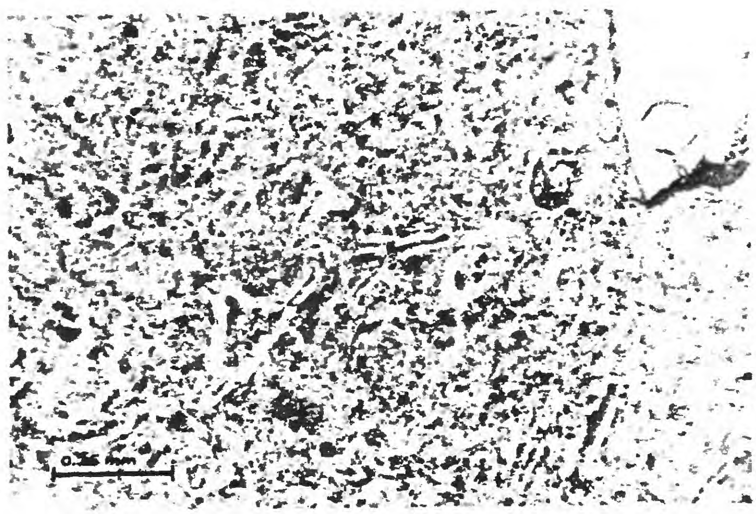


Figure 34.--Photomicrograph of silicified vitric tuff clast, Simmler Formation, southeastern Caliente Range. Note relic shards; K-feldspar crystal in upper right. Plane light.

rocks are common where the Vaqueros overlies granitic basement, and rounded clasts of quartzite and silicic to intermediate volcanic rocks are common where it overlies the upper Cretaceous-lower Tertiary sequence. Gneiss, and lesser amounts of felsic granitic rocks, make up almost all of the clasts in the Vaqueros overlying the Barrett Ridge gneiss. Further southeast, in the subsurface of the Taylor Canyon Oil Field area, the clast types most frequently mentioned in core descriptions are granitic rocks, quartzite, and gneiss. "Porphyries" are also mentioned; these are probably the silicic volcanic rocks typical of Mesozoic-lower Tertiary conglomerates. The assemblage of clasts in the Vaqueros of the Taylor Canyon Oil Field area is very similar to that of the Simmler and Vaqueros Formations of the southeastern La Panza Range.

Sandstone

The modal compositions of the sandstones of the Simmler and Vaqueros Formations are shown on figures 35 and 36, respectively. Most of the sandstones would be classified as arkose and lithic arkose in the terminology of McBride (1963), or as arkose and arkosic arenite in the terminology of Gilbert (in Williams, Turner, and Gilbert, 1958).

Lithic grains

Of the three primary components of the sandstone (quartz, feldspar, and lithic grains), the lithic grains are the most diagnostic of provenance. This is very apparent for the Simmler Formation, which unconformably overlies both older sedimentary rocks and crystalline basement rocks. The lithic grains can be conveniently subdivided into four categories: 1) volcanic rocks; 2) clastic rocks; 3) tectonite (or schistose) rocks; and 4) microgranular rocks (Dickinson, 1970). The volcanic rocks are further subdivided into four main textural groups: a) felsitic (fig. 37);

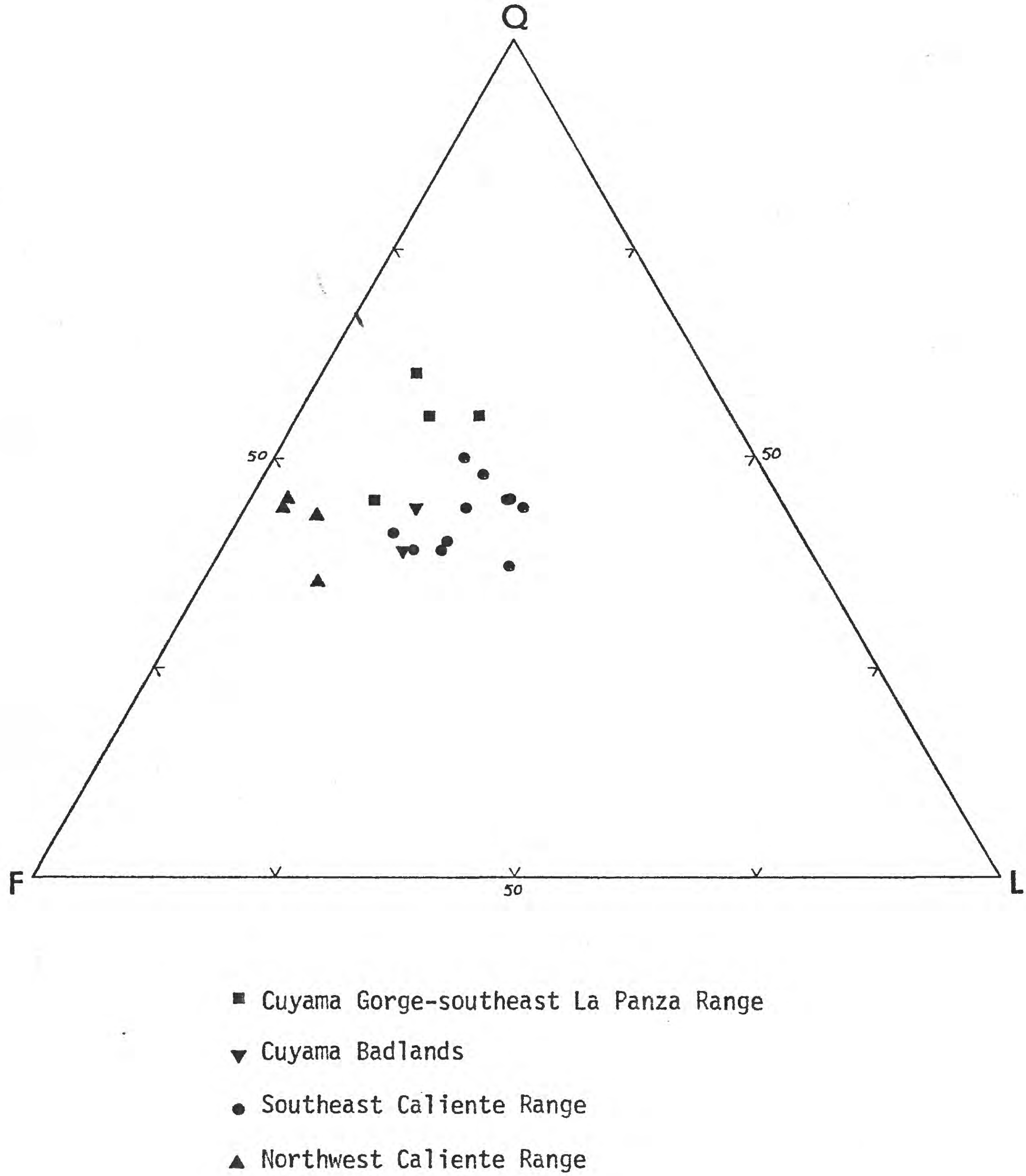
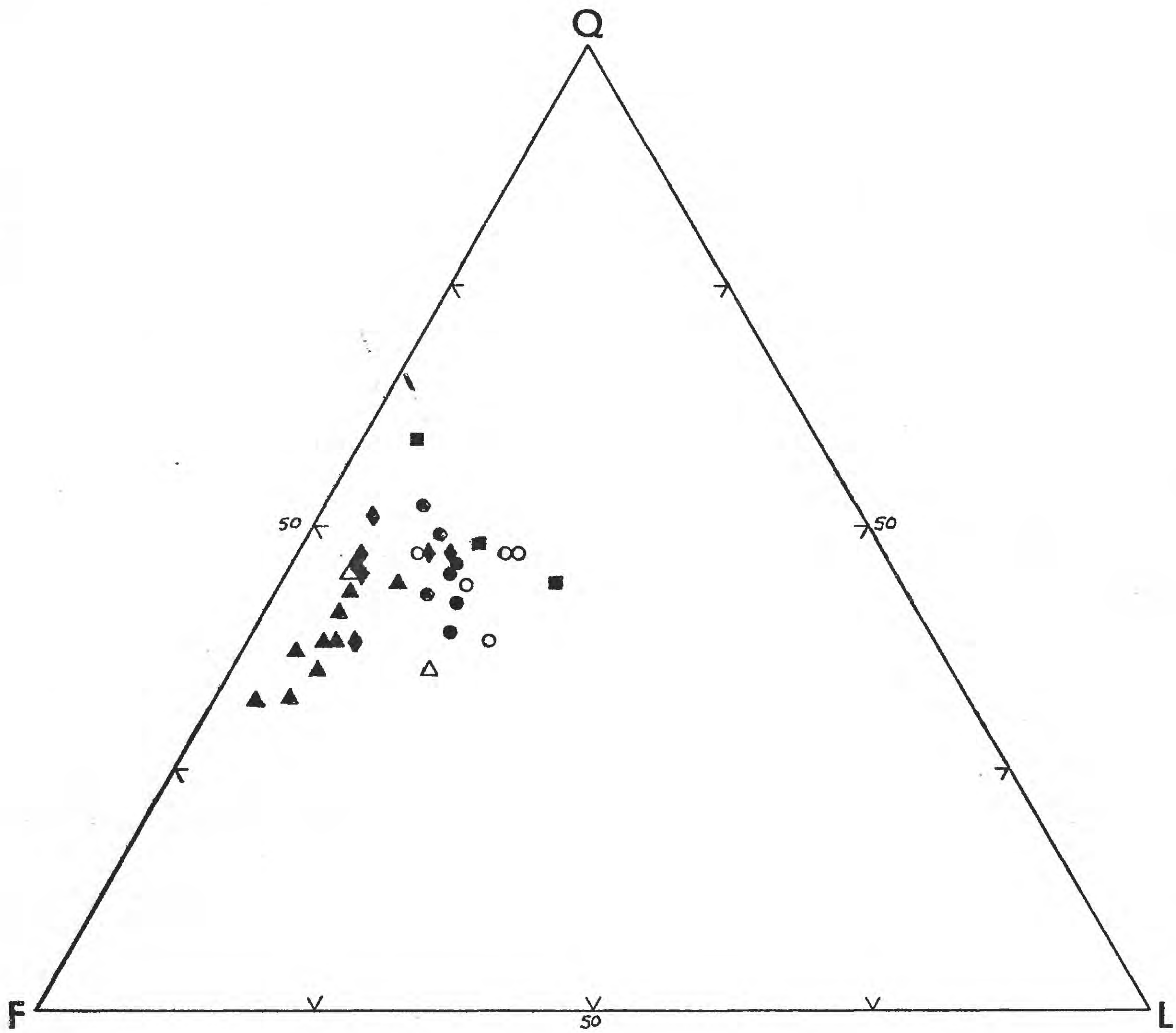


Figure 35.--Q-F-L diagram for sandstones of the Simmler Formation.



■ Southeast La Panza Range

♦ Northeast La Panza Range

Southeast-central Caliente Range

○ Quail Canyon Ss. Mem./Soda Lake Sh. Mem.

● Painted Rock Ss. Mem.

Northwest Caliente Range

△ Soda Lake Sh. Mem.

▲ Painted Rock Ss. Mem.

Figure 36.--Q-F-L diagram for sandstones of the Vaqueros Formation.

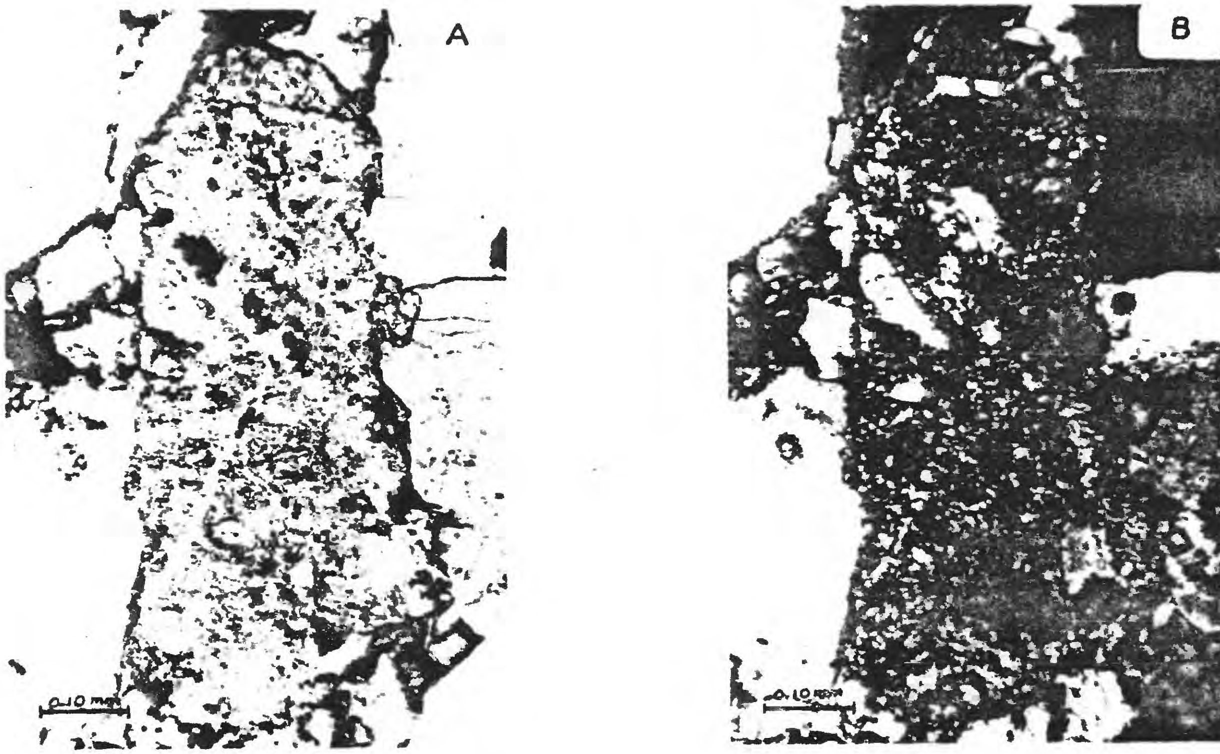


Figure 37.--Photomicrographs of felsitic volcanic lithic grain, Simmler Formation, Cuyama Gorge area. A, plane light; B, crossed polarizers.

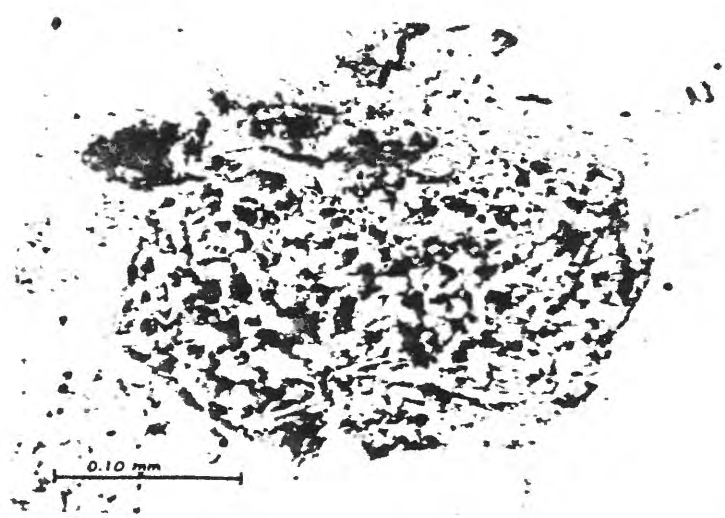


Figure 38.--Photomicrograph of microlitic volcanic lithic grain, Simmler Formation, southeastern Caliente Range. Plane light.

b) microlitic (fig. 38); c) lathwork; and d) vitric. The microgranular rocks, as defined by Dickinson, include three main types: a) hypabyssal igneous; b) hornfelsic metamorphic; and c) altered sedimentary. In this study, the first type includes rock fragments with myrmekitic and micrographic textures, as well as the more typical microgranitic texture. The microgranular category is, in effect, a left-over category for a variety of unidentifiable aphanitic lithic grains.

There are two recurring types of lithic grains in the Simmler and Vaqueros Formations that were classed as microgranular rocks. Aggregates of quartz and feldspar with mica, referred to as type "A" (fig. 39), are fairly common and could be either hypabyssal or hornfelsic types. A second type, referred to as type "B" (fig. 40), consists of siliceous microcrystalline or cryptocrystalline mosaics, most of which are probably siliceous metatuffs, but their resemblance to altered siliceous sedimentary rocks (fig. 41) often makes a positive determination nearly impossible. In addition to these two types of microgranular rock grains, there are many miscellaneous lithic grains that cannot be grouped with the other three categories of lithic grains with any degree of confidence.

The clastic lithic grains are mainly siltstone and sandy siltstone. The rare tectonite grains are mostly schistose metasedimentary(?) rocks including quartz-muscovite schist.

Cuyama Gorge and southeastern La Panza Range.--The average lithic-grain composition of sandstones in the Simmler and Vaqueros Formations is shown in table 4. In the Simmler sandstones of the Cuyama Gorge area and southeastern La Panza Range, the microgranular rocks are about half type "A" and half type "B". Type "B" grains are more abundant in the Vaqueros. Clastic sedimentary lithic grains are more abundant in this area than in any other. This is true for both formations, although

Figure 39.--Photomicrographs of type "A" microgranular lithic grains, Simmler Formation, Cuyama Badlands. A and C, plane light; B and D, crossed polarizers. Mica in both cases is chlorite. Note that crystals in lower-right corner of grain in A and B are greater than 0.0625 mm and if cross-hairs fell on this part of the grain in point-counting, the point would be counted as quartz or feldspar.


A
0.25 mm
B
0.25 mm
C
0.10 mm
D
0.10 mm

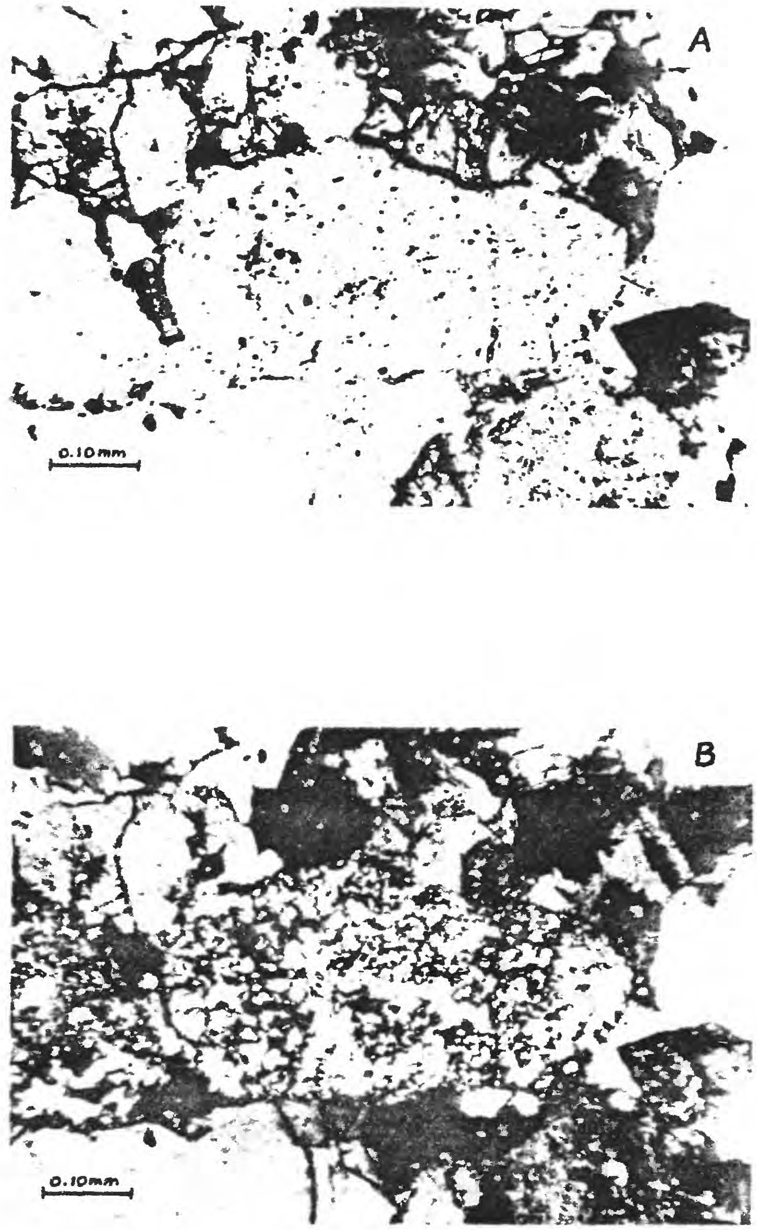


Figure 40.--Photomicrographs of type "B" microgranular lithic grain, Simmler Formation, southeastern La Panza Range. A, plane light; B, crossed polarizers.

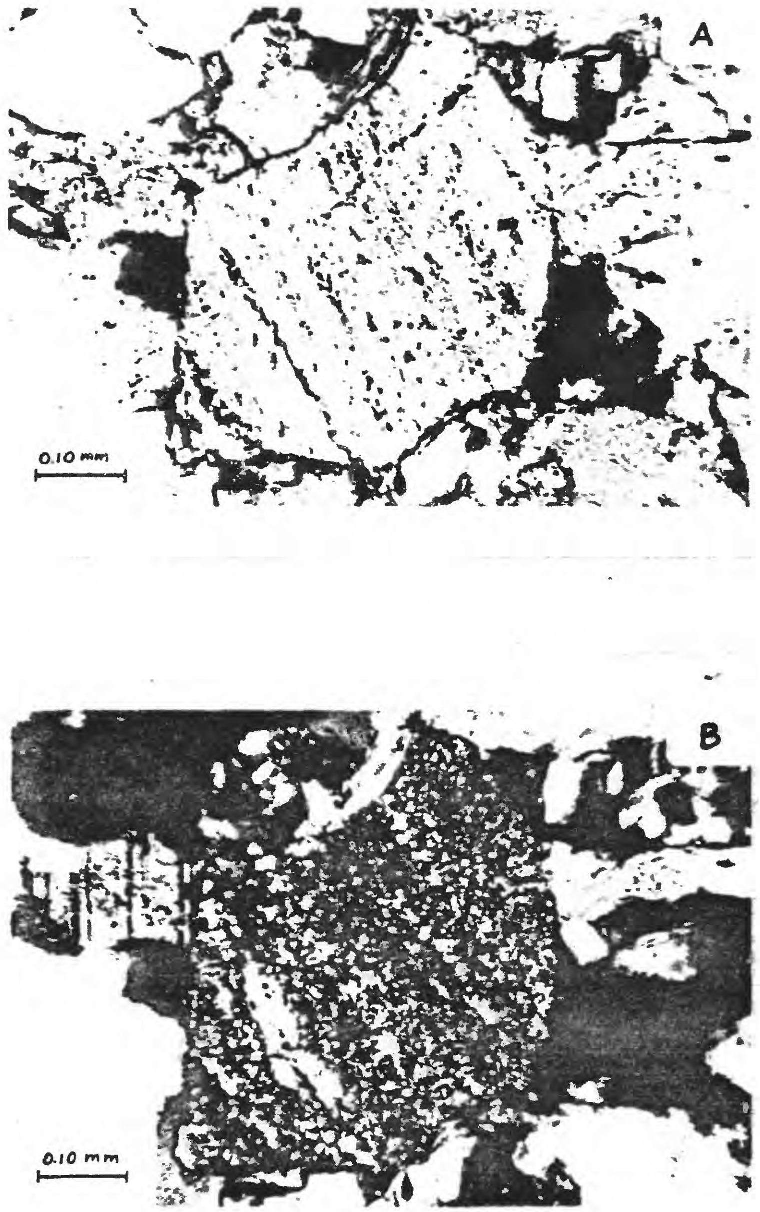


Figure 41.--Photomicrographs of chert grain, Simmler Formation, southeastern Caliente Range. This type grain (rare) is classed with the lithic grains because of impurities. A, plane light; B, crossed polarizers.

Table 4.--*Average lithic grain composition of sandstones of the Simmler and Vaqueros Formations*

[n=total aphanitic lithic grains; M=microgranular rock grains; V=volcanic rock grains; S=clastic sedimentary rock grains; T=tectonite (schistose metamorphic) rock grains]

	n	M(%)	V(%)	S(%)	T(%)
SIMMLER FORMATION:					
Cuyama Gorge-southeast La Panza Range	146	47	18	35	0
Cuyama Badlands	112	52	46	0	3
Southeast Caliente Range	690	49	35	14	2
Northwest Caliente Range	68	81	13	6	0
Average		57	28	14	1
VAQUEROS FORMATION:					
Southeast La Panza Range	114	42	43	14	1
Northeast La Panza Range	154	50	45	4	0
Southeast and central Caliente Range	444	58	29	12	2
Northwest Caliente Range	226	80	11	8	1
Average		57	32	10	1

they are most abundant in the Simmler. Felsitic or vitric volcanic grains are very common in some Vaqueros sandstones, but other types are also represented.

Cuyama Badlands.--Most of the microgranular rock grains in the Simmler sandstones in the Cuyama Badlands are type "A"; type "B" grains are much rarer than in the Cuyama Gorge area. The volcanic grains are mostly microlitic or lathwork types, but some felsitic and vitric types are present. Grains of schistose metasedimentary(?) rocks are present but very rare.

Southeastern Caliente Range.--The lithic grain types in the Simmler and Vaqueros sandstones of the southeastern Caliente Range are virtually the same as those in the Simmler in the Cuyama Badlands. The proportions are about the same (table 4) except for the addition of an appreciable amount of clastic sedimentary lithic grains. The clastic lithic grains in the Simmler are mostly mudstone and claystone that have been severely pinched and squeezed by adjacent grains. A few are reddish colored. These facts suggest that the clastic lithic grains were semiconsolidated intraformational mud chips. The clastic lithic grains in the Vaqueros are generally rare, except in the lower part of the Quail Canyon Sandstone Member, where they may form up to half of the lithic grains. Most of the microgranular lithic grains are type "A" in both formations. There are a few myrmekites in the Vaqueros sandstones. All types of volcanic lithic grains are represented, including a few vitric grains. Microlitic or lathwork types are most common.

Northwestern Caliente Range.--The lithic grains form a smaller proportion of the Simmler and Vaqueros sandstones in the northwestern Caliente Range (figs. 35 and 36). The great majority of these are type "A" microgranular rocks, but myrmekitic grains are also common. This, plus the presence of coarser hypidiomorphic- to allotriomorphic-granular rock fragments (counted as individual mineral components), suggests that most of the microgranular rock grains were derived from plutonic igneous rocks. In addition, some Vaqueros sandstones contain a few grains of what are probably metasedimentary rocks--carbonates and quartzose clastics. The few clastic sedimentary lithic grains in the Simmler are like those in the southeastern Caliente Range and were probably also semiconsolidated intraformational mud chips. The clastic lithic grains in the Vaqueros are generally rare and occur mostly in local sandstone lenses at the base of the Soda Lake Shale Member. This occurrence is similar to that in the Quail Canyon Sandstone Member of the southeastern Caliente Range.

Northeastern La Panza Range.--The lithic grains in the undivided Vaqueros Formation of the northeast flank of the La Panza Range include approximately equal proportions of microgranular and volcanic rocks. The microgranular rocks are probably all igneous types. Most of the volcanic rock grains are felsitic types, but microlitic or lathwork textural types are also common.

Quartz

Most quartz grains in the Simmler and Vaqueros Formations are monocrystalline, although some polycrystalline quartz is present in all areas; both commonly have undulatory extinction. Pure cryptocrystalline or microcrystalline chalcedony-quartz (chert) is almost totally absent. Almost all chert grains in the sandstones contain clay or mica impurities, which relegates them to the lithic grain mode.

Feldspar

The Simmler and Vaqueros sandstones of the northwestern Caliente Range form a distinct group with high feldspar and low lithic grain content. There is a minor amount of authigenic kaolinite in many of these sandstones, moreover, which may have slightly decreased their feldspar content. This will be discussed further in a later section.

K-feldspar appears to be more abundant than plagioclase--more so in the Vaqueros than in the Simmler sandstones. The ratio of plagioclase to total feldspar averages 0.42 for the Simmler and 0.34 for the Vaqueros. It should be pointed out, however, that counts were made on unstained thin-sections, which may have resulted in a low plagioclase count because of the difficulty in recognizing untwinned (or apparently untwinned) plagioclase. I believe, however, that the counts are internally consistent. It seems probable that at least half of the feldspar in the Simmler is K-feldspar and that the K-feldspar content of the Vaqueros is slightly higher than that in the Simmler.

Microcline is present in almost all thin-sections, but averages only 2 to 5% of the total feldspar. It is most abundant in the Cuyama Badlands and southeastern Caliente Range. Perthite is also common in sandstones of those areas.

Miscellaneous

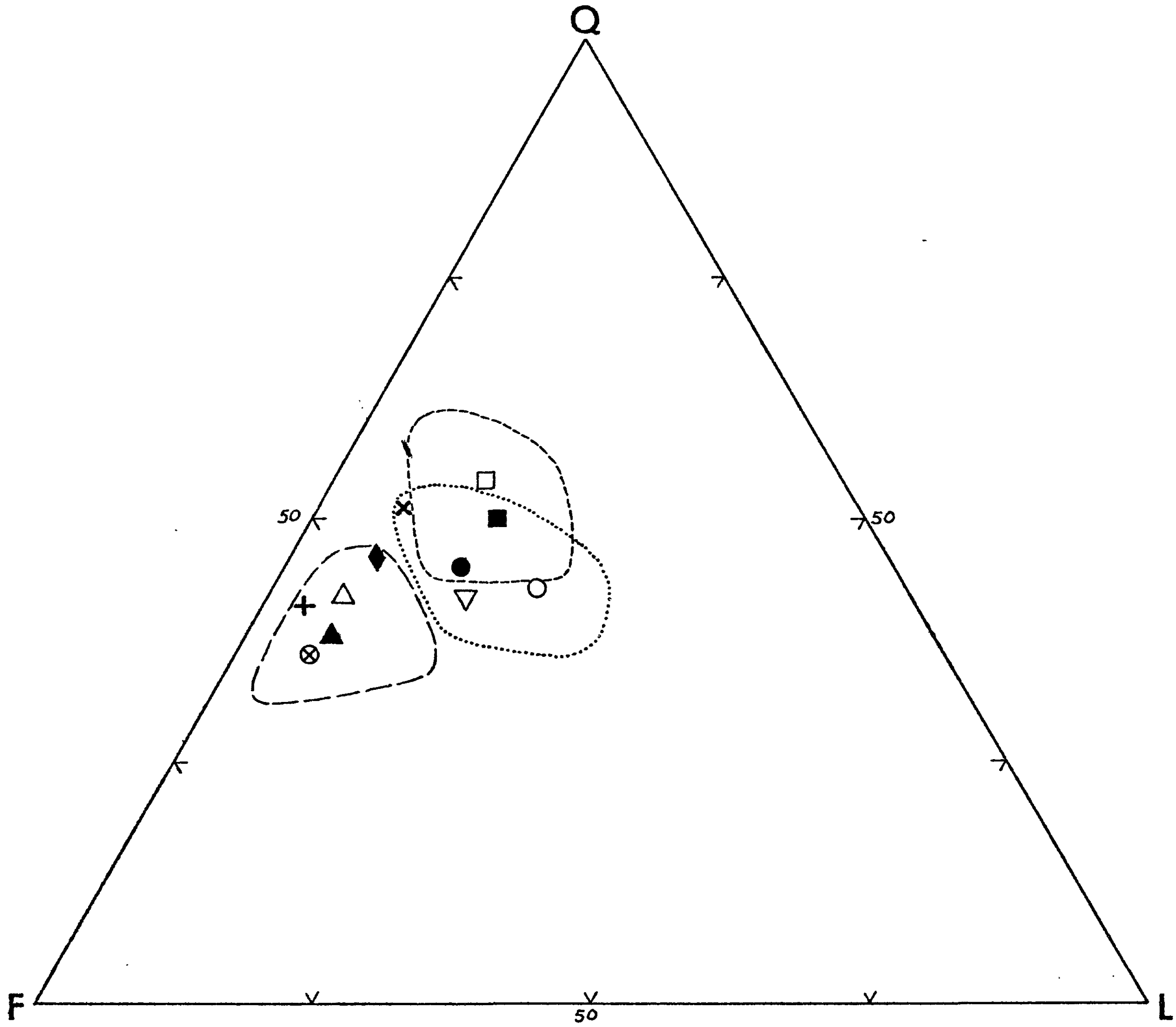
Micas are present in nearly all Simmler and Vaqueros sandstones and generally make up from 2 to 6% of the detrital grains. Mica is most abundant in fine- or very fine-grained sandstone (mostly in the Simmler) and is absent from a few coarse-grained Vaqueros sandstones. Biotite is by far the most common mica, although minor amounts of detrital chlorite and muscovite are sometimes present. Some of the chlorite appears to have altered from detrital biotite and some, principally in the Simmler, occurs in aggregates that may have been detrital volcanic lithic grains.

A few fine-grained Simmler sandstones in the southeastern Caliente Range and one in the Cuyama Gorge area contain trace amounts of fine-sand-sized rounded green pellets that are microcrystalline aggregates of a phyllosilicate mineral. Many of these pellets have a strong resemblance to glauconite, but others have an internal structure that suggests that they might be rounded detrital aggregates of chlorite.

Trace amounts of glauconite occur in a few samples from the Vaqueros Formation. It seems to be restricted to the Quail Canyon Sandstone Member and is reportedly found in great abundance in the subsurface of the Taylor Canyon and Morales Oil Field area.

Discussion

Figure 42 shows the average modal compositions for Simmler and Vaqueros Formations in various parts of the study area. It is evident from this figure that the compositions of the two formations in a given subarea are more similar than the compositions of the same formation in different subareas. Points for the middle Miocene Branch Canyon Sandstone are also included on figure 42 and show that for the southeastern and northwestern Caliente Range there was little change in composition of the sandstones from Oligocene to middle Miocene time. This seems to indicate that there was little or no change in source terranes for that period of time. As these sediments were deposited in a basin adjacent to the present-day San Andreas fault, the implication seems to be that there were no large-scale lateral movements on that fault for that period. This is consistent with presently known



SIMMLER FM.

□ Cuyama Gorge-southeast La Panza Range

▽ Cuyama Badlands

○ Southeast Caliente Range

△ Northwest Caliente Range

VAQUEROS FM.

■ Southeast La Panza Range

♦ Northeast La Panza Range

● Southeast Caliente Range

▲ Northwest Caliente Range

⊗ Cajon Pass

BRANCH CANYON SS.

+ Northwest Caliente Range

× Southeast Caliente Range

Figure 42.--Summary Q-F-L diagram showing average compositions of sandstones of the Simmler and Vaqueros Formations and Branch Canyon Sandstone for various areas. Short dashed line outlines area from figures 35 and 36 containing sandstones from southeastern La Panza-Cuyama Gorge area; dotted line outlines area for southeastern Caliente Range and Cuyama Badlands; and long dashed line outlines area for northwestern Caliente Range.

constraints on San Andreas fault history (Dickinson and others, 1972; Huffman, 1972).

The points on figure 42 fall into three main geographic groups: 1) southeastern La Panza Range-Cuyama Gorge area; 2) southeastern Caliente Range and Cuyama Badlands; and 3) northwestern Caliente Range. The clast composition of the Simmler conglomerates in the southeastern La Panza Range-Cuyama Gorge area is characterized by sedimentary rock clasts that, as pointed out in a previous section, coarsen and become more abundant southwestward toward the Nacimiento fault. The sandstones of the Simmler and Vaqueros in this area are also characterized by their relatively high sedimentary lithic grain content (table 4) and reflect the same source terrane as the conglomerate clasts. It is apparent that this material has been derived from the underlying Upper Cretaceous lower Tertiary sequence and from the Upper Cretaceous strata southwest of the Nacimiento fault. The rounded clasts of granitic and silicic to intermediate volcanic rocks have evidently been reworked from conglomerates in the older strata. The volcanic rocks are apparently represented in the sandstones by felsitic volcanic grains, and perhaps by type "B" microgranular rock grains. These are especially prominent in the Vaqueros.

It is equally apparent that the Simmler conglomerates of the Cuyama Badlands have been derived chiefly from a crystalline rock terrane. According to Ross (1972b), the basement rock exposures of the Mount Abel-Mount Pinos area (a few miles southeast of the Simmler exposures in the Cuyama Badlands) comprise a block of complexly contorted gneiss and migmatite, a granodiorite and quartz monzonite intrusive mass, and a fault-bounded block of Pelona Schist. Two of these, the gneissic rocks and the felsic granitic rocks, are abundantly represented in the Simmler conglomerates. There are no schist clasts in the Simmler conglomerates, but there are a few schistose lithic grains in the sandstones. The source of the siliceous volcanic clasts is unknown. Woodford and others (1968), in a study of the similar Poway type clasts, found no apparent source. They believe that the source rocks for these clasts have been completely removed by erosion, or buried by younger deposits.

The sandstones of the Simmler Formation from the Cuyama Badlands fall into the same area on the Q-F-L plots as the Simmler and Vaqueros sandstones in the southeastern Caliente Range. The lithic grain compositions (table 4) are also similar, with the exception of the clastic sedimentary rock grains that are locally derived mud chips in the Simmler and locally(?) derived basal transgressive sediment in the Vaqueros. The conspicuous perthite grains in the sandstone could also have been derived from the Mount Abel-Mount Pinos basement rocks. Ross (1972b) reported common perthitic feldspar in the gneiss. It is apparent that the Simmler and Vaqueros of the Cuyama Badlands and southeastern Caliente Range are genetically related. The trace amounts of glauconite(?) in the Simmler are the only thing that might require a sedimentary source terrane. If it is glauconite, it may have been reworked from Cretaceous or lower Tertiary strata.

The Simmler, Vaqueros, and Branch Canyon sandstones in the northwestern Caliente Range form a distinct group on Q-F-L plots and have a high content of microgranular lithic grains of a type probably derived from igneous rocks. The pebbles in the Vaqueros Formation are also largely derived from plutonic rocks but with a significant number of quartzite pebbles. These sediments probably had a common source that was distinct from that for the Simmler and Vaqueros elsewhere. The basement rocks in the northwestern Caliente Range-Carrizo Plain area are predominantly gneissic, yet the sediments seem to have been derived from a predominantly granitic source. The abundant quartzite pebbles are somewhat of an enigma, although they could have been derived from quartzite bodies in the gneissic terrane, like those at Barrett Ridge. According to Ross (1972b) much of the gneiss at the Red Hills is a homogeneous granitic-looking rock that also has granitic textures in thin-section. Detritus from this type of rock would not be recognized as gneissic.

It is significant that the sandstone of the Vaqueros in the Cajon Pass area, on the basis of limited data, seems to fall into this geographic group also. The basement rocks north of the San Andreas fault in the Cajon Pass area are biotite granodiorite in the vicinity of Cajon Pass and gneissic rocks farther northwest (Ross, 1972b). The gneissic rocks "are reminiscent of the rocks of the Red Hills, and to a lesser extent some of the more felsic gneisses look like the rocks of Barrett Ridge" (Ross, 1972b, p. 41). The less well-foliated rocks are hornfelsic, and in places the texture becomes granitic. Both granodiorite and gneiss contain conspicuous pinkish to salmon-colored K-feldspar, and pegmatite dikes containing the same feldspar occur in the granodiorite (Ross, 1972b). These rocks, as well as the Red Hills-Barrett Ridge gneissic terrane, should be considered as a possible source for the sediment of the northwestern Caliente Range.

The Vaqueros sandstones of the northeast flank of the La Panza Range seem to form a separate group that is not directly related to those of either the northwestern Caliente Range or the southeastern

La Panza Range. This is a somewhat variable group, as the clast types indicate, and reflects various mixtures of local "basement" lithologies. The high proportion of volcanic lithic grains in these sandstones (table 4) suggests that the volcanic unit in the Vaqueros in the Barrett Ridge area may have been a source. The presence of microcline in sandstone directly overlying the La Panza granodiorite also indicates composite sources, because Ross (1972b) found no microcline in that granodiorite.

Diagenetic Effects

Much of the sandstone in the Simmler and Vaqueros Formations has had a complex diagenetic history. Many samples have three or four authigenic minerals. It is not uncommon for sandstone of both Simmler and Vaqueros in the northwestern Caliente Range to have minor overgrowths on quartz and K-feldspar, authigenic kaolinite, and carbonate cement. One subsurface sample had a zeolite cement (probably laumontite). It would be beyond the scope of this report to give a detailed analysis of the diagenetic history of these rocks, but three of the principal diagenetic effects will be briefly considered.

Authigenic kaolinite occurs in the Simmler and Vaqueros sandstones in the northwestern Caliente Range, in the Vaqueros (but not the Simmler) in the La Panza Range, and has been reported from the Vaqueros in many wells drilled for oil in the Caliente Range-Carrizo Plain area. Interestingly, it seems to be quite common in the oil sands of the Morales-Taylor Canyon Oil Field area. It occurs principally as sandstone pore fillings of clear micaceous books with very low relief and very low birefringence, or more rarely in vermicular form (fig. 43). It was confirmed by X-ray diffraction as well-crystallized kaolinite. X-ray diffraction study of Simmler and Vaqueros claystones, on the other hand, indicates that illite is the dominant clay mineral in those rocks. This, plus the occurrence of kaolinite as a clear well-crystallized pore filling indicates that it is authigenic and not detrital. At places the well-crystallized kaolinite in pore fillings grades into detrital matrix or into micaceous material of higher birefringence (illite ?). At other places it has been partially replaced by later carbonate cement (fig. 44).

Figure 43.--Photomicrographs of authigenic kaolinite in the Vaqueros Formation. A, Pore filling of well-crystallized books of kaolinite; crossed polarizers. B, same area under higher magnification; plane light. C, authigenic vermicular kaolinite in detrital matrix (darker areas); crossed polarizers. D, same area under higher magnification; plane light. Same crystals in C and D indicated by numbers.

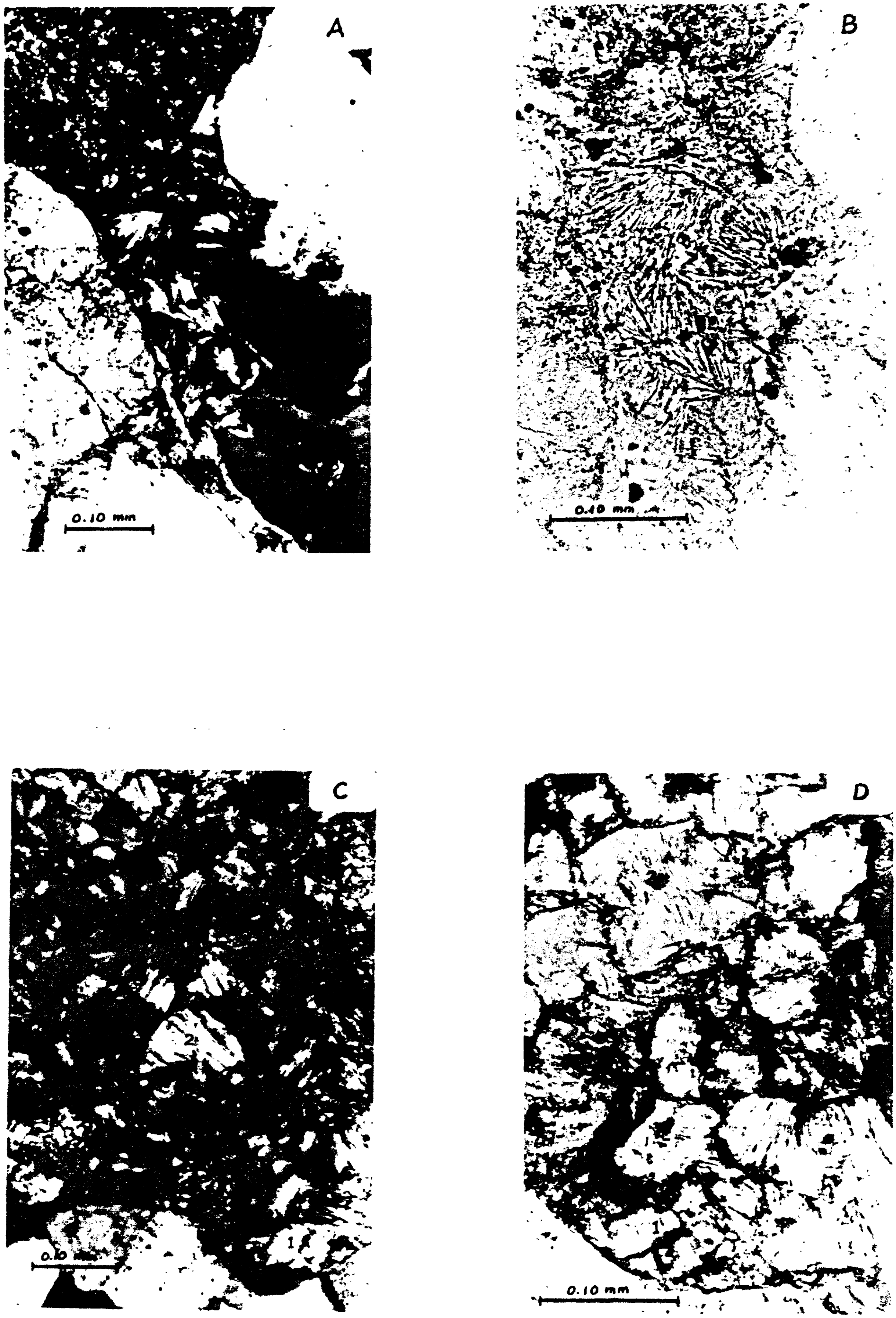

A
0.10 mm
B
0.10 mm
C
0.10 mm
D
0.10 mm

Figure 44.--Photomicrograph of euhedral dolomite replacing authigenic kaolinite, Vaqueros Formation, southeastern La Panza Range. Plane light.

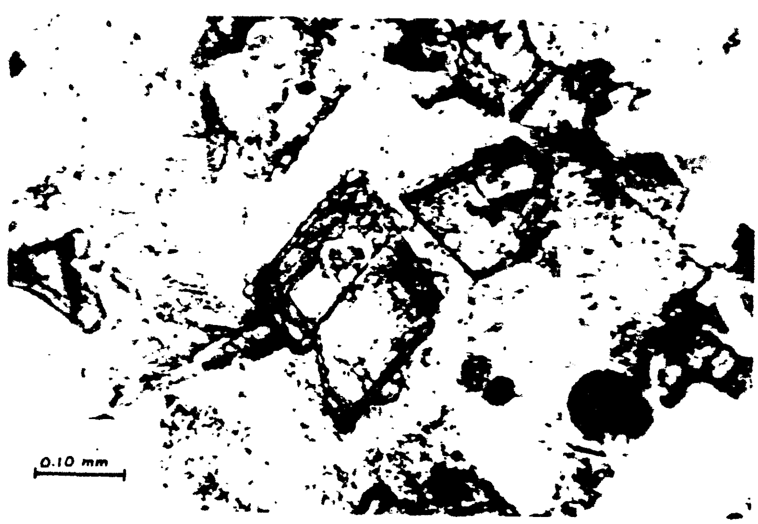


Figure 45.--Photomicrograph of ankerite in Simmler Formation, southeastern La Panza Range. Note darker limonite-stained rims on crystals. Plane light.

Experimental evidence from several workers (Rex, 1966; Hess, 1966; Mackenzie and Garrels, 1966; and Kittrick, 1969) indicates that environments favoring the formation of kaolinite are characterized by very low cation concentration and moderate silica values. Sims (1970, p. B31) states that "in order to meet these conditions large quantities of cation-free water are needed to either flush away or greatly dilute the solution products derived from the hydrolysis of unstable minerals." It is significant that the same conditions must have prevailed for both continental Simmler and marine Vaqueros Formations in the northwestern Caliente Range. The lower permeability of the muddy Simmler red beds in the southeastern La Panza Range prevented the necessary flushing action, whereas the cleaner sandstones of the overlying Vaqueros contain the most abundant kaolinite in the area (up to 12%). It is obvious that the authigenesis of the kaolinite is not related to the original depositional environment but represents a later period of fresh-water flushing that was restricted to the northwestern part of the basin. It is apparent that this flushing must have taken place before the precipitation of the carbonate cement and before the migration of the petroleum into the present reservoirs. The exact timing of these events, however, is not known and should be the subject of further research.

The kaolinite may have been derived from either feldspar or detrital clay minerals, or both. Feldspars with patches and veins of kaolinite(?) are rare in thin-section, but the association of kaolinite and detrital matrix is fairly common. This suggests that the precursors were predominantly clay minerals. Sims (1970) reached the same conclusion for authigenic kaolinite in Eocene strata in Kentucky. If, however, it is assumed that the feldspar was the principal precursor, and the kaolinite is included with the feldspar in calculating Q-F-L percentages, the feldspar mode would be increased only 2-4% in most cases. This would shift most of the sandstones from the northwestern Caliente Range area slightly toward the "F" corner of the Q-F-L diagrams (figs. 35, 36, and 42) and only serve to further separate that group.

Carbonate cement occurs in varying amounts in both Simmler and Vaqueros Formations throughout the study area, although it is most abundant in the Vaqueros. The carbonate in the southeastern Caliente Range and La Panza Range is almost all calcite except for a very minor amount of dolomite in the Simmler Formation. Dolomite in euhedral rhombs or masses of subhedral crystals is the principal carbonate in the northwestern Caliente Range in both Simmler and Vaqueros sandstones. The dolomite crystals generally have rims of limonitic material (fig. 45). X-ray diffraction study of this carbonate is inconclusive but suggests that most is ankerite (ferroan dolomite).

The carbonate cements occur mostly as pore fillings but locally may replace matrix or, as noted above, authigenic kaolinite. There is also some replacement of detrital grains in very calcareous sandstones. This is particularly true for the fossiliferous concretionary layers in the Vaqueros where there has been extensive replacement of detrital grains by sparry calcite. Thin-sections that show significant grain replacement generally contain more than about 30% carbonate and were not used for modal analysis.

Hematitic red pigment in the Simmler Formation is most prominent in the conglomerate facies of the Cuyama Gorge area and La Panza Range and is present to a lesser extent in the conglomerate facies of the Cuyama Badlands. The red pigment is restricted to the mudstone and claystone in both southeastern and northwestern Caliente Range, but the sandstone contains some limonitic cement. The pigment in the Simmler sandstone, whether hematite or limonite, commonly occurs as opaque "clots," disseminated in the matrix, or locally as halos around biotite. Flemal (1967) has discussed the origin of the red pigment in "Sespe"* red beds. Of the possible origins considered, the two most likely models are: 1) post-depositional aging and dehydration of brown iron hydroxides and oxides to hematite (Van Houten, 1968); and 2) in situ alteration of iron-bearing heavy minerals (Walker, 1967). According to Flemal, the evidence from the "Sespe" red beds favors the second model. The first alternative seems most probable, however, for the red mudstone and claystone (Van Houten, 1973).

Two related diagenetic effects tend to support the in situ alteration of heavy minerals as an origin of the red pigment. Flemal (1967) and McCracken (1969) report that the heavy mineral assemblage from the Sespe Formation is dominated by extremely stable types. Significantly, amphiboles and pyroxenes are rare or absent, although they are abundant in source rocks and in younger strata. Flemal and McCracken both concluded that these minerals were probably selectively removed by intrastratal solution. From observations made in thin-sections, I believe the same thing is true of the Simmler Formation. Heavy minerals were noted in nearly all thin-sections, but no amphiboles or pyroxenes were present, although hornblende is common in the basement rocks of the Caliente Range area (Ross, 1972b). The presence of ankerite and its association with limonitic material suggests that some of the iron and magnesium from the destruction of mafic minerals was incorporated into the carbonate cement.

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*Flemal's "Sespe Formation" was defined to include the Simmler Formation as well as other correlative red-bed units in southwestern California.

PALEOCURRENTS

Methods

Paleocurrent data was obtained almost entirely from cross-bedding. Field measurements of foreset orientations were restored to their original orientation by rotating the primary bedding back to horizontal around the strike. Angular error (in foreset azimuth) due to the plunge of fold axes in the study area is seldom more than 5° (Potter and Pettijohn, 1963, fig. 10-8) and can, therefore, be ignored. In this region of large-scale strike-slip and thrust faulting, there has probably also been some rotation around vertical axes. However, as the amount and direction of such rotations are unknown, no correction can be made. In practice, the assumption is made that the angular errors are small and uniform over fairly large areas.

Vector means (Potter and Pettijohn, 1963, p. 264) were computed for individual localities, subareas, and stratigraphic units. All computations were made by computer using a modified version of the program of Parks (1970) for the rotation operation. For a few obviously bimodal distributions, the two means were estimated by a computer program written by W.R. James and T.A. Jones at Northwestern University (described in Jones and James, 1969).

The computed vector means were tested for significance using the Rayleigh test (Curray, 1956, fig. 4 and table 1). Means of samples of 10 or more readings were generally significant at the 0.05 level. Means of samples with $p>0.20$ were considered to be not statistically significant. They could, however, still be valid in a practical sense and are shown on the paleocurrent maps (plates 5 and 6). The consistency ratio (vector magnitude/number of observations) is used as a measure of dispersion rather than the standard deviation because, as Curray (1956) demonstrates, the calculated standard deviation departs markedly from the "true" standard deviation for values above 60°. For the bimodal distributions, the computer program of James and Jones provides a scale parameter for each mode. This parameter may be converted to approximate values of vector strength (in terms of consistency ratio) by table 2 of Gumbel and others (1953). The program also determines the proportion of observations in the dominant mode. These values are considered more useful than vector strength in interpreting bimodal distributions, and they are used instead of vector strength on the paleocurrent maps.

The orientation of parting lineation could be measured at a few localities and was found to be in good agreement with cross-bedding directions from the same area. Clast imbrication in conglomerates was also measured at a few localities. The c axis orientation of about 25 tabular or disk-shaped clasts showing obvious imbrication were measured at each outcrop and the vector mean direction computed.

Simmler Formation

Paleocurrent information for the continental Simmler Formation is summarized on plate 5. Locality vector means are shown by arrows, and current roses summarize the cross-bedding data for the two principal areas of outcrop. Clast imbrication directions are also shown for two localities in the conglomeratic facies. Cross-bedding, unfortunately, is sparse in the Simmler, but enough readings were obtained to give a fairly representative picture of the paleocurrent pattern. It can be seen from plate 5 that the mean cross-bedding directions are fairly consistent from one locality to another, and the composite rose diagrams show a strong unidirectional distribution for each area.

Within the southeastern Caliente Range, the data can be broken down by lithologic unit (fig. 46). Unit 3 shows a more northeasterly mean direction than the remainder of the formation, but the direction of flow for the most part was northwesterly. Significantly, the paleocurrent direction for the northwestern Caliente Range was southerly; nearly opposite to that in the southeastern Caliente Range. As there are no Simmler outcrops in the central Caliente Range, it is impossible to say what relationship exists between the paleocurrents of the two subareas. A third system is evidenced by the clast imbrication, as well as clast size and rounding, in the conglomerate facies in the Cuyama Gorge and southeastern La Panza Range area. These currents flowed northeastward. Similar evidence in the Cuyama Badlands (not shown on plate 5) shows that currents flowed northwestward toward the Caliente Range.

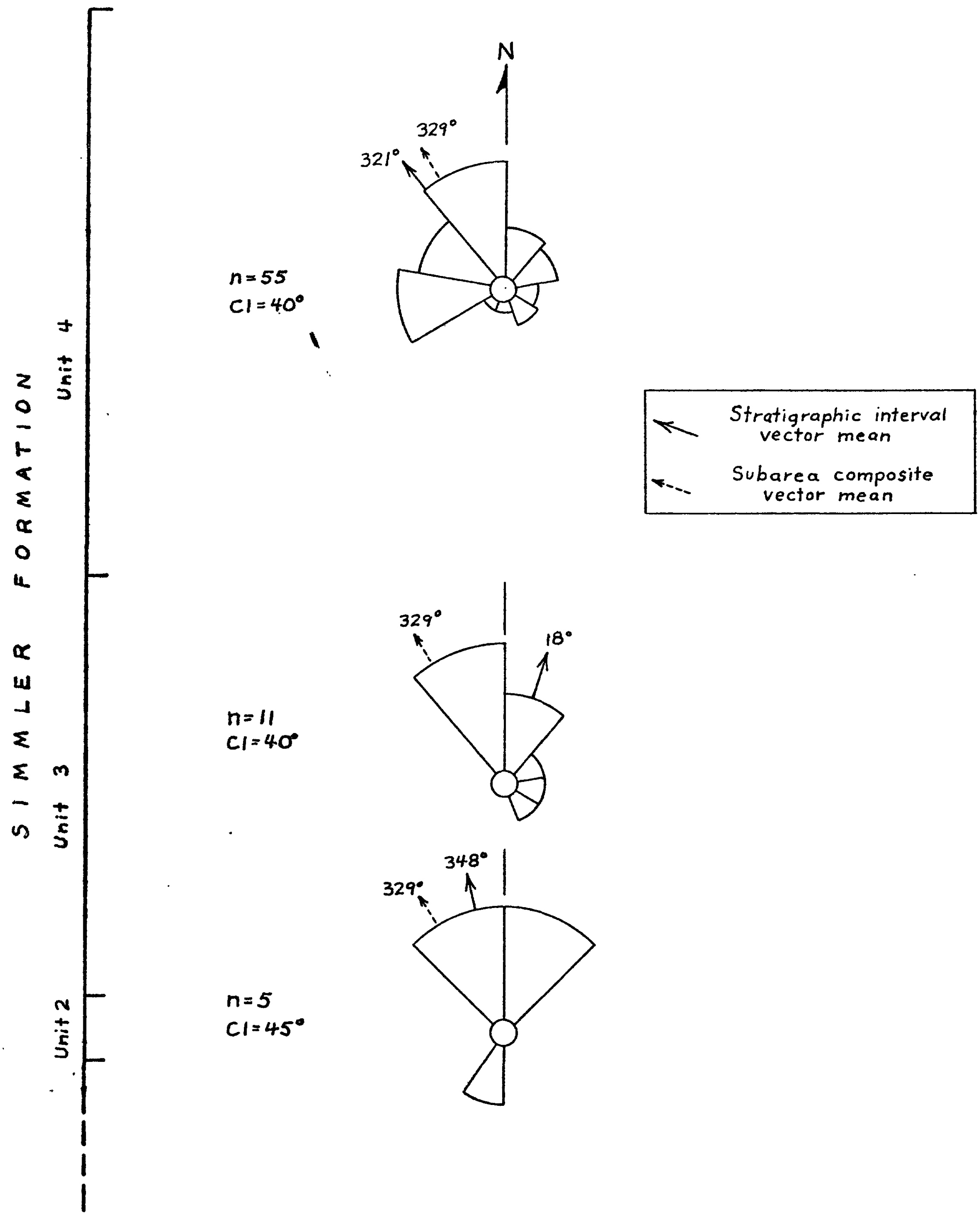

Figure 46.--Stratigraphic variation in paleocurrent directions in the Simmler Formation, southeastern Caliente Range. n=number of observations; CI=class interval of current rose diagram.

Vaqueros Formation

Paleocurrent information for the marine Vaqueros Formation is summarized on plate 6. The vector means indicate cross-bedding directions at localities in the Quail Canyon Sandstone and Painted Rock Sandstone Members and the undivided Vaqueros. No paleocurrent information was obtained from the Soda Lake Shale Member. The vector means show considerably more variation than those in the Simmler Formation, and a few localities have bimodal distributions. This is to be expected in shallow marine sandstones. In spite of the wide variation between individual localities, the composite rose diagrams for each of the three principal outcrop areas show a strong predominant direction. As a further illustration of this, a moving-average map was constructed for the Painted Rock Sandstone Member in the northwestern Caliente Range (fig. 47), using the method described by Potter and Pettijohn (1963, p. 271). The only departure from the general southerly to southeasterly net current trend in this area is in the lowermost part of the member where a local counterclockwise circulation is evident. The uniformity in trend for the major part of the area implies a predominant southerly flow through several thousand feet of section. The means for large-scale and for medium-scale cross-bedding at the same locality are generally in close agreement. At one locality in this area, however, the large-scale cross-bedding indicates southerly currents and the medium-scale cross-bedding indicates northerly currents.

In the southeastern Caliente Range, the paleocurrents are more variable. The directions in the Painted Rock Sandstone Member are bimodal (fig. 48), and opposite dipping foresets can be seen in the same outcrop. Paleocurrent directions in the Soda Lake Shale Member are probably, on

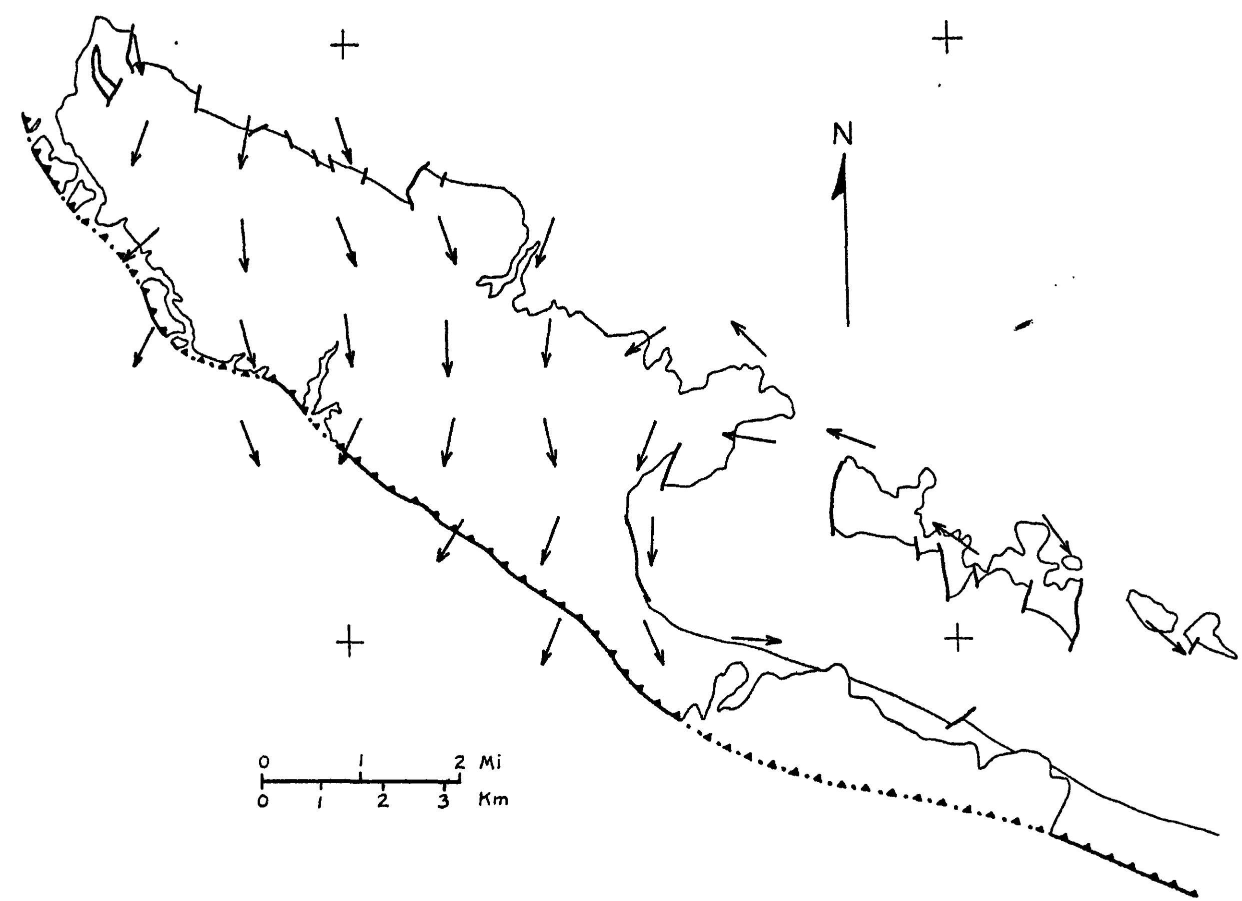

Figure 47.--Moving average of cross-bedding vector means in the Painted Rock Sandstone Member of the Vaqueros Formation, northwestern Caliente Range. Composite vector mean for this area is 176°.

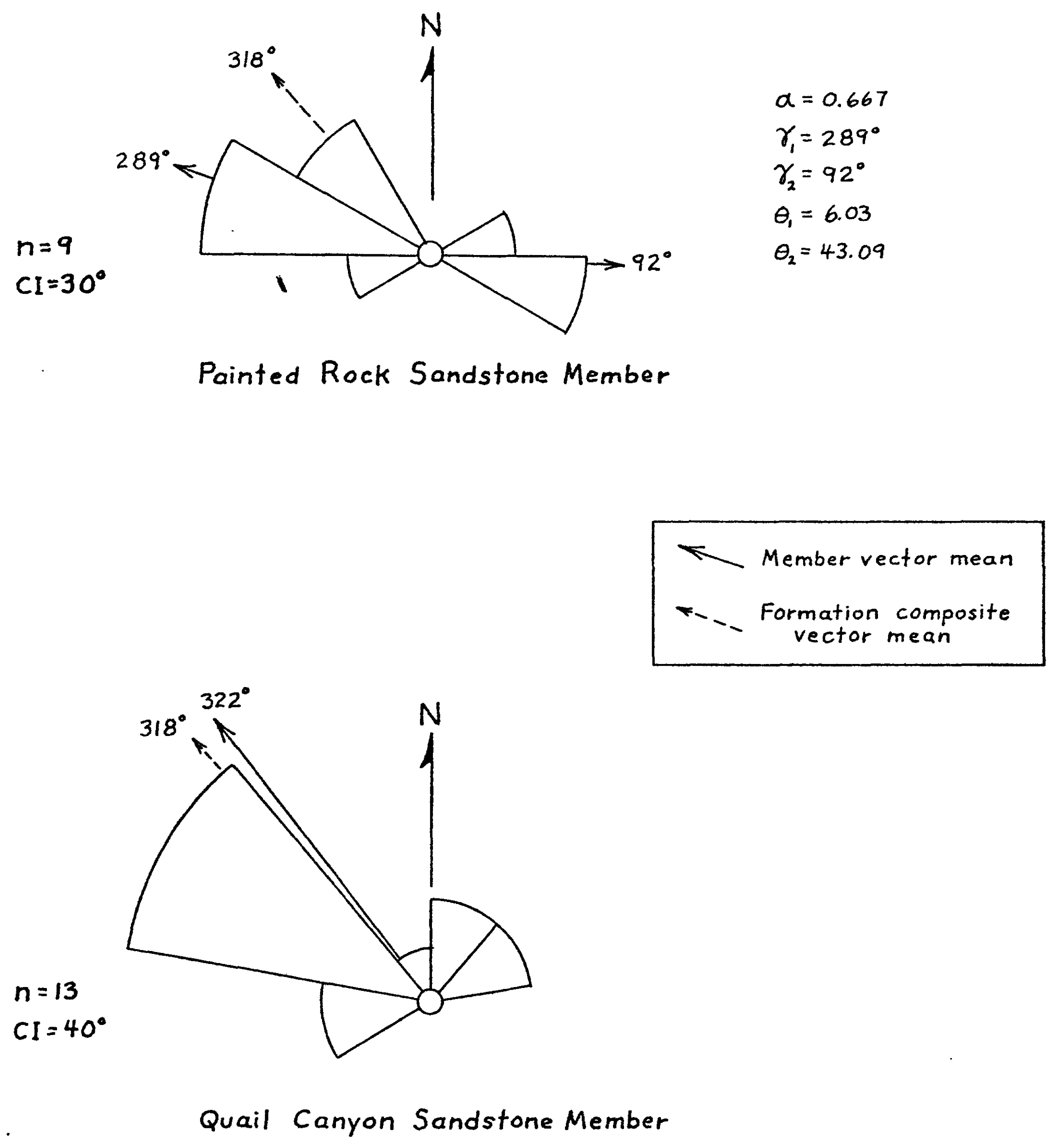

Figure 48.--Stratigraphic variation in paleocurrent directions in the Vaqueros Formation, southeastern Caliente Range. Parameters for bimodal distribution are: α, proportion of dominant mode; γ_1 , dominant current direction; γ_2, secondary current direction; θ_1, scale parameter of dominant mode; θ_2, scale parameter of secondary mode.

the basis of rare parting lineation, about the same as in the Painted Rock Sandstone Member (i.e., east or west). The Quail Canyon Sandstone Member shows a dominant west to northwest direction and secondary northeasterly direction (fig. 48), but it is not clearly bimodal. The composite rose diagram (plate 6) indicates a net west-northwesterly direction.

The locality labeled "TPR" on plate 6 is the very large-scale dune set at "The Painted Rock." That locality was not included in the summary diagrams because it seems to indicate special conditions of sedimentation, although the mean is in fair agreement with the pattern in the northwestern Caliente Range.

Although the paleocurrents of both the Simmler and Vaqueros of the northwestern and southeastern Caliente Range flowed in the same general direction, the paleocurrents of the Simmler and Vaqueros in the La Panza Range are quite different. The predominant direction for the Vaqueros in the La Panza Range is southeasterly--roughly parallel to the strike. This may represent an extension of the southerly pattern in the northwestern Caliente Range, but the faulting between the two areas complicates the interpretation.

INTERPRETATION

Simmler Formation

The Simmler Formation has been consistently identified as a continental deposit by previous workers and has been considered as such in earlier discussions in this report. This interpretation has been based largely on the pigmentation and the absence of marine fossils. The variegated nature of much of the Simmler, alternating red and green or gray beds, is common among units interpreted as continental. In addition, evidence of exposure such as desiccation cracks (figs. 3, 4, table 1) strongly suggests a continental origin. Vedder and Repenning (1965) suggested that the Simmler Formation in the southeastern Caliente Range is in part lacustrine. Flemal (1967) suggested that alluvial fan deposits, as well as the lacustrine deposits, are present in the Simmler. As lacustrine and alluvial fan deposits are often components of piedmont and alluvial plain depositional complexes, fluvial deposits, the principal component of such complexes, must be considered also.

Fluvial Deposits

Fluvial depositional model

The fluvial depositional model has been developed principally through the work of Allen (1962, 1963a & b, 1964b, 1965b, 1970b), Bernard and Major (1963), and Visher (1965a & b). This work has resulted in the recognition that formations interpreted as fluvial deposits are composed of a succession of fining-upward cycles. The characteristic elements of each cycle, according to Allen (1964b, 1965b), are a laterally persistent scoured surface at the base, overlain by sandstone, which grades up into siltstone. An intraformational conglomerate commonly occurs at the base of each cycle, and the overlying sandstone is generally cross-bedded.

The siltstone may contain calcareous concretions and interbeds of fine-grained silty sandstone. On the basis of comparisons with Recent alluvium, the sandstone is believed to represent the point-bar deposits of stream channels and to be deposited mainly through lateral accretion as the channels wandered. The upward decrease of grain size and the vertical sequence of sedimentary structures is interpreted in terms of decreasing flow regime at progressively higher positions on the point bar (fig. 49). The scoured surface at the base of the cycle represents erosion in the deepest part of the channel. The fine-grained rocks are interpreted as vertical accretion deposits of the floodplain (Bernard and Major, 1963; Allen, 1963b, 1964b, 1965b).

The sandstone facies of the Simmler Formation in the Caliente Range fits this model very well. The Simmler is largely composed of fining-upward cycles (plate 2) which display all of the characteristic elements of the fluvial model. The only departure from the model is the predominance of planar stratification (flat-bedding) over cross-bedding in the sandstone. This is not regarded as a discrepancy because, as Allen (1970b, fig. 2) shows, flat-bedding can be the dominant structure in fine-grained sandstone of channel deposits. Allen (1970b) further demonstrates that flat-bedding is a predictable structure in low-sinuosity streams. Planar stratification, or flat-bedding, is an upper flow regime structure associated with parting lineation (fig. 7). Extensive deposits of sand characterized by flat-bedding can be formed as a result of major floods (McKee and others, 1967). The implication is that much of the sandstone of the Simmler represents the deposits of major floods under upper flow regime conditions.

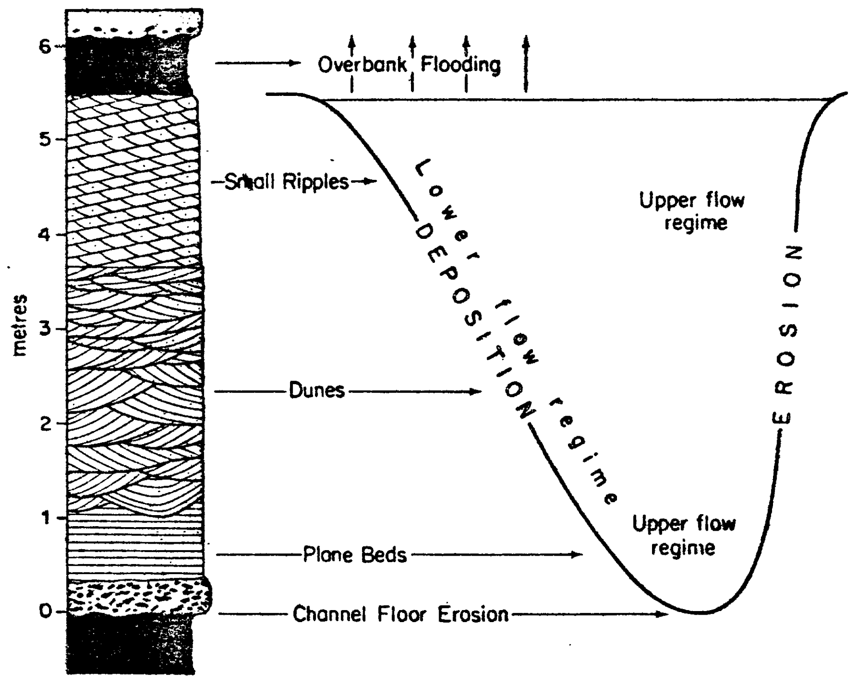

Figure 49.--Interpretation of fluvial fining-upward cycle from Old Red Sandstone of England in terms of flow regimes in meandering channel. (From Allen, 1963b)

Stream channel pattern

Stream channel patterns have been classified as braided, meandering, and straight. Straight reaches are rare, however, and the braided and strongly meandering patterns form end members of a continuum (Leopold and Wolman, 1957). Braided stream deposits are commonly coarse grained and gravelly, contain little fine-grained overbank sediment, and are markedly lenticular with individual sedimentation units occurring in channel forms (Allen, 1965a). The deposits of strongly meandering (high-sinuosity) streams are well known, largely through the work of Fisk (1944, 1947) on the Mississippi River alluvial deposits. The coarse-grained channel deposits occur in narrow linear bodies representing the meander belt. These sand bodies, which are tabular shaped and have laterally erosive contacts in the lower part, are enveloped by fine-grained flood-basin and channel-fill deposits. The channel-fill deposits ("clay plugs") are largely responsible for confining the meanders to the meander belt (Fisk, 1947) but also occur within the meander-belt sand body.

Large-scale cross-stratification that is sigmoidal in cross section and lithologically heterogeneous (epsilon cross-stratification of Allen, 1963c) has been considered an important characteristic of point-bar lateral-accretion deposits of meandering streams (Moody-Stuart, 1966). However, Allen (1970b) has shown that the transverse slope of modern point bars averages only 2-3°, which would make them very difficult to recognize in outcrops of ancient rocks. Furthermore, modern point bars do not always have smooth sigmoidal profiles but are often composed of a series of minor terraces corresponding to stages in river lowering (Frazier and Osanik, 1961; McGowen and Garner, 1970). Consequently, large-scale sigmoidal cross-stratification is of limited usefulness as a criterion for recognizing point bar deposits.

Differentiating the deposits of braided and meandering streams, as preserved in ancient rocks, is difficult with present knowledge. A facies model for braided stream deposits is illustrated by Allen (1965a, fig. 35B), and for strongly meadering stream deposits by Allen (1965a, fig. 35D) and by Moody-Stuart (1966, fig. 1). The sandstone facies of the Simmler Formation does not appear to fit either of these end-member models very well. The braided stream model can probably be eliminated for most of the Simmler because of the Simmler's relatively fine grain size and fining-upward cycles topped by fine-grained overbank deposits, and because the sandstone beds are not markedly lenticular at an outcrop scale. The thicker and coarser cycles at the top of the formation, however, may indicate a shift to braided-stream sedimentation due to increased slope. The strongly meandering stream model can probably be rejected because of the apparent absence of meander belt sandstone bodies enclosed in fine-grained overbank and floodbasin deposits. The limited exposure area and complex structure of the exposure areas would, however, make it difficult to recognize such sandstone bodies. There is also a general absence of fine-grained channel-fill deposits, with the possible exception of the partial channel form illustrated in figure 8.

As the Simmler Formation does not fit the end-member models, it must represent some intermediate type. Facies models for two different intermediate type streams, both labeled low-sinuosity, have been illustrated by Allen (1965a, fig. 35C) and by Moody-Stuart (1966, fig. 1). The Allen low-sinuosity model comes closest to describing the Simmler Formation. According to Allen, fining-upward coarse-grained channel deposits are dominant and extend across the depositional basin in tabular to wedge-shaped sheets. Fine-grained overbank deposits are thin and not laterally persistent, and occasional fine-grained channel-fill deposits may be present. As noted above, Allen (1970b) has shown that abundant flat-bedded sandstone is to be expected in low-sinuosity streams.

Cyclicity

A problem that is always present in the interpretation of a cyclic deposit is the cause of the repetition or the cyclicity. Beerbower (1964) has discussed the possible mechanisms controlling cyclic alluvial plain sedimentation and has classified them as autocyclic or allocyclic. Autocyclic mechanisms include all of the types of channel wandering resulting from normal fluvial processes. Allocyclic mechanisms are the result of external processes, such as changes in discharge, load, or slope (eustatic or diastrophic). In either case, preservation is dependent on a subsidence rate that is high relative to the rate of lateral migration of the channels. Cyclic fluvial sequences are widespread in both time and space. This suggests that there is something inherent in fluvial processes which produces deposits of a cyclic nature. The simplest explanation of the cyclicity is an autocyclic mechanism (i.e., channel wandering) together with a subsidence rate that would allow preservation of cycles of about the same thickness throughout the Caliente Range area.

A moving-average plot of cycle thicknesses for the measured section from the southeastern Caliente Range (fig. 50) shows that the cycles are organized into megacycles 22 to 23 m thick. This plot also shows the marked increase in cycle thickness at the top of the formation. These megacycles were evidently caused by an allocyclic mechanism--

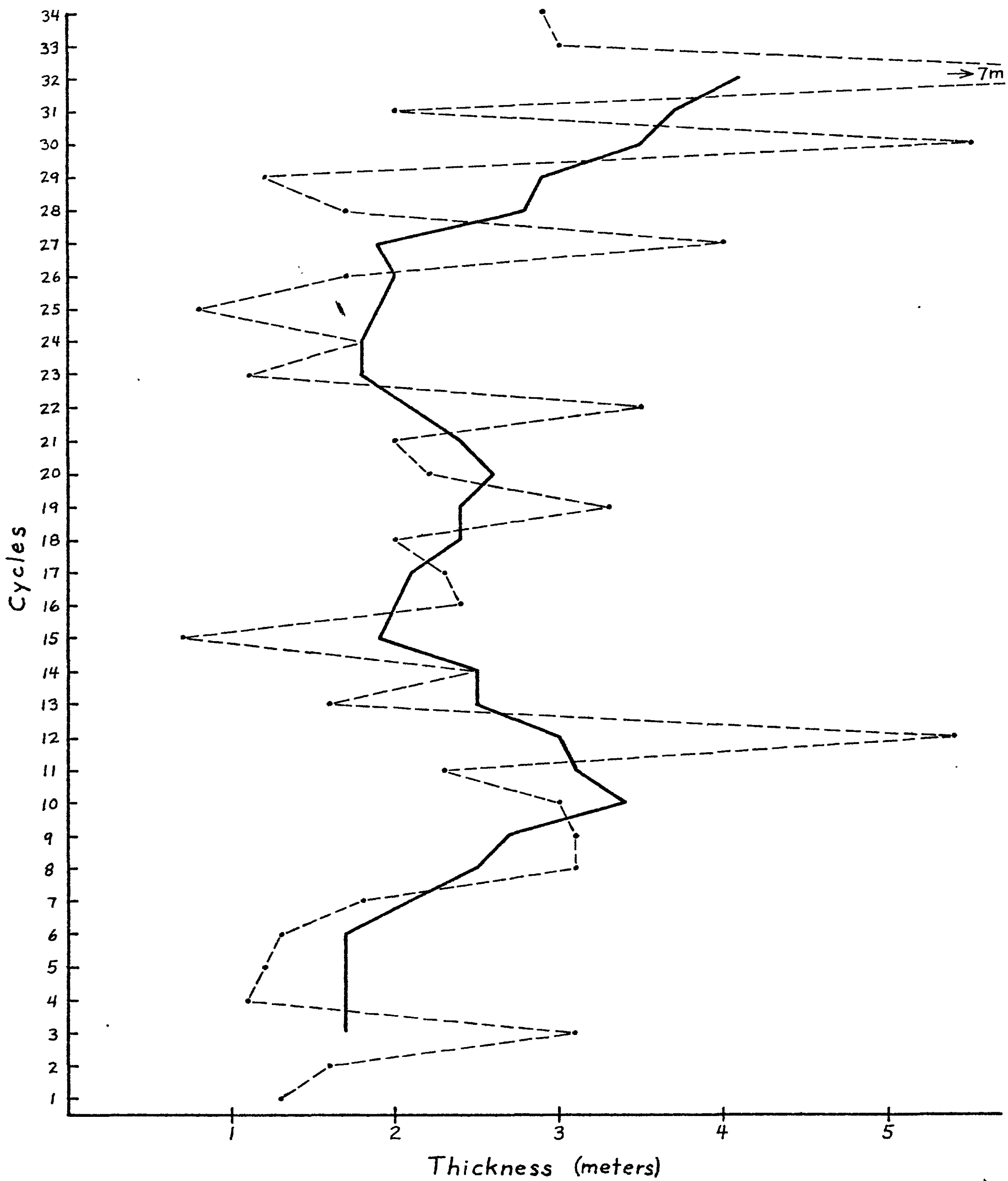

Figure 50.--Moving-average plot of cycle thicknesses for measured section from Simmler Formation in southeastern Caliente Range. Dashed line=actual thickness; heavy solid line=smoothed thickness curve. Note megacycles of about 10 cycles each, or 22 to 23 m, and increase in cycle thickness at top of section.

deposits of braided fan-channels. This interbedding of debris-flow and water-flow deposits points strongly to deposition of alluvial fans. Indeed, the only continental environment where appreciable amounts of debris-flow deposits can accumulate is on alluvial fans. Debris-flow deposits in the Simmler are most abundant in the Cuyama Gorge area. This may be due, in part, to the nearness to the inferred source because, as Hooke (1967) points out, debris flows are most common near the fan head. Hooke has also demonstrated that for fans in an arid region, the relative importance of debris flows and water flows is lithologically controlled. Debris flows require substantial amounts of fine-grained material in the source area. More debris flows would be expected from the sedimentary source terrane of the Cuyama Gorge area than from the crystalline rock terrane of the Cuyama Badlands source area. Clast imbrication in conglomerates is most prominent in the southeastern La Panza Range, indicating the greater importance of water-flow deposits on more distal parts of the fans whose fan heads were near the Cuyama Gorge.

The small isolated patches of muddy gneiss breccia on the northeast flank of the La Panza Range are probably also debris-flow deposits of alluvial fans, but grade down into a rubble zone (fig. 11) showing little evidence of transport. These basal deposits may represent colluvium or talus buried by the fan deposits.

Lacustrine Deposits

It is difficult to describe the characteristics of lacustrine deposits in general because lakes are so varied in their physical and chemical make-up. Picard and High's (1972) discussion of lacustrine deposits is concerned mainly with large long-lived lakes because, as probably diastrophism--but the worldwide Oligocene climatic deterioration (discussed below) suggests the possibility of climatic control. The thickening cycles at the top of the Simmler were followed by a marine transgression, which suggests that a basinward tilting or an increase in regional relief may have been the cause.

Alluvial Fan Deposits

Alluvial fan deposits consist of debris-flow, sheetflow, and channel deposits. Channel deposits are relatively rare, and most water-laid sediments are sheetflow deposits (Bull, 1972). Although one type of deposit may predominate in a particular fan, interbedding of debris-flow and water-flow deposits is common (Bull, 1972). The bedding in debris-flow sequences is poorly defined, whereas the bedding of interbedded debris-flow and water-flow deposits is well defined. At the outcrop level, the thicknesses of beds (particularly debris-flow deposits) can be quite uniform (Bull, 1972). Debris-flow deposits are characteristically poorly sorted, contain unsupported large fragments in a fine-grained matrix, and may be structureless. They may also show an alignment of elongate fragments parallel to the flow direction and inverse grading (Fisher, 1971).

The common muddy conglomerates and sandy to pebbly mudstones of the conglomerate facies of the Simmler Formation, in both the Cuyama Gorge-southeastern La Panza Range area and the Cuyama Badlands area, have the characteristics of debris-flow deposits. Alignment of elongate fragments and inverse grading are not readily apparent in the Simmler debris-flow deposits, but further work might reveal their presence. The debris-flow deposits are interbedded with well-sorted sandstone and conglomerate (figs. 10, 12) that are interpreted as traction-current (water-flow) they point out, only these have accumulated sediment long enough to leave a significant record. If there are lacustrine deposits in the Simmler Formation, they would probably be from small ephemeral lakes associated with the fluvial deposits of the Caliente Range. Deposits of such small alluvial plain lakes might be represented in the Simmler of the southeastern Caliente Range by the predominantly fine-grained rocks of Vedder and Repenning's (1965) unit 2, and in the subsurface near Soda Lake by some ostracod-bearing strata. These rocks are the only strata in the Simmler, other than the thin flood-basin deposit of the fluvial cycles, that suggest deposition in quiet standing water. The sedimentary structures observed in unit 2 (table 1) are consistent with an interpretation as lacustrine deposits. There are, however, no chemical sediments such as fresh-water limestones or evaporites in the Simmler as there are in the correlative Plush Ranch Formation to the southeast (Carmen, 1964).

Paleoclimate

Flemal (1967, 1968) has reviewed the evidence for the paleoclimate during the deposition of the "Sespe Formation" (including the Simmler Formation of this report). Flemal concluded that the climate had been arid, chiefly on the basis of three lines of evidence: 1) the lack of intense weathering products; 2) sedimentary features such as alluvial fan deposits and playa deposits; and 3) the presence of evaporite minerals. Flemal's discussion included all Oligocene red beds in southwestern California; some of the evidence applies to the Simmler and some does not.

There is a lack of intense weathering products in the Simmler, and the abundance of feldspar, especially in the northwestern Caliente Range, supports an arid climate interpretation. The kaolinite in those sandstones was shown to be authigenic. Alluvial fan deposits are present in the Simmler, and they contain abundant debris-flow deposits. Blissenbach (1954) suggested that mudflow (=debris-flow) deposits become more numerous with decreasing precipitation. The debris-flow deposits in the Simmler, however, are most prominent in the younger (early Miocene) part of the conglomerate facies. There are no evaporite deposits in the Simmler and no playa deposits have been identified but, as noted above, evaporites are present a few miles to the southeast in the correlative Plush Ranch Formation. The calcareous concretions that occur near the top of fluvial fining-upward cycles have been interpreted as calcareous paleosols or caliche (Allen, 1963a, 1965b; Van Houten, 1973) This suggests "a rather dry savanna climate with a low water table, but with moisture enough to maintain an immature soil profile on slowly aggrading floodplains" (Van Houten, 1973, p. 52). Further evidence of aridity is the almost complete absence of a flora or fauna in the Simmler. On the other hand, the green or gray color of channel sandstones in variegated sequences implies that they were deposited in a reducing environment below the water table (Van Houten, 1973). A year-round high water table is inconsistent with an arid climate. All in all, the evidence seems to favor a semiarid climate for the Simmler in the Caliente Range area.

The Simmler Formation and its correlatives in southwestern California thus provide some evidence bearing on aridity but not on temperature. It has been well established elsewhere, however, that a pronounced cooling occurred in the interval from late Eocene to early Oligocene time. The evidence for this cool period, which is virtually worldwide, is based on studies of microfossils (Jenkins, 1968; Cifelli, 1969), megafossils

(Addicott, 1970), land plants (Nemejc, 1964; Wolfe and Hopkins, 1967), and oxygen isotopes (Dorman, 1966; Devereux, 1967). Evidence further indicates that a warming trend following the Oligocene cool period culminated in the middle Miocene.

Although the evidence for a climatic deterioration in the Oligocene and a subsequent warming trend in the early to middle Miocene seems clear at this time, the evidence for possibly associated glacio-eustatic effects is ambiguous. Tertiary glaciation in Antarctica of probable Oligocene age is suggested by the work of Rutford and others (1968) and Margolis and Kennett (1971), but evidence for possible eustatic sea-level changes is usually masked by local tectonic activity. This is particularly true for the Pacific coast of North America where plate interactions in the Tertiary have had a strong effect on local tectonics, but the widespread Oligocene regression on the Pacific coast suggests that glacio-eustatic sea-level changes may, in fact, have occurred. There is, unfortunately, no evidence from the Simmler and Vaqueros Formations bearing directly on possible eustatic sea-level changes. The tectonics of the Caliente Range-Carrizo Plain area have effectively obscured the record in that regard.

Vaqueros Formation

The marine Miocene strata in the Caliente Range area form a transgressive-regressive sequence between the continental Simmler Formation below and the continental Caliente Formation above. The evidence, to be reviewed below, indicates that this sequence is strongly asymmetric. The deposits of the regressive phase form the bulk of the marine strata. Although this report is concerned principally with the early Miocene portion of the sequence, the marine strata of the regressive phase include middle Miocene strata in the vicinity of Caliente Mountain and late Miocene strata in the northwestern Caliente Range.

The thickness and facies relationships of the regressive deposits indicate that sedimentary progradation was the dominant, if not the sole, cause of the regression. Within a prograding sequence, the type of deposit will depend primarily on the inter-relationships of tectonics, sediment supply, and coastal processes. The possibilities range from a simple prograding beach or barrier island-lagoon complex to various types of delta complexes. The determination of which type of depositional complex is represented in the rocks is often strongly dependent on the geometry of the deposit, but in structurally complex areas this is difficult to establish. The interpretation must be based principally on the vertical succession of facies within the broad framework of the transgressive-regressive cycle. The original lateral sequence of depositional environments may then be inferred from the vertical sequence of deposits according to Walther's Law (Middleton, 1973).

Quail Canyon Sandstone Member

The Quail Canyon Sandstone Member of the Vaqueros Formation is the basal unit of the marine sequence and the first element of the transgressive phase. The fossils in the Quail Canyon Sandstone Member, although not thoroughly studied to date, are apparently all sublittoral to littoral mollusks (Vedder, 1973). There is nothing in the lithology or sedimentary structures of the member to suggest anything other than high-energy shallow-marine environments. The differences in lithology that are present, however, suggest a variety of nearshore or strandline deposits that varied with the local conditions. The common planar stratification, especially in the lower part of the member (e.g., plate 2), suggests the deposits of a beach-barrier complex, although lagoonal deposits generally appear to be absent. The upper part of the member may be interpreted as the deposits of the nearshore zone. Cross-bedding in the member usually indicates paleocurrents toward the northwest (fig. 48). This is in the same general direction as the paleoslope in the immediately underlying Simmler Formation, and may be inferred to be the offshore direction in the Quail Canyon Sandstone Member. Offshore directed cross-bedding in modern sediments is most common in the inner part of the nearshore zone (Clifton and others, 1971). Other cross-bedding (fig. 14) with original foreset dips to the north or northeast was probably formed by longshore currents.

The conglomerate and pebbly sandstone in the member in the subsurface of the Taylor Canyon and Morales Oil Field area indicate that coarse clastics were still being supplied to the basin there during the transgression. These are probably marine equivalents of part of the conglomerate facies of the Simmler Formation.

Soda Lake Shale Member

The Soda Lake Shale Member of the Vaqueros Formation represents the period during which the basin reached its maximum depth. The evidence indicates that only the lowest few hundred feet were deposited during the transgressive phase and the bulk of the member was deposited during the regressive phase.

There have, unfortunately, been no systematic studies of the foraminiferal assemblages of the Soda Lake Shale Member. Paleoecologic interpretations are limited to a few surface samples from the southeastern Caliente Range and a few paleontologic reports from scattered subsurface samples. In the southeastern Caliente Range, assemblages with the deepest water aspect occur in the lower platy shale unit about 300 to 500 feet (90 to 150 m) above the base of the member. These assemblages suggest bathyal depths. Siltstones less than 1,000 feet (300 m) stratigraphically above these assemblages contain sublittoral mollusks. Mollusks are relatively common in the member at the southeasternmost end of the range but become increasingly rare northwestward.

A few foraminiferal assemblages from the northwestern Caliente Range also suggest bathyal depths. The ages of the assemblages indicate that the cherty shale unit in the northwestern Caliente Range is approximately correlative with the lower platy shale unit in the southeastern Caliente Range. This "horizon" may be inferred to mark the time of greatest basin depth. Lithologically, this interval suggests a "starved-basin" type of sedimentation.

Where the Quail Canyon Sandstone Member is absent, as in the northwestern Caliente Range, the first transgressive deposits are usually thin very poorly sorted sandstones. In these areas the shoreline apparently traversed the area too rapidly to allow accumulation of shoreline sands. The lowest (transgressive) part of the Soda Lake Shale Member is considered to be an offshore deposit that is equivalent to the Quail Canyon Sandstone Member where the latter is present.

Most of the Soda Lake Shale Member is best interpreted as a basinal deposit with turbidite interbeds. The relatively small amount of sandstone and the distal appearance of the turbidites (e.g., fig. 15) suggests that the Caliente Range area was, for the most part, some distance from the shoreline during deposition of the member. However, the middle and upper part of the member in the southeastern Caliente Range is an exception in that it shows evidence of deposition under shallow-water near-shore conditions. The sandstone lenses in the middle part of the member there are enclosed by siltstones containing sublittoral mollusks. The uppermost of these lenses, described previously (fig. 17), is interpreted as a small sand delta of the type described by Gilbert (1883). Collinson (1969) has described very similar deltaic sedimentation units up to 130 feet (40 m) thick that occur as part of a larger delta complex in the Pennine Basin, England. If the interpretation is correct, the top of the lens approximates sea level at the time of formation (fig. 51A). The water depth could not, then, have been more than about 100 feet (30 m) at the base of the lens. This small delta marks the culmination of the first phase of the regression. The delta platform and prodelta slope became, after renewed subsidence, a marine shelf and slope. The resulting submarine topography had a strong influence on subsequent Vaqueros sedimentation. A Pleistocene example of shelf construction by delta progradation is described by Curray and Moore (1964), in which the delta platforms were drowned by eustatic sea-level rise rather than by subsidence.

The channel-fill deposits a short distance westward probably represent small gulleys on the slope that were fed sand by prograding sand deltas at the top of the slope. Such deltas may have foreset slopes

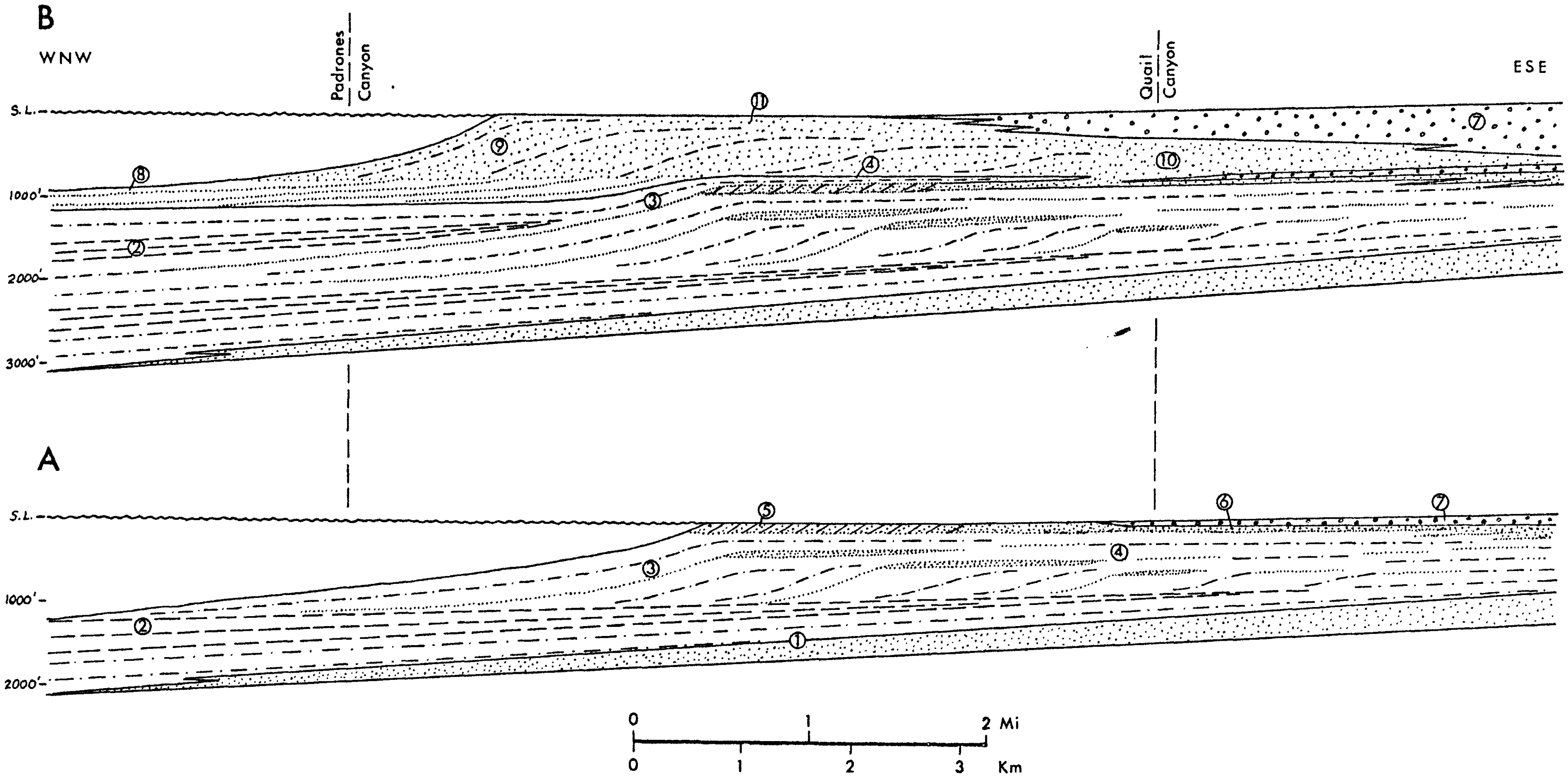

Figure 51.--Diagrammatic depositional model for Vaqueros Formation in southeastern Caliente Range showing distribution of sedimentary facies. A, during construction of small delta in Soda Lake Shale Member; B, during construction of Painted Rock delta. 1=transgressive nearshore sand and offshore silt; 2=deep basinal shale; 3=slope silts and sands; 4=shelf silts and sands; 5=delta; 6=nearshore sands; 7=fluvial sands and gravels; 8=proximal turbidites; 9=sediment gravity flow deposits of delta-front slope; 10=shelf sands; 11=beach-nearshore sands. (Depths and thicknesses only approximate.)

of 20° or more. It seems probable that high-concentration sediment gravity flows (Middleton and Hampton, 1973) generated by slumping (or by spontaneous liquefaction) on the upper delta slopes deposited much of the channel fills. Sediment gravity flows were probably more important in the deposition of the Painted Rock Sandstone Member, and they will be discussed further in the following section. The high-concentration sediment flows may have given rise to turbidity currents (Hampton, 1972; Middleton and Hampton, 1973), which deposited thin turbidites farther northwestward in the deeper parts of the basin.

The sandstone content, as well as the sublittoral mollusk content, of the upper part of the Soda Lake Shale Member in the southeastern Caliente Range decreases northwestward. The sandy portions, principally overlying the earlier delta platform and southeastward, are probably shelf deposits. Northwest of the area of delta progradation, the upper part of the member is probably a basin and lower slope deposit. Greater compaction in the areas where there was less sand may have accentuated the relief between shelf and basin.

There are no positive indications of shallow-water deposition in the Soda Lake Shale Member in the northwestern Caliente Range, although the increase in coarser sandstone near the top implies the approach of a prograding shoreline. The "chaotic" bed near the top of the member that was described previously (fig. 16) is interpreted as a sandy submarine debris-flow deposit. This suggests that the upper part of the member in that area is a slope deposit.

The Soda Lake Shale Member in the Cuyama Badlands area contains foraminiferal assemblages suggestive of upper bathyal depths to within half a mile of the San Andreas fault. The siltstones grade southward into sandstone, and that in turn grades into continental deposits to the south and southeast. This implies a deep marine trough or embayment along the trend of the present San Andreas fault.

Painted Rock Sandstone Member

The progradation continued with the deposition of the Painted Rock Sandstone Member. The position of this unit between basin slope (or shelf) deposits and overlying coarse fluvial deposits allows for interpretation under a variety of shallow-marine or strandline depositional models. The large volume of coarse clastics included in the member and the close association with coarse fluvial deposits, however, suggest a strong deltaic influence. Because the lithologic differences between the principal exposure areas of the member indicate variations in the depositional model, each area will be discussed separately.

Southeastern Caliente Range

The paleoecology of the invertebrate megafossils from the Painted Rock Sandstone Member in the southeastern Caliente Range has not been studied in detail. From what is known (Vedder, 1973), the assemblages appear to be largely, if not entirely, sublittoral to littoral. In general, megafossils become increasingly abundant upward and southeastward, which implies trends toward shallower water in those directions.

The lithology of the sandstones in the lower part of the member is strongly suggestive of sediment gravity flow processes. Middleton and Hampton (1973) classified subaqueous gravity flows according to the dominant sediment-support mechanism (table 5). These mechanisms are end members of a continuum, as was emphasized by Dott (1963), and in actual sediment flows a combination of mechanisms may be in operation. It is difficult, therefore, to distinguish between deposits of the different

Table 5.--*Classification of sediment gravity flows**

Type of flow	Sediment support mechanism
Turbidity current	upward component of fluid turbulence
Fluidized sediment flow	upward flow of escaping fluid
Grain flow	grain-to-grain interactions
Debris flow	yield strength of cohesive fluid phase

*after Middleton and Hampton (1973)

types of sediment flows. In actuality, most sediment gravity flows are probably of two main types: "1) highly concentrated flows where sediment is supported by a range of different mechanisms, including turbulence; and 2) relatively low concentration flows, with sediment supported by turbulence (turbidity currents)" (Middleton and Hampton, 1973, p. 30). High concentration sediment flows such as sandy debris flows give rise to low concentration turbidity currents, as described by Hampton (1972). In practice, deposits of turbidity currents may usually be recognized on the basis of their distinctive sequence of sedimentary structures (the "Bouma sequence"), their bedding characteristics, and their sole markings. The deposits of the high concentration sediment flows probably include those deposits of turbidite basins that have been referred to as "fluxoturbidites" and in some cases as proximal turbidites. They form a large part of the "proximal-exotic" group of facies of Walker and Mutti (1973).

The thick massive sandstones of the Painted Rock Sandstone Member (fig. 19) that are characterized by poor sorting, dispersed clasts, coarse-tail grading, and occasional reverse grading at the base are interpreted as deposits of high concentration sediment gravity flows. Whatever the actual depositional mechanism, the flows were capable of eroding small channels (e.g., fig. 20). Even the thicker graded sandstone beds that can be described by the Bouma sequence may be largely deposits of high concentration sediment flows.

The mechanisms of high concentration sediment gravity flows generally require fairly steep slopes to operate. Pure grain flows, for example, require slopes of at least 18° (Middleton, 1970). A delta of coarse-grained sediment might easily have a steep enough slope, although no actual foreset beds like those in the small delta in the Soda Lake Shale Member were observed. Nevertheless, it seems probable that the sediment flow deposits of the Painted Rock Sandstone Member originated in the same way as was proposed for the Soda Lake delta--by slumping on a steep delta-front slope. A model for the inferred downslope sequence of depositional processes is illustrated in figure 52.

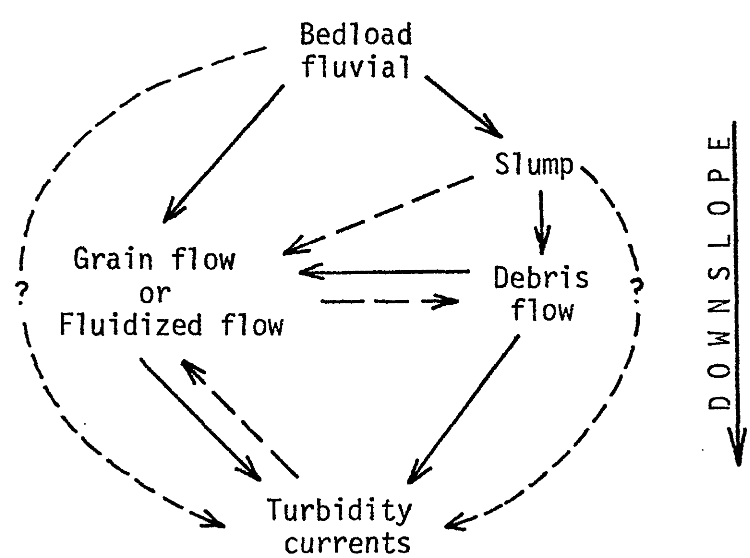

Figure 52.--Physical processes flow diagram showing the inferred downslope sequence of depositional processes on the delta-front slope (modified from Klein and others, 1972).

The presence of cross-bedding indicates that traction currents also played a part in the deposition of the Painted Rock Sandstone Member. The bimodal bipolar paleocurrent pattern for the member (fig. 48) indicates a tidal influence. The rare occurrence of medium-scale cross-bedding in graded sequences suggests that tidal channel or estuarine deposits laid down near the delta-front break in slope are also present locally.

The uppermost marine sandstones of the Painted Rock Sandstone Member (fig. 21) in a number of places contain an assemblage of sedimentary structures that are distinctly different from those of the sediment flow deposits lower in the member. These sandstones are characterized by planar stratification with reverse-graded laminae and heavy mineral concentrations that are considered to be characteristic features of beach deposits (Clifton, 1969). Associated sedimentary structures are also common features of beach-nearshore deposits (Clifton and others, 1971; Clifton, 1973). Offshore directed cross-bedding in this part of the member probably formed in the inner nearshore zone, like that in the Quail Canyon Sandstone Member.

The proposed sedimentary model for the Painted Rock Sandstone Member in the southeastern Caliente Range is that of a prograding coarse-grained delta complex in which sediment gravity flows played a large part in moving detritus down the delta-front slope. Klein and others (1972) proposed a similar model for delta-front gravity processes in the Cretaceous of Brazil. The member is composed of large lenticular sandstone bodies separated by siltstones that locally contain sublittoral megafossils. Although the lowest part of the member appears to have been deposited at greater depth than the uppermost part, there does not appear to be a single uniform progression from deep-water to shallow-water facies. Each sandstone body represents a partial shallowing cycle followed by sublittoral siltstones, but with an overall shallowing trend upward through the member. The development of such overlapping cycles was explained by Coleman and Gagliano (1964) in terms of shifting delta lobes in a continually prograding delta complex.

The vertical sequence at any one place in the southeastern Caliente Range is partly dependent on the position relative to the small shelf that was constructed during deposition of the Soda Lake Shale Member. The part of the Painted Rock Sandstone Member that prograded over this shelf is relatively thin and grades up into fluvial deposits of the Caliente Formation (fig. 51B). It includes only a minor amount of sediment flow deposits at the base overlying prodelta and shelf siltstones of the Soda Lake Shale Member. There are local beach-nearshore deposits in the upper part, and a considerable thickness of fluvial strata is probably included in the member in this area.

The part of the Painted Rock Sandstone Member that prograded westward past the edge of the shelf is considerably thicker and grades up into interbedded marine and continental deposits. The lowest few hundred feet in the Padrones Canyon area is interpreted as a proximal turbidite facies overlying basin and lower slope deposits of the Soda Lake Shale Member. The penecontemporaneous slump block in these rocks (fig. 18) indicates an appreciable slope to the depositional surface. These proximal turbidites were probably deposited on a submarine fan at the base of the delta-front slope and are probably channelized, although their occurrence in channels could not be documented. The bulk of the member in the Padrones Canyon area is composed of cycles of delta-front slope sediment-flow deposits and sublittoral siltstone and fine sandstone. The delta-front sediment-flow deposits are probably also channelized, although only a few small channels were recognized in the field. Occasional cycles may include tidal channel or estuarine deposits in their upper part. Nearshore and beach deposits appear at the top of cycles in the upper part of the member, and the uppermost three or four cycles are essentially beach-nearshore deposits and fluvial sandstone, conglomerate and red mudstone.

Northwestern Caliente Range

Most of the Painted Rock Sandstone Member in the northwestern Caliente Range represents the continuation of the regression begun during deposition of the Soda Lake Shale Member. The uppermost part, however, suggests different conditions of sedimentation, and the member then grades up into outer sublittoral and bathyal siltstone and shale of the Monterey Shale, indicating a temporary reversal of the overall Miocene regressive trend.

The absence of "Vaqueros age" megafossil assemblages from most of the Vaqueros Formation on the northeast flank of the La Panza Range strongly suggests that there was no connection with the Salinas Valley area during provincial early Miocene time. The northwestern Caliente Range-Carrizo Plain area, then, was located at the head of a gulf.

Invertebrate megafossil assemblages in the Painted Rock Sandstone Member in the northwestern Caliente Range invariably indicate inner sublittoral or shallower environments. Megafossils are rare throughout most of the member but become more abundant in the upper part. The trace fossils in the member are also shallow-water types. The very rare type of burrow consisting of a concentration of small intertwined tubes (fig. 30) has been observed elsewhere in rocks ranging in age from Late Cretaceous to Pleistocene. They always occur in rocks interpreted as deposits of a very shallow marine environment (H.E. Clifton, written commun., 1973). The large silicified wood fragments and logs (fig. 25), although relatively rare, are also suggestive of very shallow-water nearshore conditions.

The accumulation of several thousand feet of coarse clastics in a very shallow marine environment suggests a strong deltaic influence on the sedimentation in this area also. There is a similarity between the Painted Rock Sandstone Member of the northwestern and that in the southeastern Caliente Range, primarily because of the thick-bedded coarse-grained sandstone common to both areas, but there are important differences. The major difference is the abundant evidence of strong traction currents provided by medium- and large-scale cross-bedding and associated cut-and-fill structures, and planar stratification in coarse-grained sandstone (figs. 24, 26, 27, 29). Some thick pebbly sandstones, massive and poorly sorted, are present in the lowermost part of the member (fig. 23) that might be interpreted as sediment gravity flow deposits, but they are much less common than in the southeastern Caliente Range. Another difference is the greater degree of lenticularity of the sandstones in the northwestern Caliente Range.

None of these things is prohibitive of a deltaic sedimentation model for the northwestern Caliente Range, but the delta must have been quite different from the Painted Rock delta in the southeastern Caliente Range. The occasional localities with bimodal paleocurrent directions, particularly opposed medium- and large-scale cross-bedding, indicate locally strong tidal influences. It is proposed that the lower part of the Painted Rock

Sandstone Member in the northwestern Caliente Range represents a coarse-grained tide-dominated delta that was built into the head of a gulf with a fairly high tidal range. Tide-dominated deltas are characterized by sand bodies and tidal channels elongated in the direction of tidal flow (Scott and Fisher, 1969). Although there is no presently known model for sedimentation in a very coarse-grained tide-dominated delta, the Painted Rock Sandstone Member might be an ancient example of such a delta. The abundant cross-bedding indicates extensive sublittoral sand waves and dunes that are consistent with this interpretation. The predominant southerly paleocurrent directions indicate net tidal flow, and progradation of the delta, in that direction. The greater lenticularity of the sandstone bodies is probably due mostly to the orientation of the outcrop belt relative to the direction of progradation. The southeastern Caliente Range exposures provide a longitudinal section of the delta, whereas the northwestern Caliente Range exposures provide a transverse section. The lenticular bodies in the northwest may be cross-sections of elongate tidal sand bodies.

The more regular bedding in the uppermost part of the member suggests a change from deltaic sedimentation. The concentrations of megafossils in thin concretionary layers that are common to this part of the member are probably storm-related lag deposits (Brenner and Davies, 1973) and may be characteristic of open-shelf conditions. This change in conditions may have been related to the opening of the gulf to the northwest early in provincial middle Miocene time, or late early Miocene time.

Central Caliente Range

The Painted Rock Sandstone Member in the central Caliente Range also consists of a very thick accumulation of coarse clastics but does not appear to have had a direct deltaic influence. Assemblages of sublittoral invertebrate megafossils are relatively abundant throughout the member in this area (Eaton and others, 1941), and the uppermost part intertongues southwestward into the lower part of the Monterey Shale, which contains outer sublittoral foraminiferal assemblages (Phillips, 1972). The Painted Rock Sandstone Member northeast of Caliente Mountain is overlain by siltstones of the Monterey Shale containing sublittoral mollusks (Vedder, 1970, 1973), whereas the correlative strata on the southwest side of the mountain contain bathyal foraminiferal assemblages (Phillips, 1972). The offshore direction, then, was apparently toward the southwest or west.

The evenness of the bedding (fig. 22), the relatively fine grain size of the sediment, and the abundance of megafossils suggest open shelf sedimentation. The megafossils in this area, as in the upper part of the member in the northwestern Caliente Range, tend to be concentrated in thin layers that are probably storm-generated. The central Caliente Range during deposition of the Painted Rock Sandstone Member appears to have been an open marine shelf which probably received its sediment from deltas to the northwest and southeast by tidal and longshore currents.

Paleocurrent directions from the fairly common cross-bedding are inconsistent, as would be expected in shallow marine waters affected by tidal and longshore currents. Evidence for strong currents sweeping through the area is provided by the very large-scale cross-bedding at "The Painted Rock" (fig. 28). There may have been a slight shoaling in that area as a result of compaction of sediments over the buried basement ridge.

Undivided Vaqueros Formation

The relatively thin Vaqueros Formation of the La Panza Range differs from most of the formation in that it does not record a transgressive-regressive cycle. This part of the formation, regardless of its age at any one location, records only a simple transgression as the sea moved across the basin margins with subsidence. There is, of course, no time correlation between this transgression and the one recorded by the Quail Canyon Sandstone and Soda Lake Shale Members.

The Vaqueros of the La Panza Range, like much of the Painted Rock Sandstone Member, contains locally abundant sublittoral to littoral invertebrate megafossils. Assemblages suggestive of brackish water occur locally at the base and just above the thin claystone unit at both localities where the Vaqueros overlies small patches of Simmler Formation. The sequence shows an overall deepening upward from continental deposits (of the Simmler) or an unconformity at the base to foraminiferal assemblages indicative of outer sublittoral to perhaps bathyal depths in the overlying Monterey Shale. Trace fossils are more common than in the Painted Rock Sandstone Member, but the same shallow-water marine types are represented (figs. 30 and 32). Thin concretionary layers with concentrations of megafossils are also more common (fig. 31). These concretions are interpreted as storm lag deposits and are probably most common on open marine shelves (Brenner and Davies, 1973).

The basal part of the Vaqueros Formation in the La Panza Range was obviously deposited in very shallow-water nearshore environments. There was evidently a variation along depositional strike from rocky headlands to small inlets. Higher parts of the formation apparently represent open shelf sedimentation. The thin claystone unit near the base, with the associated brackish-water megafossils and thin limestone beds, probably represents lagoonal deposits formed behind a coastal barrier. The distribution of the conglomerate facies of the Simmler Formation on the northeast flank of the La Panza Range (plate 4) suggests that it was deposited in a valley cut into the basement rocks. The lagoon, then, probably formed in an inlet with a sand bar or beach ridge across the entrance.

Paleocurrent directions in the Vaqueros Formation of the La Panza Range are mostly parallel to depositional strike and probably represent longshore currents. Local reversals on the northeast flank of the range may have resulted from irregularities in the shoreline. The large-scale cross-bedding in the southeastern La Panza Range (fig. 33) indicates currents strong enough to have formed large dunes or sand waves on the shelf.

As noted in the section on stratigraphy, the Vaqueros Formation overlying the patch of Simmler Formation at the northwest end of Barrett Ridge is similar in many ways to the Painted Rock Sandstone Member to the north, and appears to have a lithology intermediate between that in the La Panza Range and that in the northwestern Caliente Range. The similarities are strongest for the upper, and age correlative, part of the Painted Rock Sandstone Member. An open marine shelf existed in both areas in provincial middle Miocene time, and there is no evidence of a major dislocation between the two areas. Furthermore, the paleocurrents of the Vaqueros in the La Panza Range are consistent with the interpretation that the two areas were contiguous, or nearly so, during deposition.

GEOLOGIC HISTORY AND PALEOGEOGRAPHY

Structural Complications

Red Hills-Chimineas-Russell Fault Trend

The combined Red Hills and Chimineas faults form an apparently continuous structure from north of the Red Hills, where the fault approaches and probably joins the San Andreas fault, to a point southeast of Barrett Ridge (plate 1). The Chimineas fault appears to have been overridden by the Big Spring thrust fault just west of Hubbard Hill and is concealed by late Pliocene continental strata of the Morales Formation southeast of Barrett Ridge.

The Russell fault, probably a continuation of the Red Hills-Chimineas fault, is a subsurface structure that has been traced northwestward from the vicinity of the South Cuyama Oil Field using adequate well control. It passes along the southwest sides of the Russell Ranch, Morales and Taylor Canyon Oil Fields, and is traced to within a few miles of the southeast end of the Chimineas fault. It has been overridden by the Whiterock thrust fault between the Taylor Canyon and Russell Ranch Oil Fields and is concealed beneath continental Pliocene and Quaternary strata in the Cuyama Valley. The Russell fault is overridden by the South Cuyama fault on the south side of Cuyama Valley and essentially disappears into a region of complex structure southeast of the South Cuyama Oil Field. The Russell fault, as well as the Red Hills and Chimineas faults, appears to form the boundary between granitic basement of Cretaceous age and older gneissic basement.

Schwade and others (1958) reported 23 miles (p. 85) or 14 miles (p. 91) (32 or 23 km) of right-lateral separation of the unconformable contact between granitic rock and Cretaceous strata by the "Russell-

San Juan" fault (=Chimineas-Russell fault of this report). The Vaqueros subcrop map (plate 4) provides better evidence for offset along this fault trend. Both the Cretaceous-basement contact at the southeast end of Barrett Ridge and the unconformable contact between the basement rocks and the Simmler Formation at the northwest end of the ridge show a right-lateral separation of about 8 to 9 miles (13-14.5 km) from the inferred subsurface position of those contacts on the southwest side of the fault. Because the Cretaceous-basement contact dips south and the Simmler-basement contact dips north, the measured separation gives a much more reliable estimate of offset than the separation on only one low-dipping contact. If the ends of the Chimineas and Russell faults are not actually joined, but overlap in en echelon fashion, a few more miles of separation on the Cretaceous-basement contact might be possible.

Restoring 8 or 9 miles (13-14.5 km) of right-lateral slip on the Chimineas-Russell fault trend effectively separates the Vaqueros Formation of the northeast flank of the La Panza Range (mostly "Temblor age") from the Vaqueros of the southeastern La Panza Range ("Vaqueros age"). This restoration brings the Painted Rock Sandstone Member in the central Caliente Range opposite the Vaqueros of the southeastern La Panza Range; both are overlain by Monterey Shale of Saucesian age.

The Red Hills-Chimineas-Russell fault trend separates Cretaceous granitic rocks from Precambrian(?) gneissic rocks. Both are overlain by Upper Cretaceous strata indicating that the juxtaposition of the two basement terranes apparently occurred during the Cretaceous. There does not appear to have been any movement from Late Cretaceous to Oligocene time because strata of those ages have about the same separation. Oligocene through upper Miocene strata are truncated by the fault, but upper(?) Pliocene strata are apparently not displaced. The offset discussed above, then, must have occurred in about early Pliocene time. The Red Hills fault can be traced through the Plio-Pleistocene Paso Robles Formation, suggesting minor displacement at the northwest end of the trend subsequent to deposition of the Paso Robles.

Major Thrust Faults

The Big Spring, Whiterock, and Morales faults form a series of northeastward-dipping thrusts that trend obliquely across the block between the Red Hills-Chimineas-Russell fault trend and the San Andreas fault (plate 1). The convex southwest pattern of these faults brings their northwest ends subparallel to the Red Hills-Chimineas-Russell fault trend. The thrusts appear to either die out into zones of folding or become bedding-plane faults at their northwest ends. The Morales thrust, however, can be traced northwestward in the subsurface from its surface termination and may merge with the Big Spring thrust. The presence of the Morales thrust along the south front of the southeastern Caliente Range can be demonstrated by a number of wells, but the map trace is only approximate. On the basis of subsurface control, the dips of the faults are generally 45° or less, but they probably steepen with depth to become reverse faults.

There is no direct evidence of the slip direction for these thrusts, but their map pattern suggests a northeast to southwest direction of thrusting. On the other hand, the regional pattern of northwest-southeast right-lateral shear suggests that an oblique north-to-south slip is more likely.

The significance of the thrusts in this study is that they separate the very thick Vaqueros Formation in the Caliente Range from the thin

Vaqueros in the La Panza Range and Cuyama Valley. The sandstone (or fluvial) facies of the Simmler Formation also appears to be largely restricted to the area northeast of the thrusts. There are no anomalous facies contrasts for correlative Vaqueros strata that would require large-scale displacements on the thrusts. The differences can be accounted for by buttressing out the Soda Lake Shale and much of the Painted Rock Sandstone Members against the basin margin so that only the uppermost part of the formation lapped over the margin. Schwade and others (1958) inferred a fault zone at the basin margin to account for the differences in thickness. The much greater subsidence of the basin, as indicated by the great thickness of sediments accumulated there, strongly suggests such a zone of normal faulting at the basin margin during early Miocene time. This zone of faulting, like some in the Salinas Valley (Kilkenny, 1948), was reactivated as thrusts in the late Tertiary and Quaternary. It is probable that the shortening across the thrusts is on the order of 2 to 3 miles (3-5 km), and possibly as much as 4 miles (6.5 km), across the southeast end of the Morales fault. It will be assumed here that the shortening was in a north-south direction.

The youngest rocks involved in thrusting on the Big Spring fault are late Miocene in age; it apparently does not displace Pleistocene sediments. The Whiterock and Morales faults both involve continental strata of early(?) Pliocene age, and subsurface evidence indicates that sediments of late Pliocene or Pleistocene age are overridden along the south front of the southeastern Caliente Range. Most of the movement on these thrusts, therefore, probably took place during the late Pliocene. There is a possibility that the Big Spring fault may be slightly older, and the southeastern part of the Morales fault has probably been active since the late Pliocene.

Restoration of displacements in the San Andreas fault system (Dickinson and others, 1972) would place the Caliente Range-Carrizo Plain block in the vicinity of the "big bend" segment of the San Andreas fault during the Pliocene. The thrusting in that block may then be related to the north-to-south compression that has characterized the Transverse Ranges portion of the San Andreas fault system in post-Miocene time (Jahns, 1973).

San Andreas Fault

This study provides no direct evidence bearing on offsets along the San Andreas fault, but the interpretations presented here are consistent with previous determinations of approximately 185 miles (300 km) of right-lateral slip since early Miocene time. (See Dickinson and others, 1972; Huffman, 1972; and Clarke and Nilsen, 1973 for summary.) According to Crowell (1973), the San Gabriel fault was the principal strand of the San Andreas fault system in southern California from late Miocene to late Pliocene time, and the San Andreas fault between the Tejon Pass area and Cajon Pass area only came into existence in latest Pliocene time. Restoring combined offsets on the San Gabriel and San Andreas faults would place the Caliente Range-Carrizo Plain block opposite the northwest end of the San Gabriel Mountains block, and the combined Caliente Range-San Gabriel block opposite the area of the present San Bernardino and Orocopia Mountains, in pre-Miocene time. The Plush Ranch Formation of the Lockwood Valley area is believed to have been contiguous with the Vasquez Formation of the Soledad basin (Crowell, 1973; Carman, 1964), and part of the Simmler Formation may also be equivalent to part of the Vasquez. Remnants of the Vaqueros Formation, however, have not been identified in the San Gabriel block. They may lie buried under

Pliocene and Pleistocene continental deposits at the northwest end of the block. The northwest end of the Carrizo Plain was probably adjacent to the Cajon Pass area, and the "Vaqueros" strata at Cajon Pass may represent the northern end of the Caliente Range-Carrizo Plain basin.

Palinspastic Reconstruction

A palinspastic base for paleogeographic maps of the Caliente Range-Carrizo Plain area was constructed by removing the effects of folding, in addition to the faulting discussed above. The total north-south shortening in the Caliente Range-Carrizo Plain block increases toward the southeast end of the area. There appears to be only a mile or two of shortening across the northwestern Caliente Range and Big Spring fault, but there may be six or seven miles of shortening across the southeastern Caliente Range and Morales fault. The South Cuyama fault, which is included in the area, changes character from a high-angle reverse fault near the Cuyama Gorge to a thrust near its southeast end. In the latter area it forms the leading edge of an area of tight folding and thrust faulting, including the Ozena fault.

Synthesis

Oligocene time

During Oligocene time (fig. 53) the Caliente Range-Carrizo Plain area was occupied by an elongate alluvial plain that was probably fault bounded. The streams flowing across this plain were of small to moderate size and carried little material coarser than medium-grained sand, suggesting that the surrounding country had relatively subdued topography. Alluvial fans may have existed at this time at the southeast end of the alluvial plain (the area of the present Cuyama Badlands).

The sediments in the northwestern part of the plain were derived from a crystalline basement terrane to the north or northwest and transported south or southeastward. Sediments in the southeastern part of the plain were derived from crystalline basement rocks to the southeast and transported northwestward. Part of the source terrane for both northwestern and southeastern areas was probably on the opposite side of the present San Andreas fault.

The drainage outlet for this alluvial plain is problematical. It is unlikely that the streams flowed eastward into the area of the present San Gabriel Mountains or Mojave Desert. The only known Oligocene continental strata in that direction are included in the Vasquez Formation of the Soledad basin, which is a more proximal facies and may be equivalent to the alluvial fan deposits in the Cuyama Badlands. An outlet through the area of Tertiary strata in the southeastern Sierra Madre would require the streams that flowed through the area of the present southeastern Caliente Range to have turned nearly 180° southward. The most likely place for an outlet appears to be approximately through the area of the present Cuyama Gorge. Evidence of this outlet would

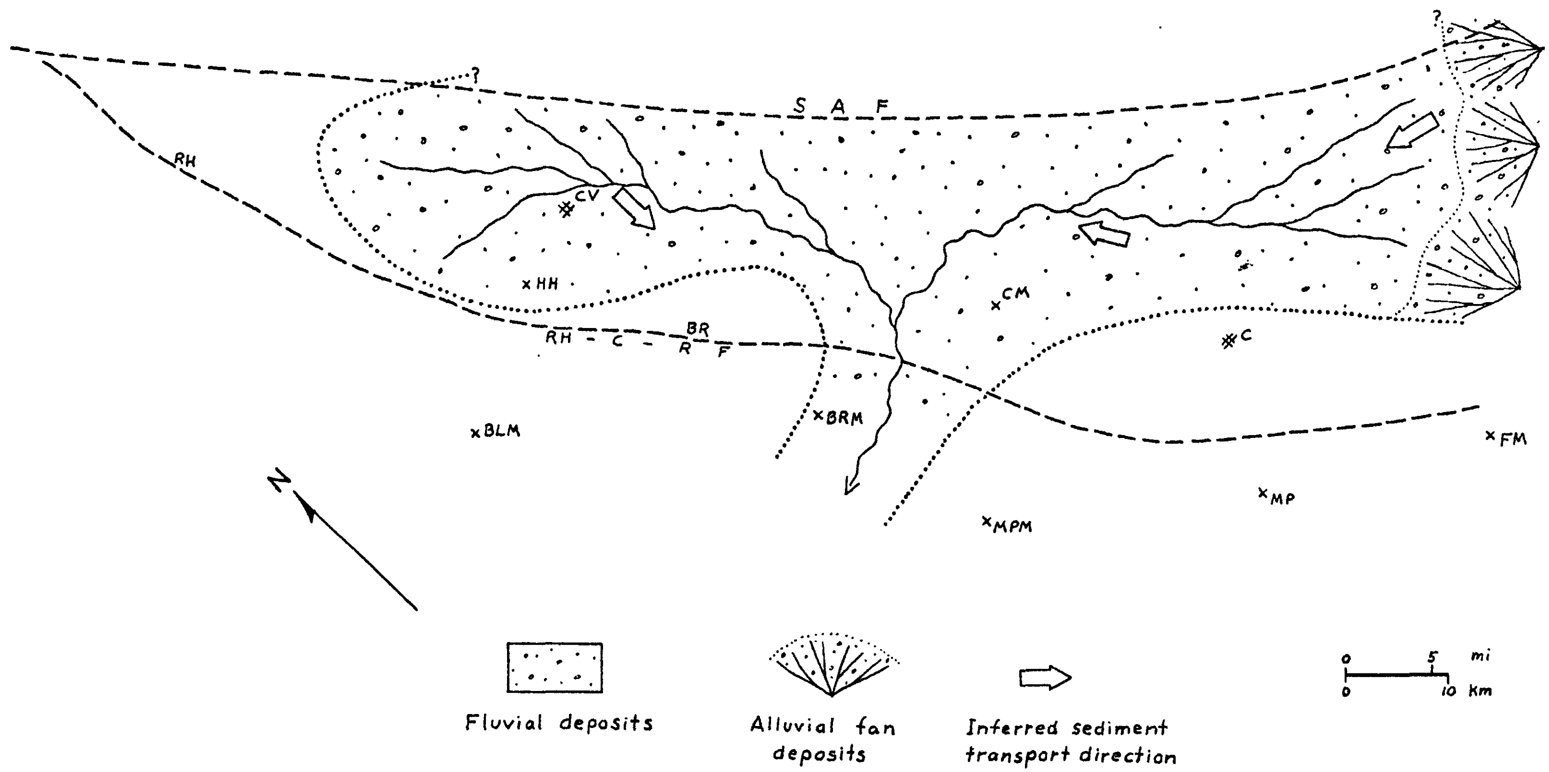

Figure 53.--Suggested paleogeography of the Caliente Range-Carrizo Plain area during Oligocene time. RH=Red Hills, CV=California Valley, HH=Hubbard Hill, BR=Barrett Ridge, CM=Caliente Mountain, C=Cuyama, BLM=Black Mountain, BRM=Branch Mountain, MPM=Miranda Pine Mountain, MP=McPherson Peak, FM=Fox Mountain, SAF=present trace of San Andreas fault, RH-C-RF=Red Hills-Chimineas-Russell fault trend.

now either lie buried under later Simmler alluvial fan deposits or have been removed by erosion. Further work would be necessary to test this hypothesis.

The coarsening and the increase in cycle thickness at the top of the Simmler indicates an increase in slope, which signals the beginning of the next tectonic phase.

Early "Vaqueros" Time

A marine transgression beginning in late Zemorrian time (ca. 25 m.y. B.P.) marks a major tectonic event. The profound subsidence of the basin indicates the beginning of a period of extensional tectonics that is probably related to the interaction between the North American and the Pacific plates. These two plates first came into contact about 29 m.y. ago opposite northern Baja California (Atwater and Molnar, 1973), and effects of their interaction became apparent progressively northwestward through time. A period of crustal extension accompanied by the formation of sedimentary basins beginning in early to middle Miocene time characterizes much of the California coastal area. A glacio-eustatic sea-level rise accompanying the post-Oligocene warming trend may have been approximately coincident with this tectonic event and may have contributed to the transgression.

The subsidence, which dropped the deeper parts of the basin from above sea level to bathyal depths, was probably localized along old fault zones on both sides of the basin. It was probably at this time that movements on the Nacimiento and Ozena faults cut off the former drainage outlet, causing alluvial fans to be built northeastward or eastward toward the basin (fig. 54). Small fans also formed northwest of Barrett Ridge, and perhaps elsewhere. The thick conglomeratic

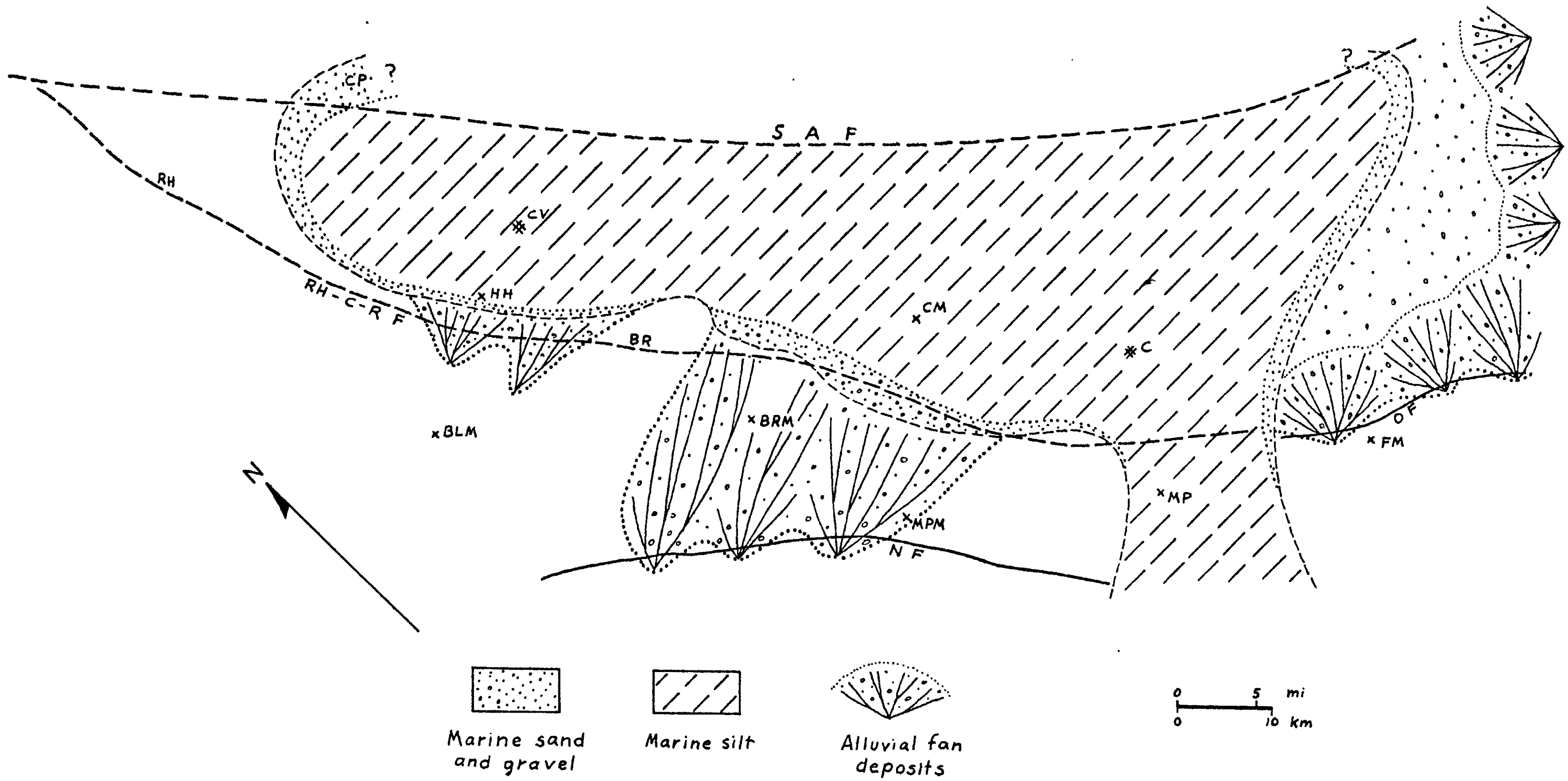

Figure 54.--Suggested paleogeography of the Caliente Range-Carrizo Plain area during early "Vaqueros" time. CP=Cajon Pass, NF=Nacimiento fault, OF=Ozena fault; other symbols as in figure 53.

Quail Canyon Sandstone Member southeast of Barrett Ridge indicates that the fans were built into the transgressing sea in that area. Most coarse sediment was apparently trapped around the basin margin or in the nearshore zone, and only silt and fine sand reached the deeper parts of the basin. The "Vaqueros" strata in the Cajon Pass area probably represent nearshore deposits at the north end of the basin that are now about 185 miles (300 km) southeast of their original position.

The sea apparently entered the Caliente Range-Carrizo Plain basin via the area of the present southeastern Sierra Madre, where lower Miocene marine strata are preserved on the crest of the range (Vedder and others, 1967). The northwest end of the basin was closed.

Late "Vaqueros" Time

Subsidence continued in late "Vaqueros" time, but sedimentation more than kept pace with the subsidence (fig. 55). Deltas of coarse-grained sediment prograded into the basin at the northwest end and along the southeast side. The basin was apparently closed at the northwest end through most of "Vaqueros" time, and the high tides at the head of this gulf produced a tide-dominated delta. Sediment entering the head of the gulf from a crystalline rock terrane to the north was transported southeastward along the southwestern shore. Sediment entering from the crystalline rock terrane to the east was dispersed across the shallow basin. There was apparently little sediment supplied from the west and southwest at this time, and the earlier alluvial fans were drowned.

Early "Temblor" Time

Accelerated subsidence at about the end of "Vaqueros" time drowned the southeastern delta and perhaps much of the northwestern delta, and

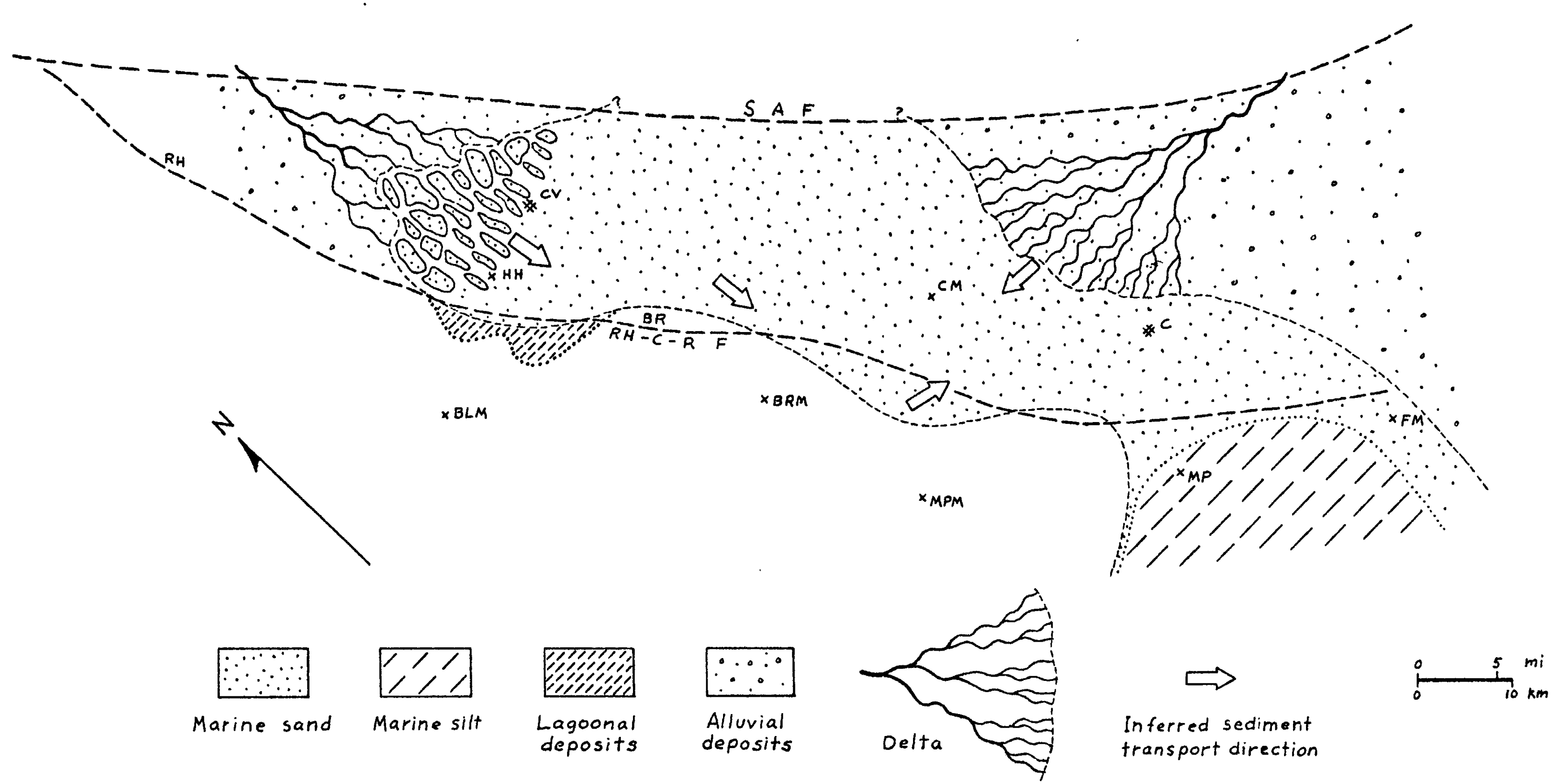

Figure 55.--Suggested paleogeography of the Caliente Range-Carrizo Plain area during late "Vaqueros" time. Symbols as in figure 53.

the gulf was opened to the northwest (fig. 56). Although there was a continuing supply of coarse-grained sediment from the same crystalline rock sources, open shelf rather than deltaic conditions prevailed in the northwestern part of the basin, and beach-nearshore deposits prograded westward into the southeastern part of the basin (Clifton, 1968). Fine-grained offshore sediments accumulated in the central and southern part of the basin. Continental deposits were apparently also prograding into the basin along the northeastern side. By this time the area to the southwest had been reduced to a low-lying island.

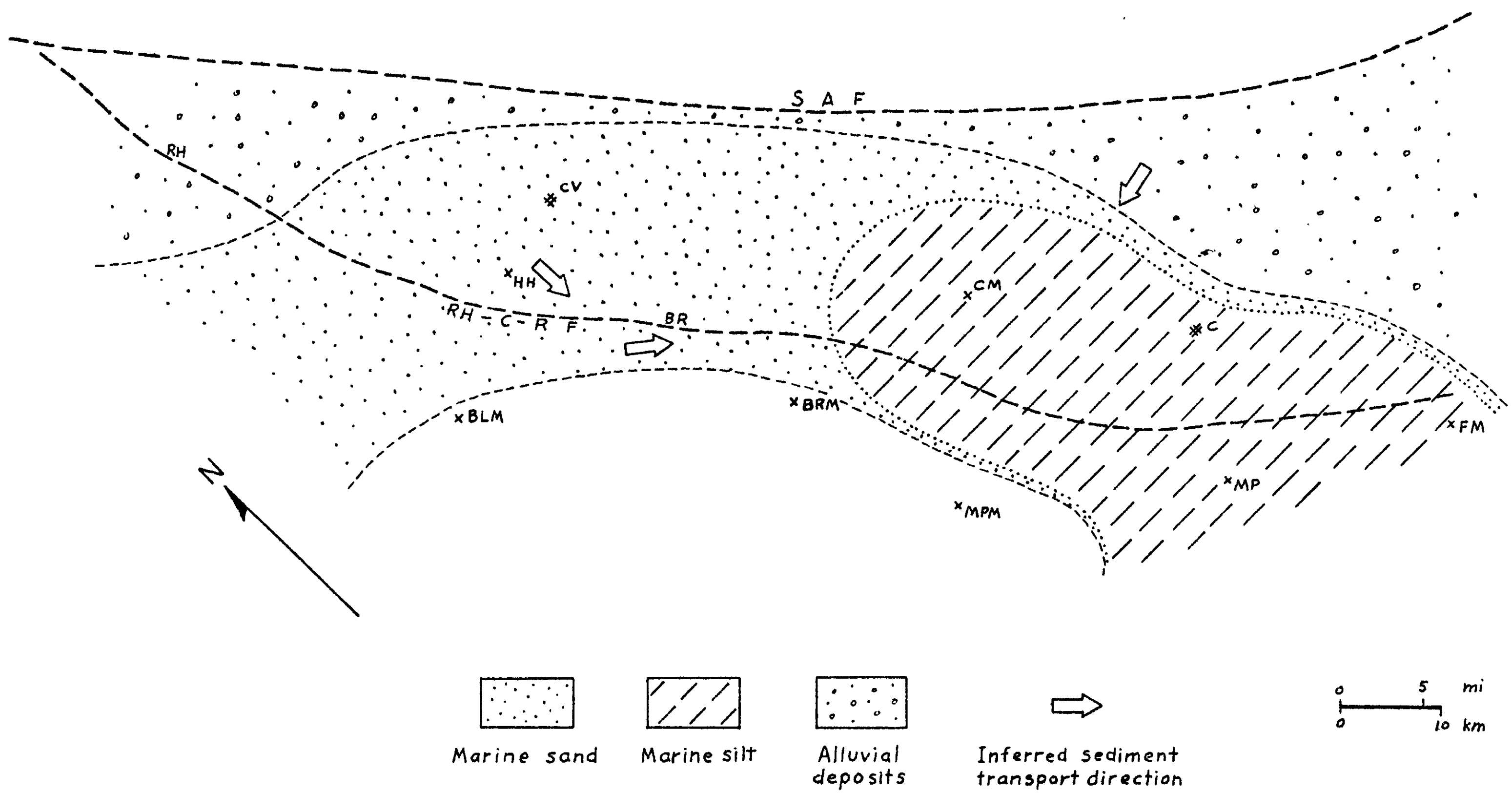

Figure 56.--Suggested paleogeography of the Caliente Range-Carrizo Plain area during early "Temblor" time. Symbols as in figure 53.

Conclusions

1. The Simmler Formation is composed principally of fluvial and alluvial fan deposits. The fluvial facies, which formed an alluvial plain in the area of the later deep marine basin, was deposited by small- to moderate-size low-sinuosity streams in a semiarid climate. The alluvial fan deposits to the southwest of the basin are lateral equivalents of the earliest Vaqueros marine sediments and developed in response to the basin subsidence and the consequent formation of fault scarps parallel to the basin margins.

2. The Vaqueros Formation of the central part of the basin forms a thick transgressive-regressive sequence. The transgressive deposits form only a minor part of the formation and consist of thin nearshore sandstones and offshore siltstones. The regressive deposits consist of a sequence of shelf and slope siltstones and deltaic sandstones that prograded basinward over basinal shales and turbidites. The sequence is topped locally by beach-nearshore deposits or by varying amounts of open-shelf sandstone and siltstone.

3. The period of crustal extension that resulted in the formation of a deep marine basin in early Miocene time was apparently related to interaction between the North American and Pacific plates, which first came into contact about 29 m.y. ago. The period of crustal extension and basin subsidence in the Miocene was followed by north-south compression in the Pliocene and Pleistocene, which resulted in basin-margin thrusting in the Caliente Range-Carrizo Plain block. The tectonic history of this area has many similarities to that in the Transverse Ranges as well as the Coast Ranges.

4. Large-scale right-lateral displacements took place along the Red Hills-Chimineas-Russell fault trend during the Cretaceous that resulted in the juxtaposition of Cretaceous granitic rocks and Precambrian(?) gneissic rocks. There is no evidence of further movement on these faults until Pliocene time, when 8 to 9 miles (13-14.5 km) of additional right-lateral slip occurred.

5. Although this study provides little evidence bearing directly on the history of the San Andreas fault, the evidence is consistent with the post-early Miocene offset of about 185 miles (300 km) postulated by previous workers. There is no evidence of large-scale lateral displacements on the San Andreas fault system from Oligocene through at least early Miocene time in the Caliente Range-Carrizo Plain area.

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