DEPARTMENT OF THE INTERIOR
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PROVENANCE OF THE UPPER MIOCENE AND PLIOCENE ETCHEGOIN FORMATION: IMPLICATIONS FOR PALEOGEOGRAPHY OF THE LATE MIOCENE OF CENTRAL CALIFORNIA

by
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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ABSTRACT

The composition of sandstone in the upper Miocene and Pliocene Etchegoin Formation in the vicinity of the southern Diablo Range is highly variable. Results of assays of framework grains and heavy minerals in Etchegoin sandstone from four stratigraphic sections, three in the Coalinga region and one in the San Benito region, suggest that many lithologically distinct types of detritus are found in Etchegoin strata. The detritus is identified on the basis of the relative abundance of quartz (Q), volcanic rock fragments (VRF), and metamorphic rock fragments (MRF) in the framework composition, and on the relation of these framework components to heavy mineral associations, which are inferred primarily from factor analysis. Three distinct types of plutonic detritus are found in sandstone of the Etchegoin and they are characterized by (1) Q found in association with green and brown hornblendes, (2) Q found in association with green and brown hornblendes, zircon, sphene, epidote, and garnet, and (3) O associated with green and brown hornblendes, epidote, and zircon. Three types of volcanic detritus are found in the sandstone, and they are characterized by (1) VRF associated with augite and brown hornblende, (2) VRF associated with hypersthene and brown hornblende, and (3) severely altered VRF not associated with volcanic accessory minerals. Metamorphic detritus is found in moderate amounts in sandstone of the Etchegoin, and it is characterized by MRF associated with actinolite-tremolite and glaucophane. Plutonic detritus characterized by Q associated with hornblende, zircon, sphene, epidote, and garnet and severely altered volcanic detritus are most abundant in sandstone in the Sulphur Creek region, and they are rare in the Etchegoin Formation in the Coalinga region.

Provenance of the Etchegoin Formation is inferred on the basis of the lithology and spatial distribution of detritus found within the sampled strata. The suite of detrital grains characterized by Q associated with green and brown hornblendes is interpreted to have been derived from hornblende-quartz-gabbroic rocks adjacent to the Vergales-Zayante fault, most of which are now covered by post-Pliocene rocks. The detritus characterized by Q associated with green and brown hornblendes, zircon, sphene, epidote, and garnet contains many grains with morphologic characteristics suggestive of a reworked origin. This detritus is similar in heavy mineral content to that found in sandstone in the Santa Margarita Formation along Anticline Ridge, from which it probably was derived. A Santa Margarita Formation source for Etchegoin detritus is supported by the presence of coarse-grained Santa Margarita detritus, Crassostrea fragments and felsic volcanic clasts, which are found as clasts in Etchegoin conglomerate. Detritus characterized by O associated with green and brown hornblendes, epidote, and zircon is found in some sandstone of the Etchegoin in the Coalinga region. This detritus may have been derived from the Sierra Nevada. A Sierra Nevada source is suspected because green and brown hornblende, epidote, and zircon are common in the mafic and intermediate plutonic rocks of the Sierra Nevada, and Sierran plutonic detritus is expected to be found in Etchegoin strata because east of the Coalinga region Etchegoin strata

grade laterally into the plutonic-rich rocks of the Kern River Formation. Kern River strata are thought to have been deposited as alluvial fans built westward into the San Joaquin basin from the plutonic basement of the Sierra Nevada. The volcanic detritus characterized by VRF associated with augite and brown hornblende or hypersthene and brown hornblende was derived from the Mehrten Formation and from coeval volcanic rocks at the crest of the Sierra Nevada in central California. A Sierra Nevada source is likely, because (1) the mineralogy of volcanic detritus in Etchegoin strata is similar to that found in the Mehrten Formation, and (2) the vertical succession of augite-rich to hypersthene-rich volcanic detritus found in Etchegoin strata in the Coalinga region occurs also in the upper Miocene volcanic rocks at the crest of the Sierra Nevada. The severely altered VRF found in Sulphur Creek sandstone is attributed to detritus recycled from volcanic-rich Franciscan rocks. A Franciscan source is inferred because altered mafic volcanic detritus is abundant in the nearby weakly metamorphosed to blueschist facies volcanic-rich strata in the Franciscan in the Diablo Range. Altered or metamorphosed mafic volcanic and intrusive rocks are found locally in the Franciscan, and they may have also contributed detritus to sandstone of the Etchegoin. The metamorphic detritus characterized by MRF associated with actinolite-tremolite and glaucophane probably was derived from blueschist facies Franciscan rocks in the Diablo Range.

Provenance of the Etchegoin Formation reflect major paleogeographic changes that occurred during the late Miocene and Pliocene in central California. Prior to the deposition of Etchegoin strata, the late Miocene of central California was characterized by two marine embayments: one in the San Francisco Bay region, the other in the central and southern parts of the San Joaquin Valley. At this time, the Gabilan Range, Santa Cruz Mountains region, and the central part of the Diablo Range were emergent. The paleogeographic changes that accompanied onset of deposition of Etchegoin strata include uplift in the northeastern and southern parts of the Diablo Range, and submergence of the Gabilan Range and most of the Santa Cruz Mountains region. Uplift in the northeastern part of the Diablo Range was responsible for changing the locus of deposition of Sierran volcanic detritus from the San Francisco Bay region to the San Joaquin Valley. Emergence of the southern Diablo Range is reflected by the presence of Santa Margarita Formation detritus as framework components and clasts in Etchegoin strata. Submergence of the Gabilan Range and most of the Santa Cruz Mountains region is inferred, because detritus characteristic of these regions is lacking in Etchegoin strata. However, the Gabilan Range probably remained a subsea high that prevented Santa Lucia Range detritus from entering the San Joaquin basin. The latter stage of deposition of Etchegoin strata was characterized primarily by continued deposition of Sierran and Diablo Range detritus in a restricted San Joaquin basin. The San Joaquin basin became restricted as a result of a closure of the southern seaway at about 6 Ma, and from a partial blockage of the northern seaway, outboard of the Coalinga region, by the Gabilan Range subsea high. The Gabilan Range subsea high was positioned outboard of Coalinga as a result of movement along the San Andreas fault, which averaged approximately 28 mm/yr during the past 7.5 Ma. The complex changes in mineralogic composition of Etchegoin strata in the southern Diablo Range and vicinity thus reflect changes in sediment dispersal caused by emergence and submergence of both nearby and far removed areas of central California.

INTRODUCTION

Throughout most of the Tertiary, the San Joaquin basin (fig. 1) was the site of nearly continuous marine deposition, which resulted in the accumulation of a thick sequence of predominantly hemipelagic mudstone and clastic turbidite sandstone (Bandy and Arnal, 1969; Webb, 1981). In the northern part of the basin and along its margins, deposits are dominantly shallow-marine or nonmarine clastics (Bartow, in press a). Tectonism and sea-level fluctuations shifted the locus of shallow-marine and nonmarine deposition along the margin of the basin in transgressive and regressive cycles. However, the deposition of the deep-water fine-grained detritus was nearly continuous in the central part of the basin. This scenario typified deposition in the basin until the late Miocene, at which time deposition of shallow-marine and nonmarine, coarse, clastic sediment spread throughout much of the basin. The late Miocene change in the San Joaquin basin may be associated with tectonism along the San Andreas fault (Harding, 1976; Blake and others, 1978); however, details of the change are poorly known. Because the composition of late Miocene strata in, and adjacent to, the San Joaquin Valley may record changes in basin morphology, provenance studies of the upper Miocene and Pliocene Etchegoin Formation may reveal some of the late Miocene changes that affected deposition in the San Joaquin basin.

Previous work on the provenance of the Etchegoin Formation was restricted to geographically small areas or small stratigraphic intervals, which hindered provenance interpretation on a regional scale. A study of the provenance and paleocurrents of 12 sandstone beds in the Coalinga region by Lerbekmo (1961) suggested that the Mehrten Formation, located in the west-central Sierra Nevada, contributed large amounts of volcanic detritus to the Etchegoin Formation. Lerbekmo further suggested that the non-volcanic detritus found within Etchegoin strata was derived from emergent areas of the Coast Ranges. Studies of the provenance, paleocurrents, and biostratigraphy of Etchegoin strata by Stanton and Dodd (1972, 1976) in the Reef Ridge and Kettleman Hills regions suggested that the primary sediment source lay to the west or south, and that a volcanic source was minor. Dibblee (1981) suggested that Etchegoin strata adjacent to the Diablo Range were derived primarily from the Diablo Range and from unspecified regions west of the San Andreas fault.

Inferences as to the late Miocene changes that occurred in and around the San Joaquin basin are difficult, because provenance determinations for different parts of the Etchegoin Formation are at variance. Such variance probably is a result of the lack of regional data regarding the composition of Etchegoin strata. This study is a determination of the framework and heavy mineral composition of Etchegoin sandstone in stratigraphic sections far removed from each other. From these data, provenance is determined and inferences are made as to some of the changes in late Miocene and early Pliocene paleogeography and tectonism that occurred in central California and affected the San Joaquin basin.

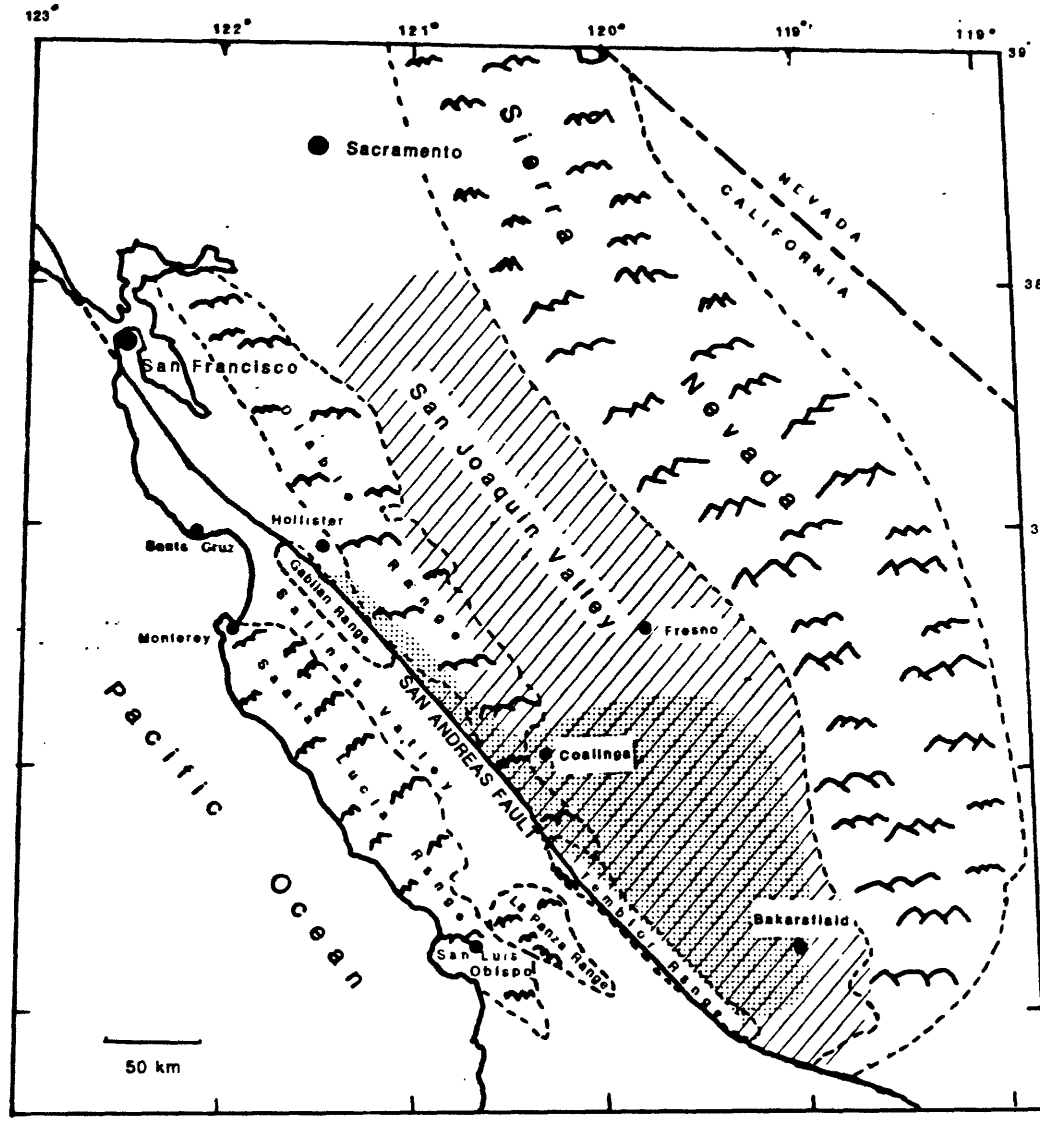


Figure 1. Map of central California showing the locations of the San Joaquin Valley (hachured area), and the original extent of Etchegoin deposition (stippled area)..

ETCHEGOIN FORMATION

Nomenclature

The nomenclature applied to the Etchegoin Formation is varied (fig. 2) owing to large compositional variations, the lack of a type locality, and the use of the term Etchegoin as a lithostratigraphic and chronostratigraphic term. Anderson (1905) applied the name "Etchegoin Beds" to sandstone, siltstone, and conglomerate on Anticline Ridge (fig. 3) that are "unconsolidated sands or gravels in which a characteristic blue or bluish-gray color predominates". A type locality was not defined and subsequent investigators have modified the original definition of Anderson (1905). Arnold and Anderson (1910) designated a region on Anticline Ridge as the type locality for the Etchegoin, and they introduced the term Jacalitos for the brownish-gray strata underlying bluish-gray Etchegoin strata. Unfortunately, the type locality defined and described by Arnold and Anderson (1910) is not mapped as Etchegoin rocks by these same authors. Nevertheless, most investigators have adopted the nomenclature proposed by Arnold and Anderson (1910), with variations generally restricted to formational boundaries. Major deviations from the nomenclature proposed by Arnold and Anderson (1910) either elevate the Etchegoin to group rank (Nomland, 1917; Bode, 1934), or discontinue formational subdivisions of the bluish-gray and brownish-gray strata (Adegoke, 1969).

Adegoke (1969) and Dibblee (1973) discontinued formational subdivision of the bluish-gray (Etchegoin) and brownish-gray (Jacalitos) strata because no regional physical or paleontological characteristic is unique to either of these units. The formational subdivisions of early workers were lowered to member or facies rank. The detailed work of Adegoke (1969) allowed Dibblee (1973) to designate a reference section along Reef Ridge (fig. 3). This report follows the nomenclature applied by Adegoke (1969) and Dibblee (1973), in that the term Etchegoin is of formational rank and includes strata called Jacalitos by some investigators. In this report, the upper part of the formation containing bluish-gray sandstone is referred to as the blue sandstone facies, and the lower part of the formation lacking bluish-gray sandstone is referred to as the brown sandstone facies.

The Etchegoin Formation is found extensively in the subsurface of the San Joaquin Valley. In the southwestern part of the valley it has been subdivided formally into two members: a lower Tupman Shale Member and an upper Carman Sandstone Member. These members are defined in well 324-19R in the Elk Hills by Berryman (1973).

Distribution and Thickness

The Etchegoin Formation is composed of marine and nonmarine sandstone, siltstone, and conglomerate that crop out extensively along the flanks of the southern Diablo Range (fig. 3). Etchegoin strata also are found in the subsurface throughout most of the central and southern San Joaquin Valley (American Association of Petroleum Geologists,

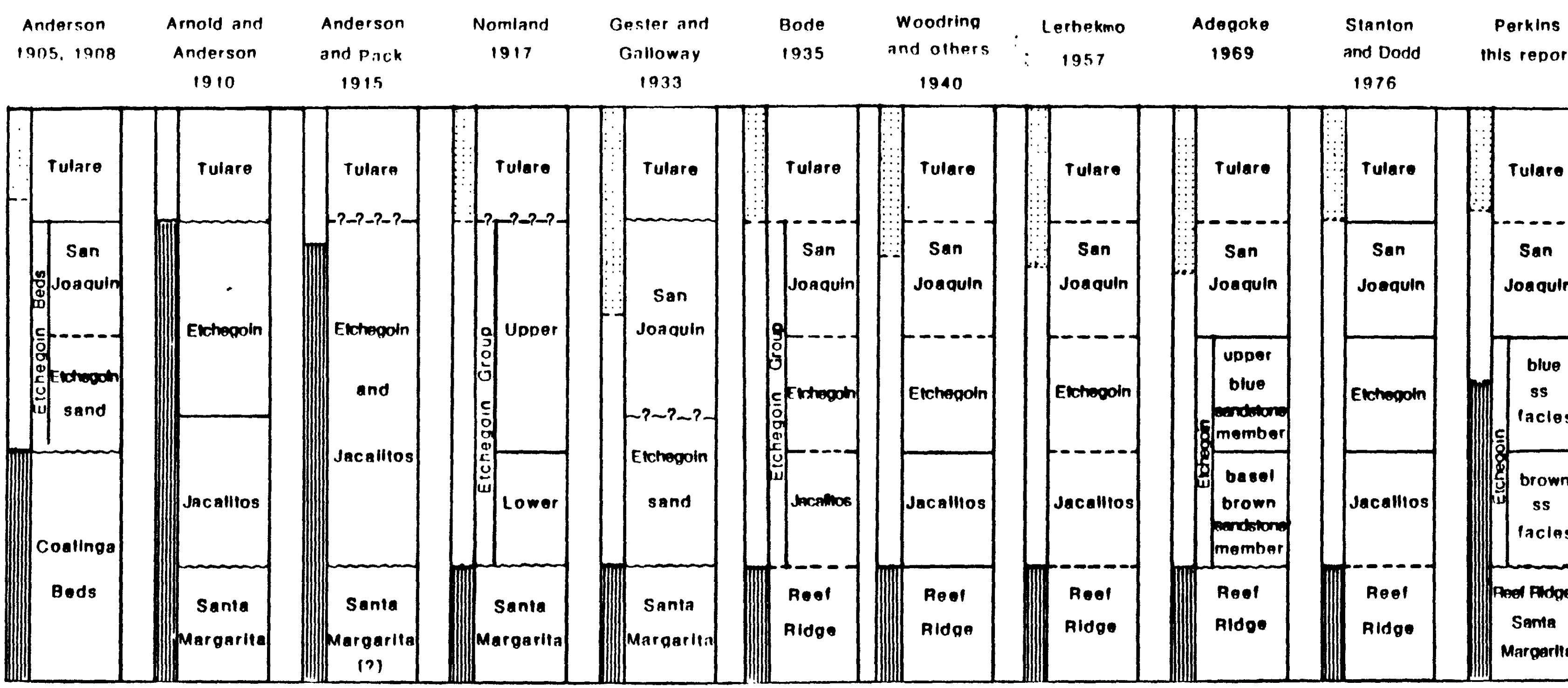


Figure 2. Nomenclature applied to the Etchegoin Formation. Age assignments are given to the left of each column; vertical lines represent the Miocene, unmarked regions represent the Pliocene, and stipples represent the Pleistocene. In the Anticline Ridge region, Adegoke (1969) subdivided the Etchegoin into three members; the lower "Basal Silty Shale Member" is only a few tens of meters thick and it is not shown in the figure.

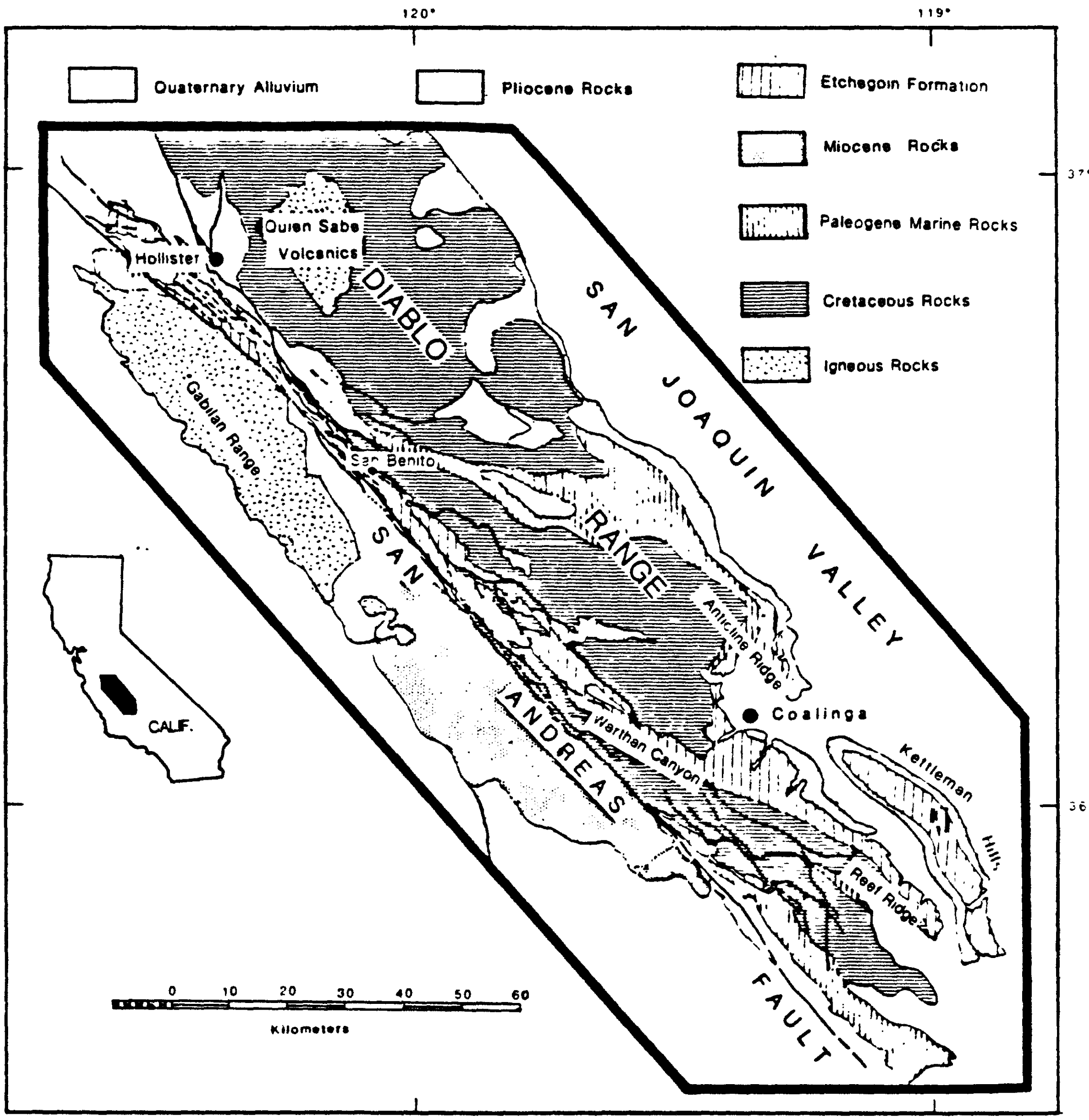


Figure 3. Generalized geologic map of the southern Diablo Range and vicinity, after Jennings and others (1977).

1958). No Etchegoin strata have been reported in the northern part of the San Joaquin Valley. However, bluish-gray and brownish-gray strata are found in the subsurface (Lerbekmo, 1962), and, although not called Etchegoin, probably are equivalent in age and lithology to the Etchegoin Formation.

The thickness of the Etchegoin Formation is quite variable, probably as a result of deposition in a semi-enclosed basin. It is thickest (approximately 1600 m) in the Reef Ridge and Warthan Canyon regions (Adegoke, 1969), whereas along the northern, eastern, and southern margins of the San Joaquin Valley, Etchegoin strata pinch out or grade laterally into nonmarine strata (Bartow, in press a and b; Bartow and Pittman, 1984; Foss, 1972). In the subsurface along the axis of the valley, the thickness of Etchegoin strata averages about 800 m (2800 ft) (American Association of Petroleum Geologists, 1957).

The thickness of both the brown and blue sandstone facies also is highly variable. The brown sandstone facies in the Reef Ridge region ranges in thickness from about 600 m (about 2350 ft) to about 900 m (about 3000 ft), and the blue sandstone facies ranges from about 350 m (1150 ft) to about 1000 m (3300 ft) (Adegoke, 1969; Stanton and Dodd, 1976). In the Warthan Canyon region, northwest of Reef Ridge, the brown sandstone facies averages about 1000 m thick and the blue sandstone facies averages about 400 m thick (estimates are based on geologic mapping of Dibblee, 1971). Along Anticline Ridge, the brown sandstone facies typically is about 200 m thick, and the blue sandstone facies typically is about 500 m thick (estimates are based on stratigraphic studies by Adegoke, 1969).

The lack of complete stratigraphic sections along the west flank of the southern Diablo Range prevents reliable estimates of the thickneses of Etchegoin strata in this region. However, a nearly complete 900-m-thick (2960-ft-thick) section is found in the San Benito region (fig. 3) along Sulphur Creek (Wilson, 1943). The upper part of the section is faulted, and approximately 150 m (500 ft) of section is missing (Wilson, 1943).

Lithology

The dominant lithology of surface exposures of Etchegoin rocks is sandstone that commonly is interbedded with siltstone, and less commonly with conglomerate. The texture and lithic composition of Etchegoin strata vary laterally and vertically over short distances. Such variations are more prevalent in the blue sandstone facies than in the brown sandstone facies.

Brown Sandstone Facies

Sandstone beds of this facies typically are fine to coarse grained, moderate yellowish brown (10 YR 5/4), semifriable, unstratified to thinly bedded, and unfossiliferous. Calcite and phyllosilicates are the primary cements. Siltstone commonly is interbeded with sandstone, and it is sandy or clayey, light olive gray (5Y 5/4), unstratified to thickly bedded, and unfossiliferous. Significant regional differences exist in the lithology and texture of rocks in the brown sandstone facies.

In the Reef Ridge region, outcrops in the lower part of this facies contain upward-fining sequences about 30 m thick. Typically, found at the base of these sequences is coarse- to medium-grained sandstone, which grades upward into sandy siltstone or interbedded silty, fine- to very fine-grained sandstone, and sandy siltstone at the top. Locally, pebbles and granules (many of which are mudstone clasts) are found in sandstone at the base of a sequence. The upper parts of these sequences often are not exposed due to their fine-grained nature. However, where exposed, the beds are unstratified, mottled (bioturbated), and may contain leaf impressions or carbonaceous debris.

Upward-fining sequences are rare in the middle and upper parts of the brown sandstone facies in the Reef Ridge region. These parts of the facies typically are composed of interbedded medium- and fine-grained sandstone, which in turn are interbedded with sandy or clayey siltstone. The beds of sandstone commonly are thinly bedded or crossbedded, and unfossiliferous. Locally, some marine fossils have been reported (Adegoke, 1969; Stanton and Dodd, 1976). Where exposed, the siltstone is slightly to severely bioturbated, very thinly bedded to unstratified, and unfossiliferous. Beds of siltstone typically are less than 5 m thick.

The brown sandstone facies in the Warthan Canyon region is composed primarily of medium- to fine-grained sandstone. Outcrops of sandstone typically are silty, semifriable, unstratified where poorly exposed, and thinly to thickly bedded where well exposed. Cement in the sandstone typically is calcite. Many sandstone beds contain shallow-marine mollusk fossils, and silicified wood has been reported (Mclaughlin, 1954; Rose and Colburn, 1963). Pebbly sandstone and conglomerate are found locally. The pebbly sandstone is coarse to very coarse grained, commonly crossbedded, and unfossiliferous. The conglomerate typically is matrix supported, unstratified to thickly bedded, and unfossiliferous. Beds of siltstone are common, and they are unstratified to thinly bedded, sandy or clayey, unfossiliferous, and range in thickness up to about 10 m.

Outcrops of the brown sandstone facies in the region north of Coalinga are characterized by upward-fining sequences that are much more well developed than those at the base of the brown sandstone facies in the Reef Ridge region. The sequences range from about 20 m to about 40 m in thickness. The base of each sequence is pebble conglomerate or pebbly sandstone that grades upward to moderately reddish-brown (10 R 4/6) or grayish-olive (10 YR 4/2) clayey siltstone at the top. The pebble conglomerate and pebbly sandstone intervals typically are less than 5 m thick. A thick, generally upward-fining (very coarse to fine grained) interval of amalgamated sandstone beds is found above the conglomerate or pebbly sandstone. The sandstone beds typically are laterally discontinuous, crossbedded, unfossiliferous, and individual beds commonly are upward fining. Oxidized, poorly exposed paleosols are common at the top of the sequences; the paleosols are reddish-brown, unstratified, mottled, exhibit a blocky or granular structure, and contain infilled root traces, or gypsum veinlets and stringers, or relict calcite(?) nodules. Leaf impressions are present in the fine-grained beds in the upper part of the sequence. Fossils in the sandstone are rare, but where present they are either silicified wood or nonmarine mollusks. A few marine fossils were found by Adegoke (1969), but they are restricted to a thin (generally less than 20-m-thick) siltstone bed found at the base of the Etchegoin along Anticline Ridge.

The brown sandstone facies in the San Benito region generally is similar to brown sandstone strata found in the Warthan Canyon region. However, sandstone in this region contains more crossbedding, and fossils of marine mollusks are common.

Blue Sandstone Facies

The Etchegoin Formation is noted for the markedly bluish-gray sandstone beds that are ubiquitous in this facies. The distinctive color results from authigenic phyllosilicates that coat the non-opaque grains (Lerbekmo, 1957). As reported by Lerbekmo, the bluish color is selective and occurs only on dark-colored grains and only where the coating is less than 0.01 mm thick. Another factor, not previously reported, is that the blue color is, in part, dependent upon the intensity of weathering that has occurred at the outcrop. Sandstone that is brownish-gray in outcrop may exhibit the distinctive bluish tint when excavated below the intensely weathered zone.

The blue sandstone facies is characterized by very pale blue (5B 8/2) to light blue (5B 7/6) sandstone that is interbedded with brownish-gray sandstone and siltstone. The brownish-gray sandstone and siltstone are similar to those found in the brown sandstone facies. Beds of blue sandstone in this facies are not composed of several thick, distinctive beds as reported by Dibblee (1971, 1973), but rather, they are composed of many, thin (generally less than 10-m-thick), lenticular beds as described by Woodring and others (1940). The beds of blue sandstone are discontinuous and locally bifurcate, such that individual beds can rarely be followed for more than a few kilometers. Beds with the distinctive blue color rarely comprise more than 50 percent of the facies, and they are not present in the San Benito region.

In outcrop, sandstone beds of this facies typically are crossbedded, medium to coarse grained, moderately well sorted, subrounded to rounded, unfossiliferous, and commonly pebbly. The cement in the bluish-gray sandstone is composed of phyllosilicates, whereas in the brownish-gray sandstone it is either phyllosilicates or calcite. Along Anticline Ridge, bluish-gray sandstone beds occur in the lower and middle parts of upward-fining sequences, which grade upward to brownish-gray sandstone and siltstone. In the Warthan Canyon and Reef Ridge regions, the bluish-gray sandstone beds sometimes grade upward into brownish-gray sandstone and siltstone. Where upward-fining sequences are absent, bluish-gray sandstone commonly is interbedded with 5- to 20-m-thick beds of brownish-gray sandstone or siltstone.

Conglomerate

Conglomerate beds in the Etchegion Formation are most common in the region north of Coalinga. Along Anticline Ridge conglomerate comprises an estimated 5 percent of the strata. In the Reef Ridge region, outcrops of conglomerate are rare; in fact, in a complete stratigraphic section in the central part of Reef Ridge, only three, thin (less than 2-m-thick), matrix-supported pebble conglomerate beds were seen by the writer. Although conglomerate beds are more abundant in the Warthan Canyon region than in the Reef Ridge region, they are nowhere as abundant as in the Anticline Ridge region. The overall distribution of conglomerate in the Etchegoin Formation of the Coalinga region is one of a southward decrease in frequency, bed thickness, and clast size.

No marked difference was observed between conglomerate in the blue and brown sandstone facies, and conglomerate in both facies exhibits a variety of textures. Conglomerate is found as distinct thin beds or as amalgamated beds. Conglomeratic intervals typically are less than 4 m thick, and may be laterally continuous for many hundreds of meters, or channelform, or lenticular. Both framework-supported and matrix-supported conglomerate are common. The framework-supported conglomerate typically contains pebbles, rarely contains cobbles, and it is horizontally stratified, unfossiliferous, with a matrix of granular, medium- to very coarse-grained sandstone. The matrix-supported conglomerate is similar in texture to the framework-supported conglomerate but crossbedding is the dominant stratification type. Commonly, in addition to the general upward-fining nature of intervals of amalgamated beds, individual beds are upward-fining, with a decrease in clast size or abundance up section. Also somewhat common is framework-supported conglomerate that grades upward into matrix-supported conglomerate.

Subsurface - San Joaquin Valley

Few data are avaiable on the lithology of Etchegoin strata in the subsurface of the San Joaquin Valley, but shale and sandstone commonly are reported. In the southwestern part of the valley, the Tupman Shale Member is composed primarily of shale, but sandstone beds ("Olig", "Fitzgerald", or "Potter sands") commonly are found at or near its base (Metz and Whitworth, 1984). The shale was described as olive gray, laminated, glauconitic or phosphatic, and typically it is silty or sandy (Berryman, 1973). The sandstone was described as very fine to very coarse grained, rarely pebbly, dominantly unstratified, and unfossiliferous (Maher and others, 1975). Megafossils are rare throughout the Tupman Shale Member, but where found they are shallow-marine mollusks. Foraminifera are common in the Tupman Shale, especally *Buliminella elegantissima* (Berryman, 1973). The Carman Sandstone Member is composed of interbedded sandstone and siltstone. The sandstone typically is light olive gray to yellowish gray, locally glauconitic or phosphatic, slightly silty, medium to very fine grained, and fossiliferous (Berryman, 1973). The interbedded siltstone typically is light olive gray, clayey or sandy, laminated, and micaceous. No andesite-rich or bluish-gray sandstone has been reported from either the Tupman Shale or Carman Sandstone Members.

Stratigraphic Relations

Along the west side of the San Joaquin Valley the Etchegoin Formation is found unconformably over the upper Miocene Reef Ridge Shale of the Monterey Formation, and it is conformably overlain by the Pliocene San Joaquin Formation (fig. 4). In the west central part of the valley, the unconformity occurs where the dominantly silty strata of the Reef Ridge Shale give way to the dominantly sandy strata of the Etchegoin Formation (Adegoke, 1969; Foss, 1972). In the southwestern part of the valley, the unconformity typically occurs at the base of the lowest sandstone in the Tupman Shale, that is, at the base of the "Olig", "Potter", or "Fitzgerald" sandstones (Foss, 1972; Berryman, 1973; Maher and others, 1975). North of Coalinga, the Etchegoin Formation is both conformable and unconformable on the underlying Santa Margarita Formation (Adegoke, 1969). The top of the Etchegoin Formation along the western part of the valley is placed at the base of the Cascajo Conglomerate Member of the San Joaquin Formation, which is defined as the lowest conglomerate bed above highest *Pseudocardium*-bearing sandstone in the Etchegoin Formation (Woodring and others, 1940).

Along the axis of the San Joaquin Valley, the Etchegoin Formation is thought to be conformable with the underlying Reef Ridge Shale and with the overlying San Joaquin Formation (American Association of Petroleum Geologists, 1958; Foss and Blaisdell, 1968; Bartow, in press b). However, these subsurface stratigraphic relations are poorly defined because they are based on the interpretation of well-log data. Along the axis of the northernmost part of the valley, north of the latitude of Coalinga, the Etchegoin Formation is unconformable on the Santa Margarita Formation (Bartow, in press b).

Along the eastern side of the San Joaquin Valley, the Etchegoin Formation unconformably overlies either the Chanac Formation or the Santa Margarita Formation (Bartow and McDougall, 1984; Bartow, in press b). Either the San Joaquin Formation or the Kern River Formation conformably overlies the Etchegoin (Foss, 1972; Bartow and Pittman, 1984).

Along the west flank of the Diablo Range, the stratigraphic succession of the Etchegoin Formation is not well defined, as a result of poor exposure and structural complexities. In the Warthan Canyon region, Etchegoin strata lie unconformably on strata as old as the Cretaecous Panoche Formation. Either unnamed nonmarine strata of Dibblee (1971) or the Hans Grieve Formation of Rose and Colburn (1963) overlie the Etchegoin Formation. The unnamed strata of Dibblee are conformable on the Etchegoin, whereas the Hans Grieve Formation is not (Rose and Colburn, 1963; Dibblee, 1971). In the San Benito region, northwest of Warthan Canyon, the Etchegoin Formation rests conformably(?) on unnamed coarse-grained nonmarine rocks of Dibblee (1979), and additional unnamed fine-grained nonmarine rocks of Dibblee (1979) conformably(?) overlie Etchegoin strata.

San Joaquin Valley					Diablo Range	
West Side (1)	West Side (2)	Axis	East Side (3)	East Side (3)	West Flank (4)	West Flank (5)
Central	Southern	(3)	Central	Southern	Warthan Cyn	San Benito
San Joaquin	San Joaquin	San Joaquin	San Joaquin or Kern River		Hans Grieve or unnamed nonmarine strata	unnamed nonmarine strata
Etchegoin	Etchegoin	Etchegoin	Etchegoin	Etchegoin	Etchegoin	Etchegoin
Reef Ridge or Santa Margarita	Reef Ridge	Reef Ridge or Santa Margarita	Santa Margarita	Chanac	Reef Ridge or older strata	unnamed nonmarine strata

(1) Adegoke, 1969
Foss, 1972

(2) American Association of
Petroleum Geologists, 1957

(3) Bartow and Pittman, 1984
Bartow, inpress b

(4) Dibblee, 1971, 1979
Rose and Colburn, 1963

(5) Dibblee, 1979, 1981

Figure 4. Stratigraphic succession of Etchegoin strata in various locations in the San Joaquin Valley and along the west flank of the southern Diablo Range.

Age and Correlation

Age

Rocks of the Etchegoin Formation contain fossils that define the "Jacalitos" and "Etchegoin" stages of the Pacific Coast Molluscan Chronology (Clark, 1941; Weaver and others, 1944; Corey, 1954; Durham, 1954). These stages traditionally have been assigned to the lower and middle Pliocene, but reinterpretation of the Pacific Coast Molluscan Chronology has resulted in the assignment of all of the "Jacalitos" and most of the "Etchegoin" to the upper Miocene (Evernden and others, 1964; Addicott, 1970, 1972).

Magnetostratigraphic and tephrachronologic data place constraints on the age assignments of the "Jacalitos" stage, thereby constraining the age of the base of the Etchegoin Formation. An age of about 9 Ma for the base of the Etchegoin Formation is suggested by magnetostratigraphic studies on "Jacalitos" stage strata in southern California (Ensely and Verosub, 1982). Also, stratigraphic correlation of Etchegoin strata with the Kern River Formation in the southeastern San Joaquin Valley suggests a minimum age of 8.2 Ma for the beginning of the "Jacalitos" stage there (Bartow and Pittman, 1984). These data suggest that the beginning of the "Jacalitos" stage is about 9 Ma.

The molluscan assemblage that characterizes the "Etchegoin" stage is difficult to recognize in strata outside the San Joaquin Valley (Addicott, 1972), and no age determination for the top of the Etchegoin Formation can be made on the basis of stratigraphic correlations with other "Etchegoin" stage strata. However, a tuff at the top of the Etchegoin Formation in the Kettleman Hills has been estimated by Obradovich and others (1979) to be about 7 Ma, and by Sarna-Wojcicki and others (1979) to be about 4 Ma. The former authors base their age estimate on fission-track dating on zircon; whereas, the latter authors base their age estimate on chemical similarity to the Lawlor Tuff. The younger age is considered to be the more reliable because fission-track dating can overestimate the true age of tephra (Meyer and others, 1980). The tephrachronology developed by Sarna-Wojcicki and others (1979) is stratigraphically consistent in the Pliocene and younger rocks of the San Joaquin Valley, and the chemical similarity to the Lawlor Tuff is strong.

Six tuffs were recovered from Etchegoin and related strata along Anticline Ridge (fig. 5, Appendix I), one by the author and five by Steve Warner (California State University, Fresno). The trace and minor element chemical composition of these six tuffs was determined by Sarna-Wojcicki (U. S. Geological Survey, Menlo Park) and cluster analysis was used to determine their chemical affinities to tephra of known age. Tuff SW-C was recovered less than 50 m above the base of the Etchegoin Formation and it is most strongly correlated with tephra of Crater Lake (Table 1). A genetic similarity of tuff SW-C to Crater Lake tephra is unlikely, because Crater Lake tephra are late Pliestocene in age. Tuff SW-C is also correlative (similarity coefficient of 0.9524) with a Pliocene tuff in DSDP core 470 (leg 6), but this correlation is poor and the age of tuff SW-C is indeterminate. Tuffs SW-A and 15-27 were recovered about 200 m above the base of the Etchegoin Formation, and

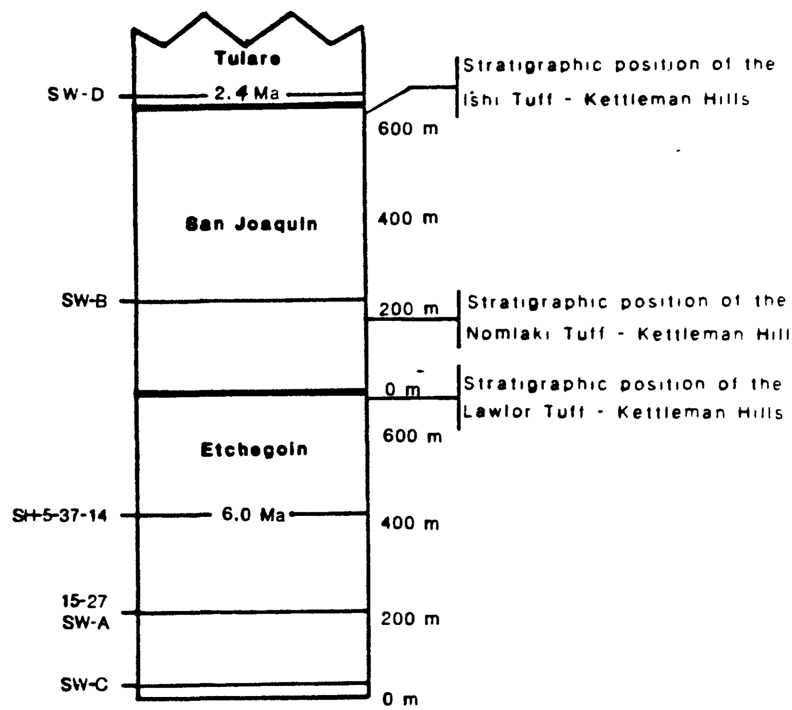


Figure 5. Composite section showing the tephrachronology of Etchegoin and related strata along Anticline Ridge. The stratigraphic positions of the Lawlor, Nomlaki, and Ishi tuffs are shown as they occur in the Kettleman Hills.

they are separated by about 9 km along strike (Appendix I). The two tuffs are correlative with each other (similarity coefficient of 0.9739) and to the Nomlaki Tuff that is dated at 3.4 Ma (Sarna-Wojcicki and others, 1979). Tuff SW-A is also correlated (similarity coefficient of 0.9846) with the Glacier Peak Tuff of Pleistocene age (Table 1), but a Pleistocene age for tuff SW-A is improbable. Tuff SH-5-37-14 was recovered approximately 420 m above the base of the Etchegoin Formation, and it is chemically similar (similarity coefficient of 0.9846) to a 6 Ma tuff in the Wilson Grove Formation (Fox 1983; Sarna-Wojcicki and others, 1979). The fairly high similarity coefficient and reasonable age makes this correlation probable. The fifth tuff, SW-B was recovered from the San Joaquin Formation, but, because it is poorly correlated with tephra of known age, the age of this tuff is indeterminate. Tuff SW-D was recovered from the base of the Tulare Formation and it is correlative with the 2.4 Ma Ishi Tuff.

Four of the six tuffs, recovered from Etchegoin and related strata along Anticline Ridge, are correlative with tephra of known age, but a reversal occurs within the stratigraphic succession of these tuffs (fig. 5). Tephrachronologic data from the Kettleman Hills (Sarna-Wojcicki and

TABLE 1. CORRELATION DATA RELATING TO TUFFS FOUND IN THE ETCHEGOIN FORMATION

TEPHRA	SIMILARITY COEFFICIENT	AGE
	Tuff SW-C	
Crater Lake Tephra	0.9752	late Pleistocene
same	0.9640	same
same	0.9624	same
Tuff from DSDP 470	0.9524	4.3 Ma
	Tuff 15-27	
Nomlaki	0.9880	3.5 Ma
same	0.9354	same
same	0.9807	same
same	0.9786	same
Tuff SW-A	0.9739	
	Tuff SW-A	
Nomlaki	0.9888	3.4 Ma
Glacier Peak	0.9846	late Pleistocene
Nomlaki	0.9774	3.4 Ma
Nomlaki	0.9773	same
	Tuff SH-5-37-14	
Tuff in the Wilson Grove Fm. (Sears Point tuff)	0.9846	5.7-6.1 Ma
same	0.9768	same
same	0.9751	same
same	0.9715	same
	Tuff SW-D	
Ishi Tuff	0.9664	2.2 - 2.6 Ma
same	0.9563	same
same	0.9535	same
same	0.9505	same

others, 1979) suggests that the stratigraphic reversal is a result of spurious correlations of tuffs SW-A and 15-27 with the Nomlaki Tuff. Shown in figure 5 are the stratigraphic positions of the Lawlor, Nomlaki, and Ishi Tuffs as they occur in the Kettleman Hills. The Nomlaki Tuff in the Kettleman Hills is found in the lower part of the San Joaquin Formation, about 120 m above the 4 Ma Lawlor Tuff and about 400 m below the Ishi Tuff. Along Anticline Ridge, Nomlaki correlative tuffs (SW-A and 15-27) are found in the lower part of the Etchegoin Formation, about 200 m below the 6 Ma tuff SH-5-37-14 and about 1000 m below tuff SW-D - the Ishi Tuff. The stratigraphic positions of tuffs SH-5-37-14 and SW-D are consistent with the tephrachronology developed by Sarna-Wojcicki and others (1979) in the Kettleman Hills; whereas, the position of the two Nomlaki correlative tuffs is not. These data suggest that the correlations of tuffs SW-A and 15-27 with the Nomlaki Tuff are not valid, and that these correlations are responsible for the stratigraphic reversal in the succession of tuffs found along Anticline Ridge.

The stratigraphic position of the Lawlor Tuff at the top of the Etchegoin Formation in the Kettleman Hills places a well constrained age of 4 Ma for the top of the Etchegoin Formation. Tuff SH-5-37-14 is positioned 280 m below the top of the formation, and an age difference of 2 m.y. and a stratigraphic separation of 280 m, yields a sedimentation rate of 140 m/m.y. Projecting this rate downsection from tuff SH-5-37-14 results in an age of 8.9 Ma for the base of the Etchegoin Formation along Anticline Ridge. The age estimate for the base of the Etchegoin Formation along Anticline Ridge is in good agreement with that predicated by correlation of lower Etchegoin strata with other "Jacalitos" strage strata within and outside the San Joaquin Valley.

Correlation

The Etchegoin Formation is correlative with strata within the San Joaquin Valley and with strata in the Salinas Valley and eastern San Francisco Bay region (fig. 6). Stratigraphic correlations are based primarily on biostratigraphy, but are constrained by absolute age determinations where possible. The Etchegoin Formation, as a whole, is correlative with the upper part of the Mehrten Formation (Wagner, 1981), and the nonmarine Carbona Formation of Raymond (1969) in the northern San Joaquin Valley (Bartow, in press a), the Kern River Formation in the southern and central San Joaquin Valley (Bartow and Pittman, 1984), and with the upper part of the Contra Costa Group in the San Francisco Bay region (Creely and others, 1982). Biostratigraphic correlations suggest that the brown sandstone facies is correlative with the Santa Cruz Mudstone (Greene and Clark, 1979) and the Pancho Rico Formation (Durham and Addicott, 1965) in the Salinas Valley, and with the upper part of the Neroly Formation found in the San Francisco Bay region (Creely and others, 1982). The blue sandstone facies is correlative with the Purisima Formation (Greene and Clark, 1979) and the lower part of the Paso Robles Formation (Addicott and Galehouse, 1973; Galehouse, 1967) in

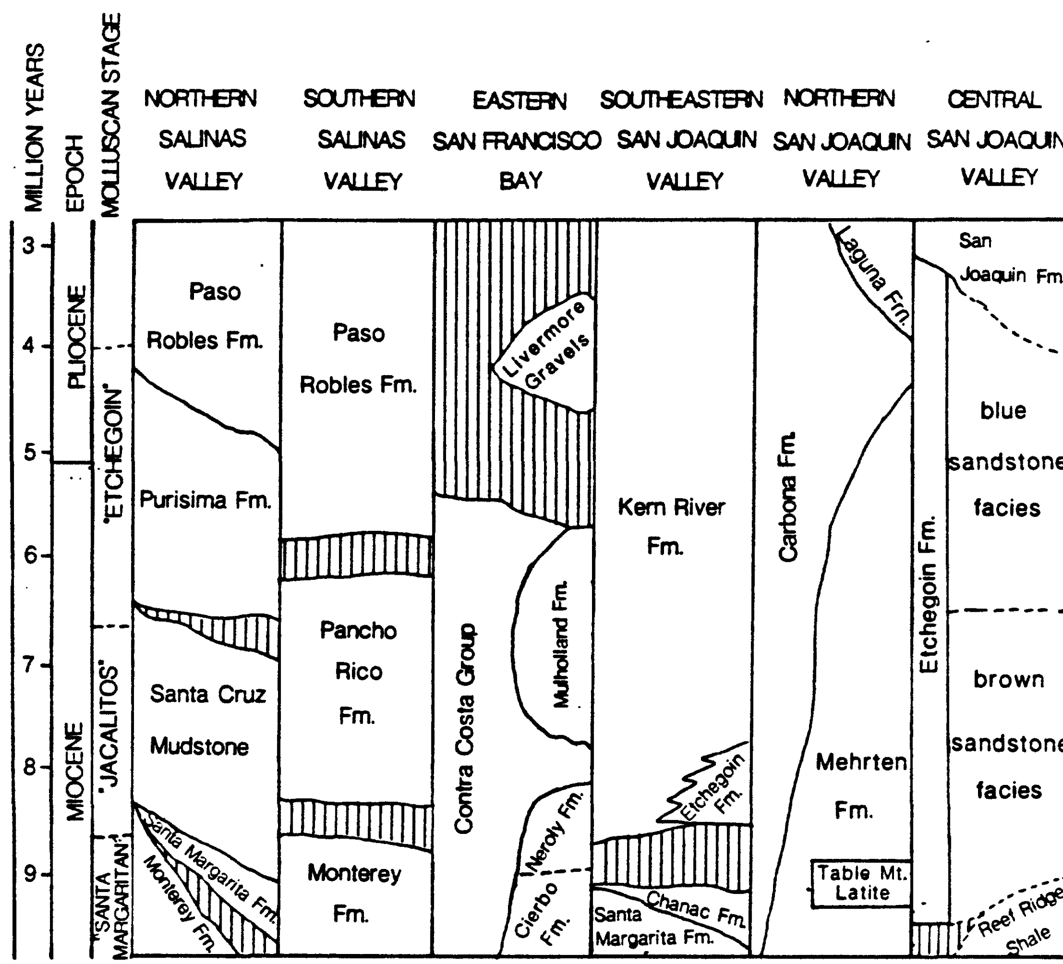


Figure 6. Stratigraphic correlations of upper Miocene and Pliocene rocks in central California. Correlations are based in part upon data reported by Addicott and Galehouse (1973), Bartow (in press a), Bartow and Pittman (1984), Creely and others (1982), Durham and Addicott (1964), Greene and Clark (1979), Raymond (1969), and Wagner (1981).

the Salinas Valley, and with the upper part of the Mulholland Formation in the San Francisco Bay region (Creely and others, 1982). The uppermost part of the blue sandstone facies is also correlative with part of the Livermore Gravels of Clark (1930) (Sarna-Wojcicki and others, 1979).

Depositional Environments

Few reports have detailed the depositional environments of Etchegoin strata, and those that did concentrated on strata in the Coalinga region. The widespread occurrence of plant fragments (leaf impressions and silicified wood), paleosols, the paucity of marine fossils, and the occurrence of terrestrial vertebrate fossils have led many investigators to assign a nonmarine origin to Etchegoin strata north of Coalinga (Arnold and Anderson, 1910; Anderson and Pack, 1915; Nomland, 1916, 1917; Adegoke, 1969). These nonmarine strata are thought to have been deposited by a southward or southwestward flowing meandering river system (Werner, 1986).

Stanton and Dodd (1976) reported that Etchegoin strata in the Reef Ridge region were deposited in a variety of environments, which included fluvial, lagoonal, beach, nearshore, and offshore environments. In all but the lowest approximately 200 m, shallow-marine environments tended to dominate; however, strata of fluvial origin are locally interbedded with the marine strata (Stanton and Dodd, 1976). A dominantly shallow-marine origin also is attributed to Etchegoin strata in the Warthan Canyon region by Rose and Colburn (1963), on the basis of ubiquitous shallow-marine mollusk fossils contained within these strata.

Etchegoin strata in the southeastern part of the Coalinga region probably were deposited at or near sea level. Strata in the lower half of the Etchegoin Formation in the Kettleman Hills are dominantly siltstone and contain abundant carbonaceous material (including carbonized leaves) and pyritized diatoms (Goudkoff, 1934). Shallow-marine mollusk fossils have been reported locally in lower Etchegoin strata, but they tend to be restricted to the interbedded sandstone (Goudkoff, 1934). Carbonized leaves, pyritized diatoms, and locally abundant shallow-marine fossils suggest that deposition was associated with reducing conditions at or near sea level. Reducing conditions at or near sea level commonly are found in estuaries and topset deltaic environments (Reineck and Singh, 1980; Coleman, 1984). However, what is important here is not a specific environment of deposition of these strata, but rather, that these strata evidently were deposited in an environment that was closely associated with the strand line. Lower Etchegoin strata in the Kettleman Hills probably were deposited in, or near, a zone of transition that separated the dominantly shallow-marine environments to the west from the dominantly nonmarine environments to the east and northeast.

The zone of transition between marine and nonmarine deposition that probably existed during deposition of lower Etchegoin strata probably continued to exist throughout deposition of Etchegoin strata in the Kettleman Hills region. Stanton and Dodd (1970, 1972) suggested that strata in the uppermost part of the Etchegoin Formation in the Kettleman

Hills were deposited in environments that ranged from outer bay to paludal. The outer bay environments tended to dominate in the northwestern part of the region, whereas fresh-water environments tended to dominate in the southeastern part (fig. 7). Therefore, the strand line probably was in the vicinity of the Kettleman Hills throughout deposition of the Etchegoin strata.

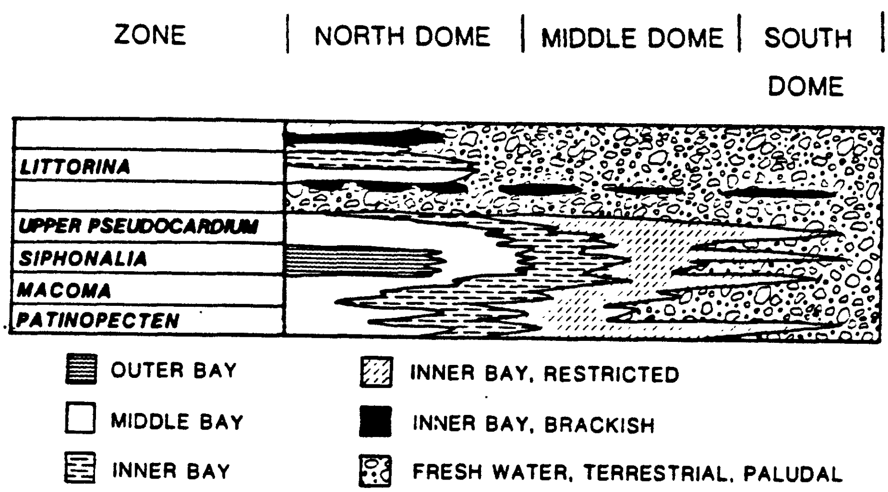


Figure 7. Diagrammatic north-south cross section showing facies patterns in upper Etchegoin strata in the Kettleman Hills. Listed to the left are faunal zones within these strata. Approximately 200 m of strata are represented by the figure, after Stanton and Dodd (1970).

Little has been reported on the environments of deposition of Etchegoin strata in the subsurface of the San Joaquin Valley. Common throughout much of the strata of the Tupman Shale Member in the Elk Hills region are phosphate pellets and shallow-marine Foraminifera (Berryman, 1973); shallow-marine megafossils are rare in these strata (Berryman, 1973; Maher and others, 1975). The formation of phosphate pellets commonly occurs in regions of marine upwelling in water depths between 100 and 150 m (Bushinski, 1964). Therefore, lower Etchegoin strata in the Elk Hills region probably were deposited in marine waters 100 to 150 m deep. Because the basin was generally eastward-shallowing, 100-150 m may have been the greatest water depths attained in the basin during deposition of Etchegoin strata.

Strata in the Carman Sandstone Member in the Elk Hills region were deposited as a shallow-marine delta front that prograded to the northwest in four distinct cycles (Maher and others, 1975). Found at the base of each cycle is sandstone that contains shallow-marine megafossils. The sandstone grades upward to siltstone and sandstone that contain brackish-marine or fresh-water megafossils (Maher and others, 1975). The last and most complete cycle is contained within strata that are less than 60 m thick, suggesting that water depths during deposition of upper Etchegoin strata were on the order of about 60 m. A shallowing with time in the southern part of the San Joaquin basin is expected, because the southern seaway, located outboard of the Elk Hills, was closed by about 6 Ma (Addicott and Galehouse, 1973). Not only would the uplift that caused the closure of the seaway shallow the southern part of the San Joaquin basin, but the closure would restrict the seaward transport of sediment. Basin shallowing also is reflected in Carman Sandstone strata in the easternmost part of the Elk Hills, which are interpreted by Maher and others (1975) to have been deposited as part of a second deltaic system, one that had prograded westward from the Sierra Nevada. Deltaic deposits from the Sierra Nevada in the vicinity of Elk Hills suggests that shallowing was widespread in the southern San Joaquin basin.

A basinwide estimate of the depositional environments of Etchegion strata is shown in figure 8, and it is based on data from Anticline Ridge, Reef Ridge, Kettleman Hills, Warthan Canyon, and Elk Hills. Shown in figure 8 are areas of dominantly marine, alternating marine and nonmarine, and dominantly nonmarine sedimentation. This reconstruction must be considered only an approximation, because environmentally sensitive data for most Etchegoin strata in the subsurface of the San Joaquin Valley are lacking. However, the regions used in the reconstruction are especially sensitive to basinwide sedimentation, because they were positioned at or near the primary seaways connecting the San Joaquin basin to the Pacific Ocean. Some data indicate that a significant shallowing occurred in the San Joaquin basin during deposition of the Etchegoin Formation. Therefore, during the deposition of lower Etchegoin strata the areal extent of dominantly marine sedimentation was greater, and that of dominantly nonmarine sedimentation was less, than that shown in figure 8. Conversely, during the deposition of upper Etchegoin strata the areal extent of dominantly marine sedimentation was less, and that of dominantly nonmarine sedimentation was greater, than that shown in figure 8. Such environmental reconstructions are important in provenance studies, because they place constraints on the possible sediment dispersal patterns in the basin.

CONGLOMERATE COMPOSITION

The composition of conglomerate clasts often provides important constraints on provenance because they yield large fragments of source rock. Also, inferences can be made as to the proximity of some source terranes on the basis of the relative distribution of clast types. Eleven conglomerate beds in the Etchegoin Formation along Anticline Ridge and two beds in the Warthan Canyon region were sampled to determine the abundance of clast types (fig. 9). The average clast size of the sampled beds ranges from fine to coarse pebble. No attempt was made to preselect a specific size fraction for assay, therefore, pebble counts represent the actual composition of conglomerate beds. Counts of 100 representive clasts were made for each of the sampled conglomerate outcrops (Table 2).

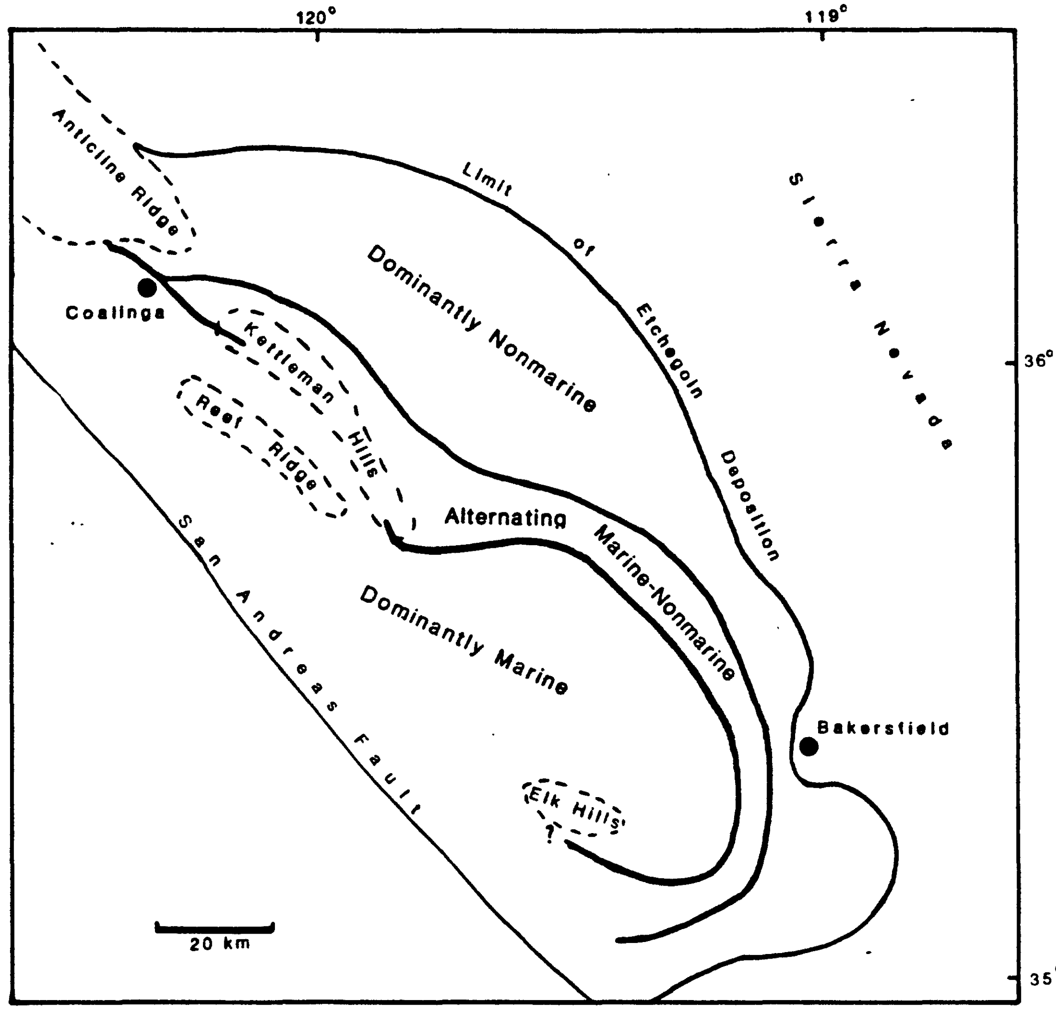
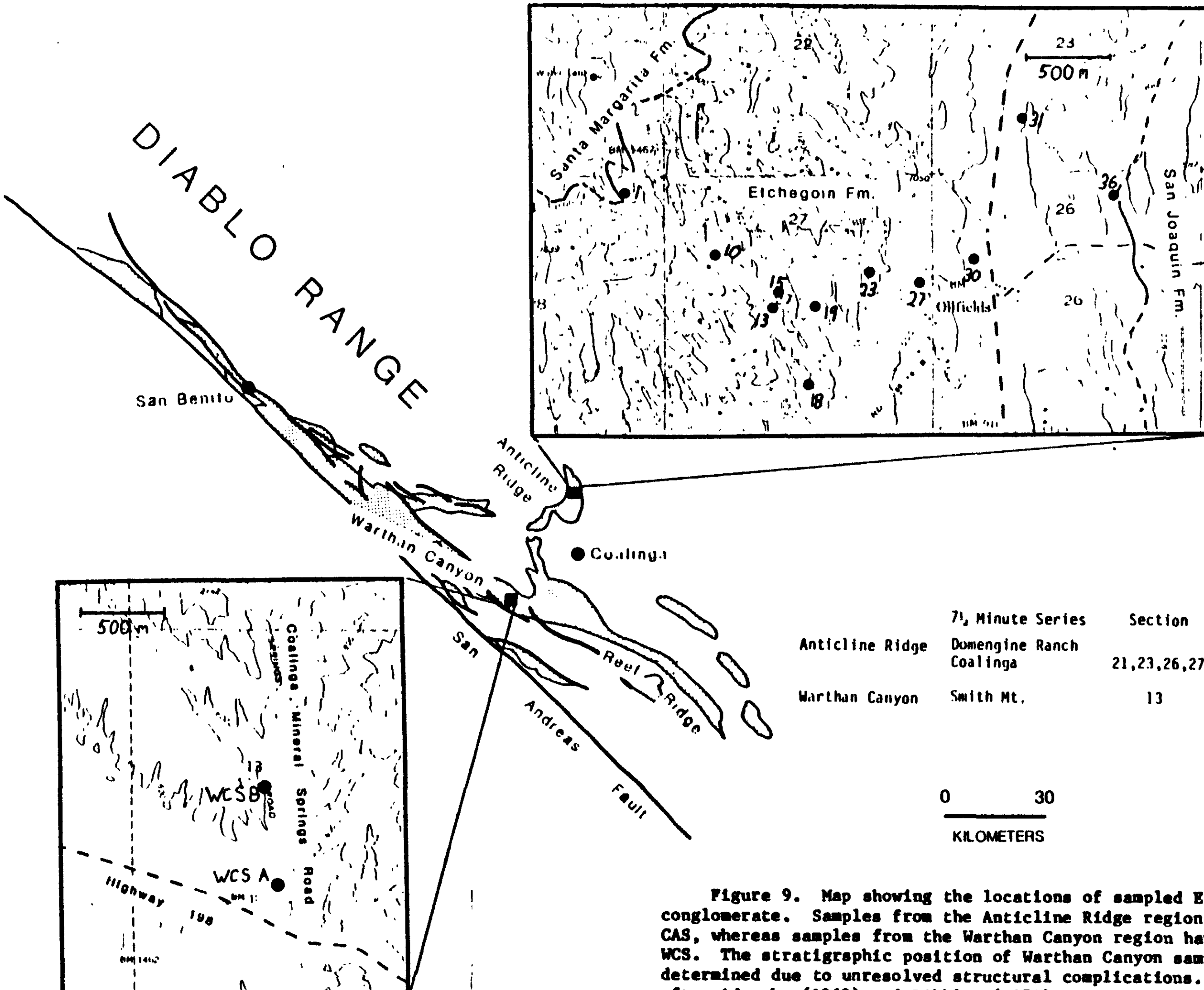


Figure 8. Map showing regions of dominantly marine, alternating marine and nonmarine, and dominantly nonmarine sedimentation in the San Joaquin Valley during deposition of Etchegoin strata, modified from Foss (1972).



	7½ Minute Series	Section	Township-Range
Anticline Ridge	Domengine Ranch Coalinga	21,23,26,27	T.19S.,R.15E.
Warthan Canyon	Smith Mt.	13	T.21S.,R.13E.

Figure 9. Map showing the locations of sampled Etchegoin conglomerate. Samples from the Anticline Ridge region have the prefix CAS, whereas samples from the Warthan Canyon region have the prefix WCS. The stratigraphic position of Warthan Canyon samples could not be determined due to unresolved structural complications. Geologic mapping after Adegoka (1969) and Dibblee (1971).

TABLE 2. COMPOSITION OF ETCHEGOIN CONGLOMERATE

Sample Number	Stratigraphic Position (above base)	Siltstone/Claystone	Sandstone	Quartz	Plutonic	Green Chert	Red Chert	Black Chert	Metasandstone	Metasiltstone/Claystone	Metaconglomerate	Metavolcanic/Greenstone	Other Metamorphic	Mafic Volcanic	Felsic Volcanic	Tuffaceous	Crassostrea Fragments
		Percent															
BROWN SANDSTONE FACIES																	
CAS- 1	10 m	0	5	10	2	2	0	2	13	19	1	9	17	2	18	0	0
CAS-10	110 m	0	4	3	2	6	0	2	27	24	5	12	8	0	7	0	0
CAS-13	181 m	0	4	6	2	2	0	1	23	15	3	6	16	1	20	1	0
WSC- A		0	0	2	1	0	0	9	28	31	2	12	10	0	5	0	0
BLUE SANDSTONE FACIES																	
CAS-15	200 m	0	6	1	9	1	1	5	17	18	7	14	15	0	6	0	0
CAS-18	220 m	0	8	2	4	4	2	4	19	17	3	6	17	3	10	1	0
CAS-19	235 m	1	5	4	6	3	0	4	11	19	6	17	13	3	8	0	0
CAS-23	405 m	1	2	6	1	1	1	2	18	14	4	17	21	0	10	2	0
CAS-27	495 m	0	4	2	8	2	2	0	17	23	5	14	16	2	5	0	0
CAS-30	580 m	0	10	7	2	1	0	2	13	17	2	21	20	0	5	0	0
CAS-31	630 m	0	2	5	0	8	1	1	17	14	1	14	22	3	12	0	0
CAS-36	710 m	1	3	9	1	3	1	2	19	13	4	13	12	0	8	1	10
WCS-B		0	2	4	3	0	0	3	12	33	2	20	8	2	11	0	0

The compositions of clasts in all of the conglomerate units sampled are similar (Table 2). Approximately 70 percent of the clasts contained in these conglomerate beds are metamorphic rock types: metasandstone, metasiltstone/claystone, metavolcanic/greenstone, metaconglomerate, and other metamorphic rock types. Metasandstone is composed primarily of fine- to medium-grained metagraywacke, severely altered graywacke, and medium-grained, very altered, serpentinite-rich sandstone. Clasts of metasiltstone/claystone are composed primarily of dark-colored veined and unveined hornfels or phyllite. All porphyritic, dense, and very altered volcanic rock clasts were classified as metavolcanic/greenstone, as were serpentinite and greenstone clasts. Metaconglomerate and pebbly metasandstone were classified as metaconglomerate. The class of other metamorphic rock types is composed primarily of veined quartz, schist, and calcsilicates.

Volcanic rock types comprise about 11 percent of the clasts, and they were subdivided on the basis of color and density. The dark-colored, volcanic-rock clasts typically are moderately dense and porphyritic, but the phenocrysts are much too altered to allow identification of specific minerals. The light-colored, volcanic-rock clasts typically are much less dense than the dark-colored clasts, and these light-colored volcanic clasts contain phenocrysts of quartz, feldspar, and biotite. The dark-colored, volcanic-rock clasts are thought to represent mafic volcanic rocks, whereas the light-colored, volcanic-rock clasts are thought to represent felsic volcanic rocks. All clasts with a vitroclastic texture were classified as tuffaceous. No flow-banded volcanic-rock clasts were observed.

Significant quanties of chert, sandstone, plutonic, and Crassostrea clasts are found in the conglomerate beds. Chert clasts were subdivided on the basis of color: red, green, and black. Sandstone clasts are rare in the conglomerate beds, and they typically are light colored, friable, fine to medium grained, and calcite cemented. The class quartz is composed dominantly of unveined, milky-white quartz. Plutonic rock clasts are rare, and they dominantly are of felsic varieties. All plutonic clasts were too altered to identify accessory minerals, but the color index of these clasts typically is less than 20. Crassostrea fragments are common in one of the conglomerate outcrops sampled, and they were included as a clast type because they were reworked from older sedimentary rocks. A reworked origin is attributed to the fragments because their shell thickness is greater than 2.5 cm, which is too great to have been derived from the Ostrea indigenous to Etchegoin strata. Ostrea vespertina and Ostrea atwoodi are indigenous in Etchegion strata, but they are small species with shell thicknesses of less than 1 cm (C. Powell, oral. comm., 1986). On the other hand, very large and giant Crassostrea are common in the underlying Santa Margarita Formation, and many shells attain a length of 40 cm and have shell thicknesses of more than 10 cm. Therefore, the shell fragments found in Etchegoin conglomerate are considered to be clasts.

SANDSTONE COMPOSITION

Sample Selection

To determine the composition of Etchegoin strata on a regional scale, sandstone was sampled in four stratigraphic sections that are far removed from each other. The sections are located along Anticline Ridge (CAS), Reef Ridge (RRS), and Warthan Canyon (WCS) in the Coalinga region, and along Sulphur Creek (SCS) in the San Benito region (fig. 10). The Anticline Ridge and Reef Ridge sections are stratigraphically complete, whereas the upper part of both the Warthan Canyon and Sulphur Creek sections is missing. Typical exposures in all sections are poor. Sandstone was sampled from nearly all outcrops in the Warthan Canyon and Reef Ridge sections, and it was sampled at representive intervals in the Anticline Ridge and Sulphur Creek sections. Medium-grained sandstone was sampled where possible, but fewer than half of the samples are of this size; most are fine- to very fine-grained sandstone.

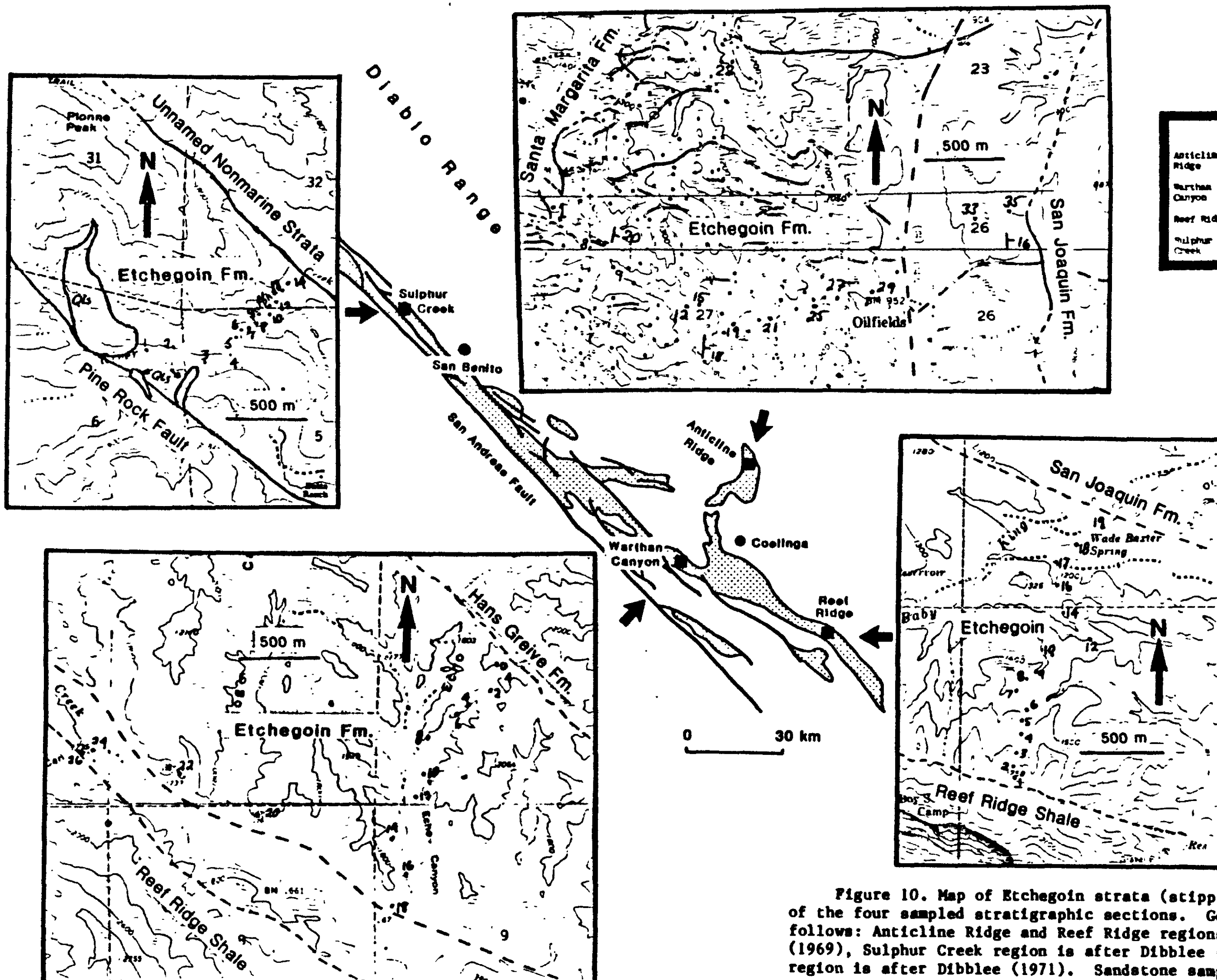
The stratigraphic position of the sampled sandstone in the Anticline Ridge, Warthan Canyon, and Reef Ridge sections was determined by measurement of stratigraphic sections. Measurement of the Anticline ridge section was by a combination of tape, Jacob's staff, and pacing, whereas pacing was used exclusively in the Warthan Canyon and Reef Ridge sections. In the Sulphur Creek section, the published measured section of Wilson (1943) was used to determine the stratigraphic position of sandstone intervals, and pacing was then used to determine the stratigraphic position of the sampled bed within each sandstone interval.

Framework Composition

Petrography

From the four stratigraphic sections, 54 samples were analyzed for the type and abundance of framework grains. Twelve samples each were selected from the Anticline Ridge and Warthan Canyon sections, 14 from the Sulphur Creek section, and 16 from the Reef Ridge section. From these sandstone samples, compositional variations within and between sections were determined that allow assessment of the framework composition of Etchegoin strata on a regional scale.

From each of the 54 samples a total of 300 framework grains were identified. The Glagolev-Chayes method of assay was employed; it approximates volume percent and allows statistical analysis of the frequency data (Galehouse, 1971). Grain types assayed include quartz (Q), feldspar (F), chert (C), volcanic rock fragments (VRF), plutonic rock fragments (PRF), and metamorphic rock fragments (MRF). Shown in Table 3 are the average percentages of these grain types that are found in each of the stratigraphic sections. The frequency data for individual samples are given in Appendix II. The six detrital modes were chosen as a bsis to define the framework composition because they are genetically robust. Classifications such as those described by



	7 1/2 Minute Series	Sections	Township-Range
Anticline Ridge	Domengine Ranch Coalinga	21,23,26,27	T.19S., R.15E.
Warthan Canyon	Sherman Peak Smith Mt.	4,5,6,8,9	T.21R., R.15E.
Reef Ridge	Garza Peak	6,7	T.23S., R16E.
Sulphur Creek	Pickmore Canyon Canyon	5,6 32	T.16S., R.8E. T.15S., R.8E.

Figure 10. Map of Etchegoin strata (stippled) showing the locations of the four sampled stratigraphic sections. Geologic mapping is as follows: Anticline Ridge and Reef Ridge regions are after Adegoke (1969), Sulphur Creek region is after Dibblee (1979), Warthan Canyon region is after Dibblee (1971). Sandstone samples have the following prefixes; Anticline Ridge section - CAS, Reef Ridge section - RRS, Warthan Canyon section - WCS, and the Sulphur Creek section - SCS.

TABLE 3. FRAMEWORK COMPOSITION, AVERAGED FOR EACH STRATIGRAPHIC SECTION

Stratigraphic Section	Percent					
	Quartz	Feldspar	Chert	VRF	PRF	MRF
Anticline Ridge	19	20	4	43	2	12
Warthan Canyon	24	15	2	39	2	18
Reef Ridge	21	13	3	41	2	20
Sulphur Creek	29	24	4	21	3	19

Dickinson (1970), Dickinson and Suczek (1979), and Zuffa (1980) were not employed, because they are robust in discriminating between tectonic provinces. The tectonic province of the Etchegoin is well known to be that of a complex magmatic arc. Therefore, class types were defined to exploit intraprovince provenance. Because many of the sandstones sampled have undergone severe diagenesis, the original composition of many relict framework grains had to be estimated.

Quartz grains were classified as monocrystalline quartz (Q), PRF, or MRF depending upon their optical character. All monocrystalline quartz grains were assigned to the class Q; most of these have undulatory extinction. Less common are monocrystalline quartz grains with trains of vacuoles, microlites, or inclusions of apatite(?). The class Q was not subdivided on the basis of grain morphology or extinction characteristics, because these parameters may be dependent on grain size (Blatt, 1967), which is not uniform in this study. Diagenetic quartz is thought to be rare in Etchegoin sandstone, because very few quartz overgrowths were observed. Polycrystalline quartz grains that are composed of polygonal crystals of relatively uniform size greater than about 0.05 mm were classified as PRF. Polycrystalline quartz grains composed of crystals that exhibit a preferred crystallographic orientation, or that are composed of crystals of non-uniform size, were classified as MRF.

Both plagioclase and potassium feldspar varieties are present in the sandstone sampled. In stained thin sections, the frequency of potassium feldspar ranges from trace to approximately half the total feldspar. Both twinned and untwinned potassium feldspar are present, and sanidine is present but rare. Discriminating between grains of potassium feldspar and grains of plagioclase that have been altered to potassium-rich phyllosilicates could not be done consistently. Therefore, no attempt was made to subdivide the feldspars.

Most volcanic rock fragments are of andesitic composition. These grains lack potassium feldspar and quartz, and plagioclase phenocrysts range from about An 34 to about An 67. The VRF exhibit a wide variety of textures; the most common are: (1) pilotaxitic, with microlites or small laths of plagioclase; (2) pilotaxitic, with microlites or laths of plagioclase, abundant large phenocrysts of plagioclase, commonly with large phenocrysts of hornblende, augite, or hypersthene; (3) cryptocrystalline, with abundant microlites, rare laths of plagioclase, and no large phenocrysts; and (4) seriate, with plagioclase phenocrysts ranging from microlites to 0.1 mm, commonly with phenocrysts of hornblende, augite, or hypersthene. The phenocrysts found in these VRF dominantly are euhedral. The aforementioned textures primarily are found in VRF in sandstone in the Coalinga region, and they are rare in VRF in sandstone in the Sulphur Creek region. The most common texture of VRF in the Sulphur sandstone is holcrystalline, with anhedral or subhedral phenocrysts of plagioclase. Many plagioclase phenocrysts in these VRF exhibit a sieved texture. Identified accessory minerals are uncommon in these VRF, but individuals or aggregate clusters of opaques are common. Also, the groundmass in VRF of Sulphur Creek is highly altered.

In addition to polycrystalline quartz, the class PRF includes composite grains of quartz and feldspar that exhibit no preferred crystallographic orientation. Within the class PRF, the most common potassium feldspars are orthoclase and microcline, and observed plagioclase ranges from albite to labradorite. Most composite grains lack accessory minerals, but where present they include biotite, muscovite, hornblende, and opaques.

The class MRF is composed primarily of polycrystalline quartz, but it also includes schist fragments and composite grains of quartz and feldspar. Such composite grains were assigned to the class MRF only if their crystals exhibited a preferred crystollographic orientaion, or their crystals were of varying sizes. Accessory minerals in MRF include biotite, glaucophane, actinolite, and tremolite.

Sedimentary rock fragments are rare in sampled sandstone of the Etchegoin Formation. Chert is overwhelmingly the most abundant grain type, and only it was included in the assay. Other sedimentary rock fragments that were observed but not counted are siltstone and claystone. Siltstone and claystone fragments make up much less than one percent of the framework grains, and therefore, little information is lost by exclusion of these framework grains from the assay.

The frequency of these six classes of framework grains may be affected by the grain size. To assess the relationship between frequency and grain size, statistical tests were preformed on 24 sandstone samples from the Warthan Canyon and Anticline Ridge sections (Table 4). T-tests indicate that a significant correlation ($\alpha = 0.05$) between grain size and the frequency of quartz, VRF, and PRF. Pearson correlation coefficients (r^2) indicate that 41 percent of the variance of quartz, 33 percent of VRF, and 16 percent of PRF can be attributed to

TABLE 4. STATISTICAL DATA RELATING TO FRAMEWORK COMPOSITION

Class Type	t-Ratio	Pearson Correlation Coefficient (r^2)
Quartz	4.12	0.41
Plagioclase	1.92	0.10
Chert	0.80	0.01
VRF	-3.53	0.33
MRF	0.49	0.04
PRF	2.35	0.16

variations in grain size. These relatively strong correlations between frequency and grain size make rigorous statistical techniques to identify compositional variations inappropriate, at least in the sampled population of Etchegoin sandstone, because grain size is not standardized. However, restricting the compositional analysis to sandstone within a narrow size range would reduce the data base to an unacceptable level. Therefore, all data are used, but no rigorous quantitative techniques are employed to identify compositional variations in the framework grains.

Compositional Variations

The framework composition of Etchegoin sandtone is summarized in figure 11 as the relative percentages of monocrystalline quartz (Q), feldspar (F), and lithic fragments (L) - the sum of chert, VRF, PRF, and MRF. There are no marked differences in the framework composition between samples from the four sampled stratigraphic sections. Samples recovered from the Reef Ridge and Sulphur Creek sections tend to cluster, whereas those from the Warthan Canyon and Anticline Ridge sections exhibit a moderate amount of variation. Plotting sandstone composition with respect to monocrystalline quartz (Q), MRF, and VRF reveals much variation in the framework composition (fig. 12 A). All four sections exhibit considerable variation, and these data are the basis of identifying variations in the composition of framework grains in Etchegoin sandstone.

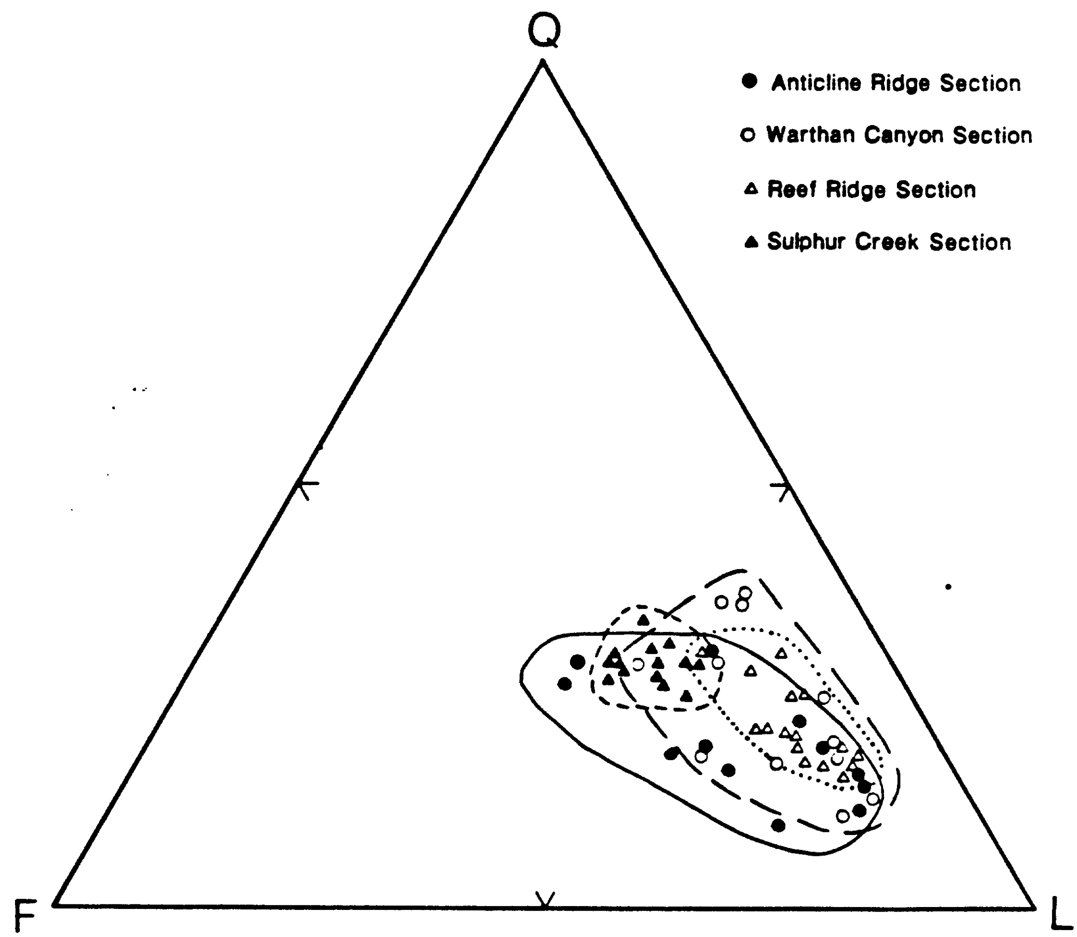
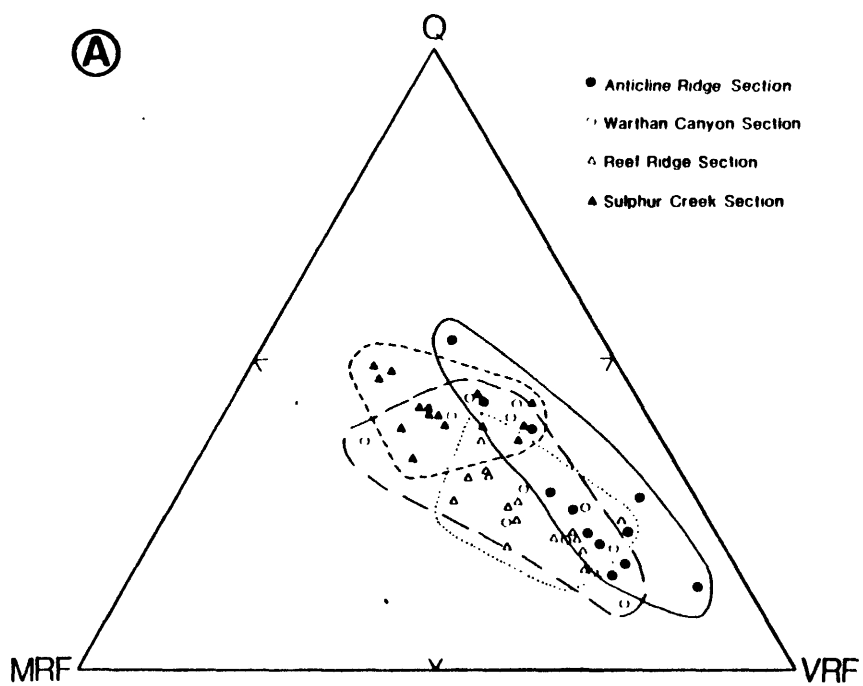


Figure 11. Plot showing the relative percentages of quartz (Q), feldspar (F), and lithic fragments (L) in sandstone sampled from the Etchegoin Formation. Fields that contain all samples within individual sections also are shown.



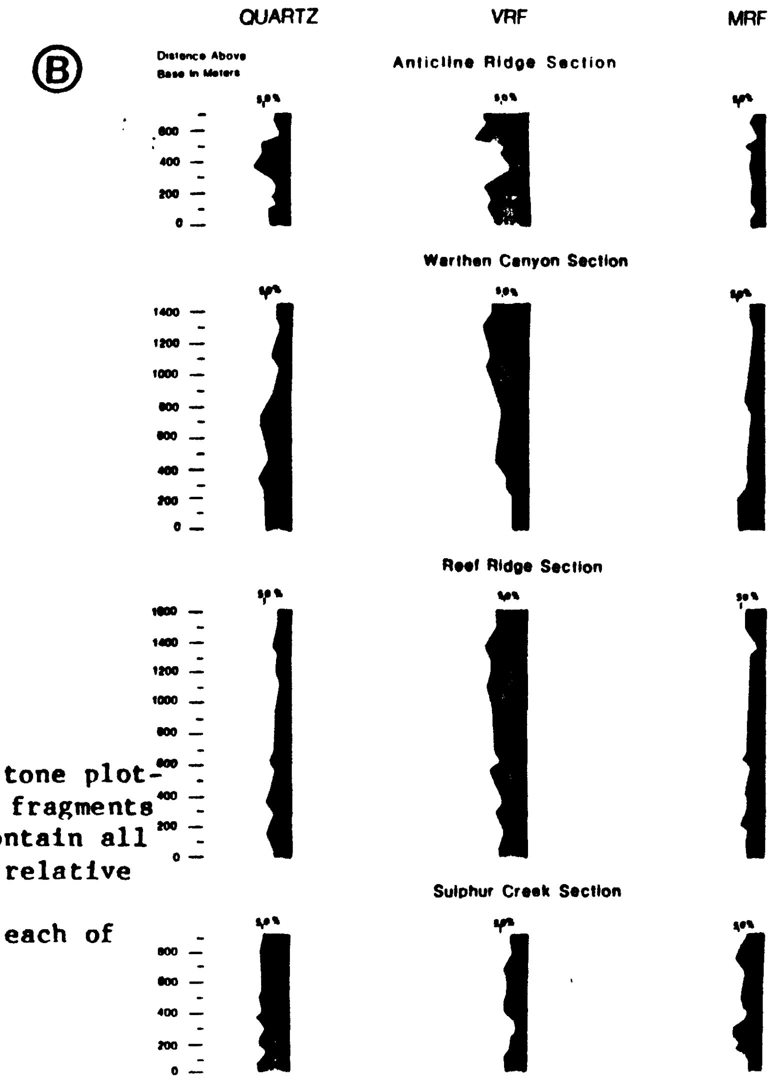


Figure 12. (A) Framework composition of Etchegoin sandstone plotted as the relative proportions of quartz (Q), volcanic rock fragments (VRF), and metamorphic rock fragments (MRF). Fields that contain all samples within individual sections are also shown. (B) The relative proportions of Q, VRF, and MRF plotted as a function of the stratigraphic positions of Etchegoin sandstone sampled from each of the four sections.

To assess both spatial and temporal variations, the relative percentage of Q, VRF, and MRF are plotted as a function of stratigraphic position (fig. 12 B). Both spatial variation between sections and temporal variations within sections are apparent in figure 12 B. Quartz is most abundant in the Sulphur Creek section and in the lower part of both the Reef Ridge and Warthan Canyon sections. Quartz is moderately abundant in sandstone in the Anticline Ridge section only in the interval between 300 m and 500 m above the base. VRF are most abundant in the Anticline Ridge section, where they comprise more than 50 percent of these grain types. In both the Reef Ridge and Warthan Canyon sections, the abundance of VRF increases upsection from about 30 percent in the lower part to more than 50 percent in the upper part. Sandstone in the Sulphur Creek section contains a percentage of VRF lower than that found in the three sections in the Coalinga region. On the other hand, the class MRF is most abundant in the Sulphur Creek section, which averages more than 30 percent MRF. The Anticline Ridge section has the lowest abundance of MRF, whereas MRF in both the Reef Ridge and Warthan Canyon sections decrease slightly upsection.

Heavy Minerals

To provide further documentation of compositional variations in Etchegoin strata and to increase provenance sensitivity, the type and abundance of heavy minerals in Etchegoin sandstone were determined. Assemblages of heavy minerals often are unique to specific source terranes, and provenance determinations can be made with a fair degree of confidence (see Imbrie and van Andel, 1964; Galehouse, 1971; Rappeport, 1976; Gwyn and Dreimanis, 1979).

Petrography

All samples used in the framework analysis, plus two additional samples from the base of the Warthan Canyon section, were assayed for their contained heavy minerals. The sandstone samples were disaggregated using HCl or H_2O_2, and the residue was sieved. Heavy minerals in the sieved fraction between 1.5 phi and 4.0 phi were extracted by the use of bromoform. The splits were then mounted on glass slides for assay. A total of 300 non-opaque, monomineralic grains were identified for each sample using the ribbon method of assay (Hunter, 1967; Galehouse, 1971).

Heavy mineral grain types assayed are green hornblende, brown hornblende, sphene, hypersthene, epidote, actinolite-tremolite, zircon, garnet, glaucophane, and augite (Table 5, Appendix III). Trace amounts of zoisite, antigorite, and olivine were noted, but due to their low abundances were not assayed. The color determination of hornblende was made with crystals in a similar orientation. Hornblende exhibited nearly a continuous spectrum of color from very dark brown to very pale green. Because the color of hornblende is in part dependent upon grain thickness, it was difficult to consistently discriminate between brownish-green hornblende and greenish-brown hornblende. In such cases,

TABLE 5. HEAVY MINERAL DATA, AVERAGED FOR EACH SECTION

Stratigraphic Section	Percent									
	Green Hornblende	Brown Hornblende	Sphene	Hypersthene	Epidote	Actinolite-Tremolite	Zircon	Garnet	Glaucophane	Augite
Anticline Ridge	25	33	1	10	2	1	2	0	1	23
Warthan Canyon	35	33	2	8	4	1	3	0	6	8
Reef Ridge	31	30	1	12	2	1	2	0	1	20
Sulphur Creek	34	16	10	1	11	3	12	3	7	3

the stage was rotated 90 degrees and the color determination made. Nonopaque basaltic hornblende was included in the brown hornblende fraction. Discrimination between actinolite and tremolite was not made, and both actinolite and tremolite were grouped into the class actinolite-tremolite.

Assessing the compositional variation in this heavy mineral data set is difficult, because it is large and the associations of heavy mineral grains may be subtle. To overcome these difficulties, factor analysis was performed on the heavy mineral data.

Factor Analysis

Factor analysis is a statistical technique that extracts a small number of uncorrelated variables from a data set that contains a large number of correlated variables. The overall effect of this statistical treatment is a reduction in dimensionality. Only a brief overview of factor analysis is presented here; for an extensive treatment of factor analysis see Harmon (1967) or Klovan (1975).

The reduction in dimensionality that is produced by factor analysis is easily envisioned by a geometric model. Samples are plotted in N-dimensional space with axes defined by the original variables; in this case N equals the number of heavy mineral types. New independent axes (eigenvectors) are created that account for the same spatial distribution of the original data. The eigenvectors are referred to as factors, and their relative importance in explaining the distribution of these original data is represented by an eigenvalue. Factor loadings are a measure of the importance of individual factors on individual samples, and they range from -1 to +1. The magnitude of the loading is of primary concern, not the sign. The higher the loading, the more the sample reflects the composition of the factor.

Factor analysis is a step-by-step process; that is, each factor is created to account for the maximum variance remaining in the data set. The first factor, the principal factor, accounts for the greatest variance, and it tends to load significantly on many samples. Subsequent factors are orthogonal to all pre-existing factors. These subsequent factors tend to be moderate and about zero. Determining the factor composition of these subsequent factors is difficult unless a factor rotation is used. Factor rotation simplifies interpretation because it tends to produce factors that have sample loadings that are either very high or very low. The Q-mode factor analysis performed in this study employs a varimax rotation (Nie and others, 1979).

Commonly, the frequency of heavy minerals will vary as a function of grain size (see Luepke, 1984). To remove the effects of grain size on the frequency of heavy mineral grain types, statistical tests were performed on 24 sandstone samples from the Warthan Canyon and Anticline Ridge sections. T-tests indicate a significant correlation ($\alpha = 0.05$) between grain size and the frequency of zircon and glaucophane (Table 6). Pearson correlation coefficients (r^2) indicate that 22 percent of the variance in zircon and 19 percent in glaucophane is accounted for by variations in the grain size of the sampled sandstone. Prior to factor analysis, the heavy mineral data were standardized by a z-transformation. The frequency data for zircon and glaucophane were excluded from factor analysis, because variations in grain size probably would have been reflected in the composition of factors.

TABLE 6. STATISTICAL DATA RELATING TO HEAVY MINERALS

Grain Type	t-Ratio	Pearson Correlation Coefficient (r^2)
Green Hornblende	1.0	0.00
Brown Hornblende	-0.96	0.00
Sphene	-0.08	0.04
Hypersthene	-0.99	0.00
Epidote	1.82	0.09
Actinolite-Tremolite	0.57	0.03
Zircon	2.77	0.22
Garnet	-0.81	0.01
Glaucophane	2.56	0.19
Augite	-1.24	0.02

Q-mode factor analysis of Etchegoin heavy mineral data results in four factors that account for about 86 percent of the variance in the heavy mineral data (Table 7). The composition of these factors was determined on the basis of end members, which are defined as samples that have a very high positive or negative loading on an individual factor. The end member for each of the four factors is shown in Table 8. Factor loadings for each sample are given in Appendix IV.

Factor 1 accounts for the greatest variance, 36.5 percent, and it contains the most information. The end member of this factor is exemplified by sample WCS-18, which contains abundant green and brown hornblendes, and is deficient in sphene, epidote, garnet, augite, and hypersthene. Of the 28 samples that load negatively on factor 1, 14 contain a relatively high abundance of green and brown hornblendes, but they also contain relatively high abundances of sphene (11%), epidote (18%), and garnet (3%). This compares to samples that load greater than +0.7 on factor 1, which average less than 1 percent sphene, less than 2 percent epidote, and much less than 1 percent garnet. The other 14 samples that load negatively on factor 1 average 60 percent augite plus hypersthene, which compares to 7 percent for the samples that load greater than +0.7. Thus, these data indicate that factor 1 reflects the abundance of green and brown hornblendes, and a paucity of sphene, epidote, garnet, augite, and hypersthene.

Sandstone samples that have high positive loadings on factor 2 are represented by sample RRS-9, which contains a high abundance of augite and brown hornblende. Samples that have loading greater than +0.7 contain an average of 76 percent augite plus brown hornblende. This factor represents a heavy mineral association of augite and brown hornblende, which accounts for 28.5 percent of the variance in the heavy mineral data.

Factor 3 reflects the frequency of hypersthene, and to a lesser extent that of brown hornblende. As represented by sample WCS-0, sandstone samples that have high negative loadings, less than -0.7, average 39 percent hypersthene and 20 percent brown hornblende. Although most of the variance of brown hornblende was extracted by factors 1 and 2, apparently enough residual variance exists to make brown hornblende an important component of factor 3. This factor represents a heavy mineral association of hypersthene and brown hornblende, which accounts for 11.7 percent of the variance in the heavy mineral data.

Factor 4 is composed primarily of actinolite-tremolite as shown by sample SCS-11 (Table 8). Sandstone samples that have loadings greater than +0.7 contain an average of 8 percent actinolite-tremolite, whereas samples that have negative loadings contain an average of only 0.2 percent. This factor accounts for 9.5 percent of the variance in the heavy mineral data.

TABLE 7. FACTORS

Factor	Eigenvalue	Percent of Variance	Cumulative Percent
1	15.9	36.5	36.5
2	6.6	28.5	65.0
3	5.3	11.7	76.7
4	4.3	9.5	86.2

TABLE 8. END MEMBERS

Percent

	Sample Number	Green Hornblende	Brown Hornblende	Sphene	Hypersthene	Epidote	Actinolite-Tremolite	Zircon	Garnet	Glaucophane	Augite
Factor 1	WCS-18	45	48	0	0	2	1	2	1	1	0
Factor 2	RRS-9	17	41	0	0	4	1	<1	<1	<1	35
Factor 3	WCS-0	16	18	0	40	0	1	1	0	1	23
Factor 4	SCS-11	38	38	1	0	1	8	6	2	2	4

Compositional Variations

To identify variations in the heavy mineral content of Etchegoin sandstone the abundances of the four heavy mineral associations are plotted as a function of stratigraphic position of the sampled sandstone (fig. 13). As is evident in figure 13, marked variations exist in the heavy mineral content in all four stratigraphic sections.

The Anticline Ridge section contains significant amounts of each of the four mineral associations (fig. 13). As shown by loading on factor 2, the association of augite and brown hornblende is common in sandstone in this section. The association of green and brown hornblendes (factor 1) is relatively abundant only in two intervals, 50-200 m and 300-500 m above the base. Most of the uppermost 200 m is characterized by a marked decrease in green and brown hornblendes that is reflected by negative loadings on factor 1. However, the association of hypersthene and brown hornblende, as reflected by high negative loadings on factor 3, is found in abundance in sandstone in the upper 200 m. As shown by loadings on factor 4, actinolite-tremolite is found only in moderate amounts and only in the lower part of the section.

The most common heavy minerals found in the Warthan Canyon section are the green and brown hornblendes association and the hypersthene and brown hornblendes association (fig. 13). Sandstone in the lower 1100 m of section contains a large amount of the mineral assemblage of green and brown hornblendes, as reflected by generally high positive loadings on factor 1. Sandstone in the upper 250 m of section contains few green and brown hornblendes, but it does contain a large amount of hypersthene and brown hornblende, as reflected by generally high negative loadings on factor 3. The association of augite and brown hornblende (factor 2) and actinolite-tremolite (factor 4) are minor in this section.

In general, sandstone in the Reef Ridge section is characterized by an abundance of the associations of green and brown hornblendes in the lower part, augite and brown hornblende in the middle part, and hypersthene and brown hornblende in the upper part (fig. 13). The association of actinolite-tremolite is not abundant in sandstone in this section.

Characterizing the Sulphur Creek section is difficult because the only factor with even moderately high loadings is factor 4, which is characterized by actinolite-tremolite (fig. 13). Only one sample each loads positively on factor 1 or 2, and no samples load negatively on factor 3. These data suggest that sandstone in this section lacks the heavy mineral associations of green and brown hornblendes, augite and brown hornblende, and hypersthene and brown hornblende.

Inspection of the raw heavy mineral data (Table 5, Appendix III), indicates that a fifth heavy mineral association is found in the Sulphur Creek section. The raw heavy mineral data for sandstone samples in the Sulphur Creek section indicate that green and brown hornblendes are the dominant heavy mineral types. The hornblende-rich sandstone samples in this section are not reflected by positve loading on factor 1, because they contain a relatively large amount of sphene, epidote, and garnet. Nine sandstone samples from this section contain an average of 45 percent green hornblende, 20 percent brown hornblende, 4 percent sphene,

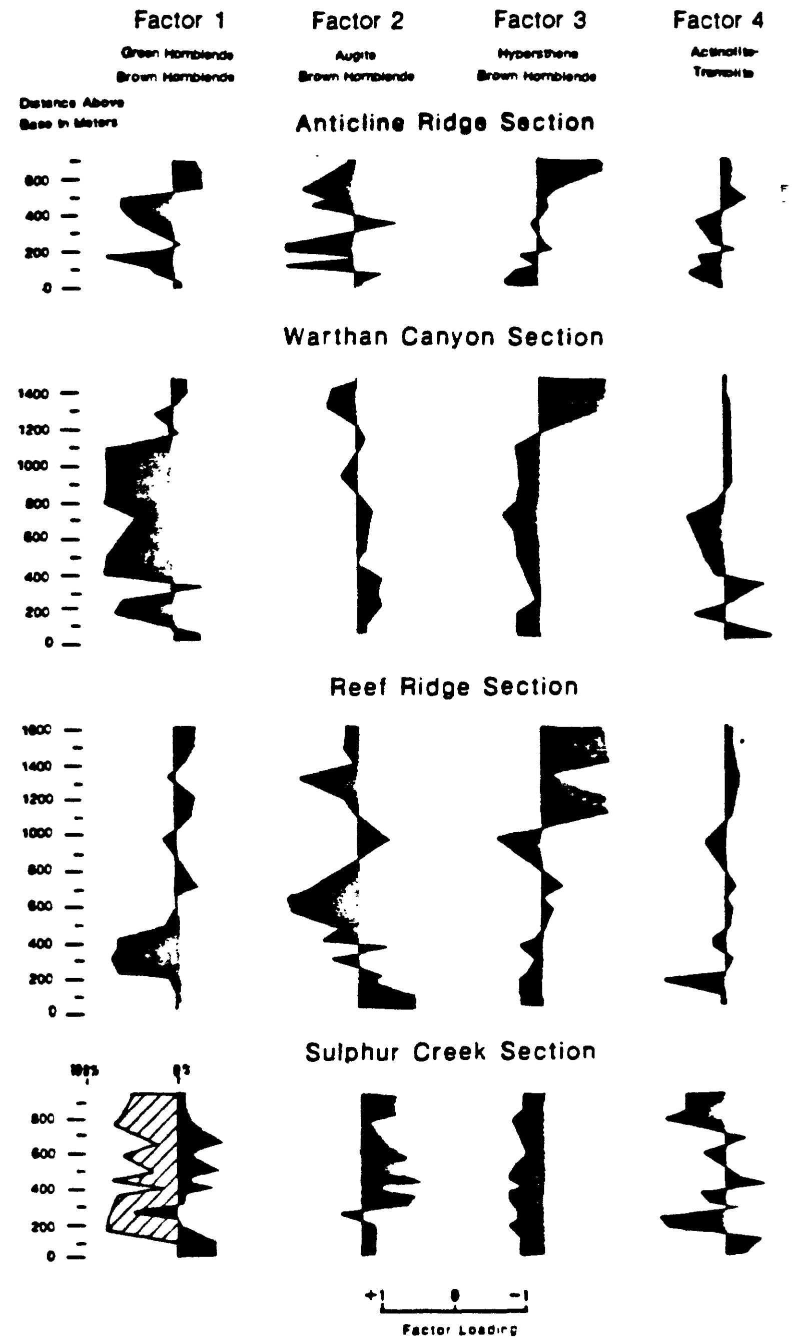


Figure 13. Factor loading plotted as a function of the stratigraphic position of sampled Etchegoin sandstone from each of the four sections. The hachured area in the graph of factor 1 for the Sulphur Creek section represents the abundance of green hornblende, which represents the heavy mineral association of green and brown hornblendes, zircon, sphene, epidote, and garnet.

Figure 14. The character of zircon in sandstone SCS-3 showing multiple degrees of rounding (A), and two of its varied crystal shapes (B and C).

7 percent epidote, and 2 percent garnet. Factor analysis accounted for the variance in the heavy mineral data produced by this mineral assemblage by grouping it in with other parameters to define the green and brown hornblendes association of factor 1. However, the other parameters, such as the frequency of augite and hypersthene, were accounted for by factors 2 and 3. The abundance of green and brown hornblendes, sphene, epidote, and garnet was not accounted for by additional factors. Therefore, to quantify the relative amount of the fifth heavy mineral association the abundance of green and brown hornblendes is plotted as a function of stratigraphic position; the abundance of green and brown hornblendes is shown in figure 13 as the hachured area of factor 1 for the Sulphur Creek section. Almost the entire section above 200 m is characterized by this mineral association. Thus, the Sulphur Creek section is characterized by an abundance of a fifth heavy mineral association, and it has moderate abundance of the actinolite-tremolite association.

PROVENANCE

Provenance of the Etchegoin Formation is inferred from the type and abundance of framework grains and heavy mineral associations found in the sandstone, and, to a lesser extent, from the composition of conglomerate. These data suggest that detritus in the Etchegoin Formation was derived from several source terranes, which contained plutonic, volcanic, and metamorphic rocks or detritus. Estimates of the relative amount of detritus derived from the different source terranes are based primarily on the framework composition data. The identification of specific sources of detritus is based primarily on heavy mineral associations. However, prior to discussing provenance of Etchegoin sandstone, an overview of provenance of Etchegoin conglomerate is presented, because the distribution and composition of coarse-grained detritus is a sensitive indicator for the proximity of source terranes.

Etchegoin conglomerate is most abundant in the Coalinga region, and within this region there is a southward decrease in frequency, clast size, and clast abundance. These data indicate that the primary source of coarse-grained detritus was north of the Coalinga region.

Most of the clasts found in Etchegoin conglomerate are composed of metamorphic rock types. Metasandstone, metasiltstone/claystone, metavolcanic/greenstone, metaconglomerate, and other metamorphic rock types account for approximately 70 percent of the total clasts. The closest source of metamorphic rocks north of Coalinga that contains such a diverse suite of metamorphic rock types is in the Franciscan rocks in the Diablo Range. The Franciscan is composed of weakly metamorphosed to blueschist facies graywacke, shale, chert, mafic volcanics, and ultramafic rocks. The closeness and similarity of lithology make the Franciscan the likely source for the metamorphic detritus found in Etchegoin conglomerate. The Franciscan also contains variegated chert, which comprises approximately 6 percent of the clasts found in Etchegoin conglomerate. The Franciscan is not a unique source of chert, but considering the similarity of other rock types derived from it, it is reasonable to attribute the chert clasts in Etchegoin conglomerate to a Franciscan source. The Franciscan of the Diablo Range probably supplied the bulk of the coarse-grained detritus found in Etchegoin conglomerate.

The non-Franciscan detritus in Etchegoin conglomerate is difficult to attribute to specific source terranes, except for the Crassostrea fragments and the felsic volcanic clasts. As previously stated, the Crassostrea fragments are considered clasts, and they probably were derived from the Santa Margarita Formation. Similarly, the Santa Margarita is suggested as the source for the felsic volcanic clasts, because it is the nearest source of coarse-grained felsic volcanic detritus. Along Anticline Ridge, the writer noted that nearly one third of clasts found in Santa Margarita conglomerate are felsic volcanic clasts that have a similar texture and color to those found in Etchegoin conglomerate. Abundant felsic volcanic clasts in the arkosic Santa Margarita seems unusual; however, Clark (1981) found that a similar situation exists in Santa Margarita conglomerate in the Santa Cruz Mountains, which contains nearly 40 percent felsic volcanic clasts. The Pinnacles Volcanics may have been positioned near to the Coalinga region, but they did not contribute the felsic volcanic detritus, because the flow-banded rhyolites that are common in the rocks of the Pinnacles Volcanics are not found as clasts in Etchegoin conglomerate. An alternative to a Santa Margarita source for these clasts is the Quien Sabe Volcanics of Taliaferro (1948) in the central Diablo Range (fig. 3), which contain significant amounts of felsic volcanic rocks. However, the Quien Sabe Volcanics are not a likely source for two reasons. First, the Quien Sabe Volcanics are much farther from the Coalinga region than is the Santa Margarita, and the more proximal source is preferred. Second, intermediate and mafic rock types, especially andesite, are the most common rock types in the Quien Sabe Volcanics (Lieth, 1949: Prowell, 1974; Drinkwater, 1984), and these rock types are very rare in Etchegoin conglomerate. These data suggest that neither the Pinnacles Volcanics nor the Quien Sabe Volcanics contributed detritus to Etchegoin conglomerate.

The provenance of Etchegoin conglomerate indicates that both the Franciscan and Santa Margarita Formation contibuted detritus to coarse-grained Etchegoin strata. It is reasonable to assume that these two sources also contibuted detritus to Etchegoin sandstone, and they should be reflected in the framework composition and heavy mineral content of the sandstone.

On the basis of the framework composition of sampled sandstone, volcanic, metamorphic, and plutonic detritus is present in Etchegoin sandstone. Volcanic rock fragments average slightly over one third of the total framework grains, and they are the most abundant grain type. Metamorphic rock fragments average slightly under 20 percent of the total framework grains. Plutonic rock fragments are a minor component of the total framework composition; however, the class PRF does not represent the total amount of plutonic detritus in Etchegoin sandstone, because the grain sizes of possible plutonic sources adjacent to the San Joaquin Valley are as large, or larger than that of most sampled Etchegoin sandstone. Therefore, the abundance of plutonic detritus should primarily be reflected in the frequency of quartz and feldspar, and composite grains of PRF are not expected to be abundant. Most monocrystalline quartz grains included in the class quartz have weakly undulose extinction and are xenomorphic but not elongated, suggesting that many grains in the class Q originally were derived from plutonic rocks. Few monocrystalline quartz grains are elongate in shape and strongly undulose, suggesting that grains of metamorphic origin are rare. Similarly, few monocrystalline quartz grains have very sharp extinction, are embayed, or are euhedral, which suggests that grains of volcanic origin are rare in the class Q. Therefore, the origin of grains in the class quartz is attributed to a plutonic source. Microcline and orthoclase are common feldspars, suggesting that feldspars were derived from either a plutonic or metamorphic (gneissic or amphibolitic) source. Discriminating between plutonic versus metamorphic feldspar is difficult. However, diagnostic heavy minerals associated with such metamorphic rocks, such as sillimanite, andalusite, and kyanite, are absent in Etchegoin sandstone; therefore, most feldspar is probably of plutonic origin. A primary versus reworked origin for these framework grain types is difficult to assess on the basis of texture, and no attempt was made solely on the basis of the framework grains.

Specific source rocks are inferred for each of the heavy mineral associations. The association of green and brown hornblendes (factor 1) is diagnostic of mafic plutonic or amphibolite-grade metamorphic rocks. A mafic plutonic source is suggested because brown hornblende is relatively uncommon in felsic plutonic rocks. An amphibolite-grade metamorphic source for this association is unlikely, because Etchegoin sandstone contains a paucity of accessory minerals of amphibolite-grade rocks, such as sillimanite, andalusite, and kyanite. Therefore, the heavy mineral association of green and brown hornblendes is attributed to a mafic plutonic source terrane. The heavy mineral association of augite and brown hornblende (factor 2) is attributed to an augite-rich volcanic source, because augite and brown hornblende commonly are phenocrysts in VRF in Etchegoin sandstone. Factor 3 reflects the abundance of hypersthene and brown hornblende, and this association is attributed to a hypersthene-rich volcanic source, again because both hypersthene and brown hornblende are common in grains assigned to the class VRF. The abundance of actinolite-tremolite in Etchegoin sandstone, which is reflected by factor 4, is attributed to derivation from a metamorphic source. In Etchegoin sandstone, glaucophane is more abundant than actinolite-tremolite, but it was excluded from factor analysis because of its relatively strong correlation with grain size. Both actinolite-tremolite and glaucophane are characteristic minerals of blueschist facies rocks in California (Bailey and others, 1964), and their combined abundance is thought to reflect the abundance of blueschist metamorphic detritus in Etchegoin sandstone. The fifth heavy mineral association, that of green and brown hornblendes, zircon, sphene, epidote, and garnet, commonly occurs in plutonic terranes. Zircon was excluded from factor analysis, but zircon is correlative with sphene (r^2=0.71), epidote (r^2=0.49), and garnet (r^2=0.67); therefore it is included in this association. Many grains in this fifth heavy mineral association, especially sphene and zircon, exhibit multiple degrees of rounding and varied crystal shapes. Shown in figure 14 are three such zircon grains, one that exhibits two degrees of rounding (A), the other two representing both euhedral (B) and subhedral (C) grains. The multiple degrees of rounding and varied crystal shapes found in some

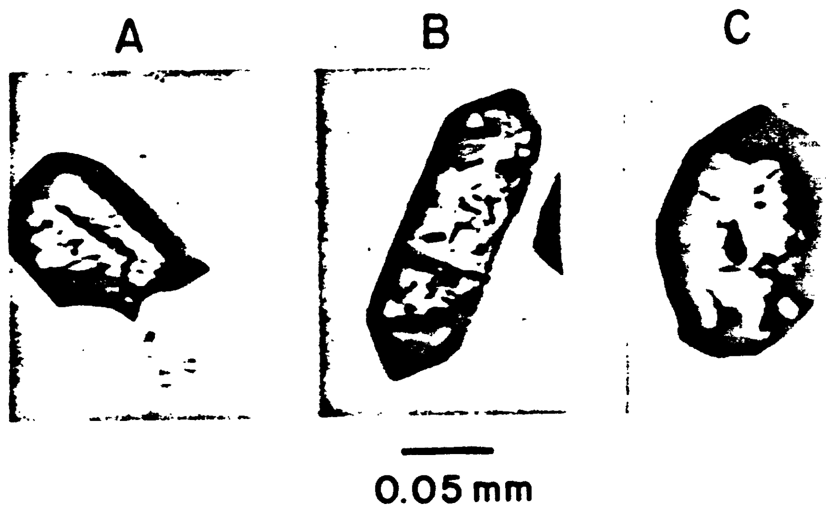


Figure 14. The character of zircon in sandstone SCS-3 showing multiple degrees of rounding (A), and two of its varied crystal shapes (B and C).

of these grains suggest that this detritus was recycled. Therefore, a sedimentary rock source that is rich in plutonic detritus is thought to have contributed some of the plutonic detritus found in Etchegoin sandstone.

Plutonic Source Terranes

There are numerous source terranes in central California that may have contributed plutonic detritus to the Etchegoin Fomation (fig. 15). Because large scale right-lateral movement has occurred along the San Andreas fault since the deposition of Etchegoin strata, the possible plutonic sources that are located west of the fault are found today far northwest of their late Miocene location. In figure 15, 220 km of right-lateral movement has been restored along the San Andreas fault.

The abundance of quartz in Etchegoin sandstone suggests that plutonic detritus is abundant, and at least two distinct types of

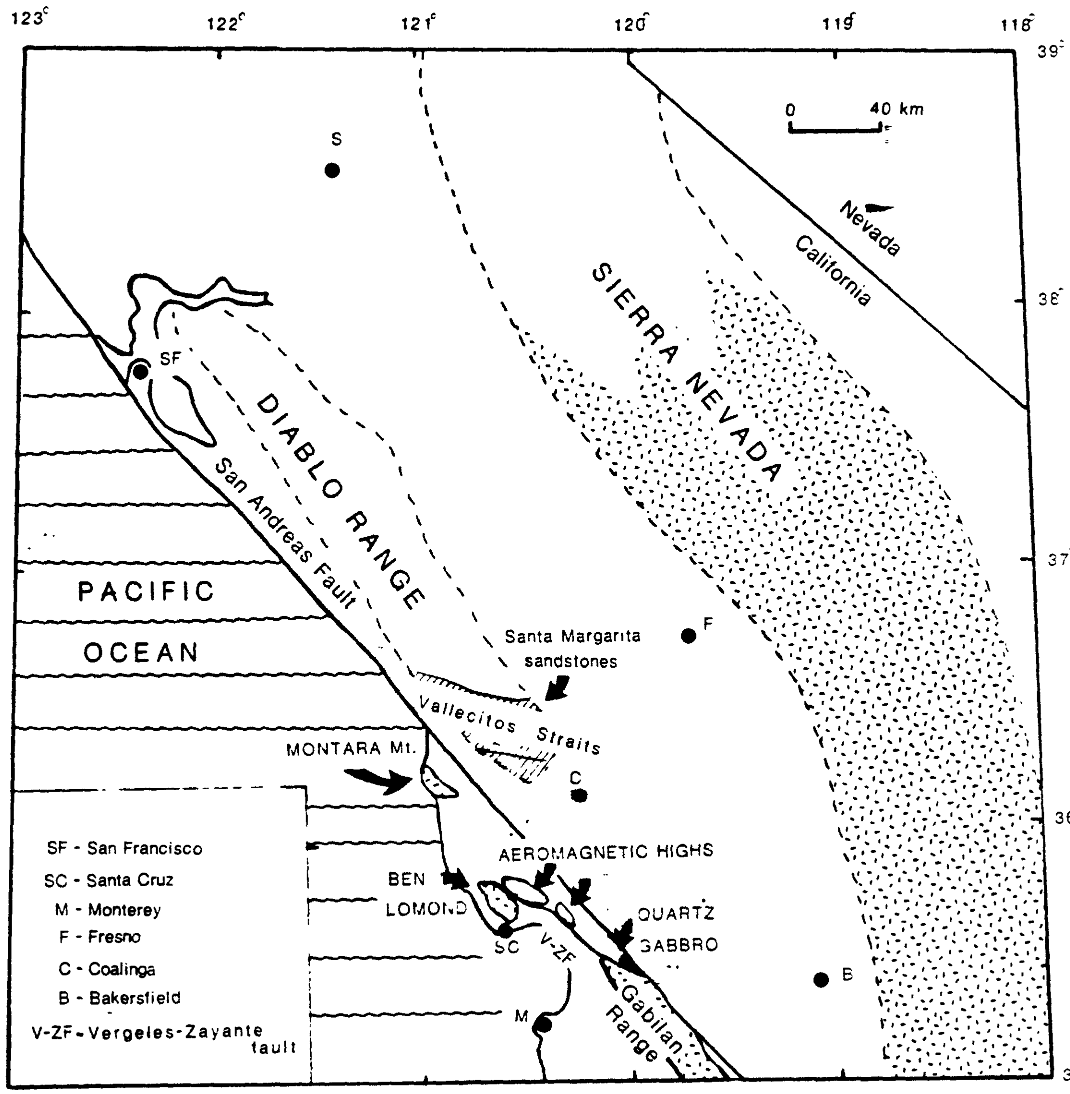


Figure 15. Possible sources of plutonic detritus contained in Etchegoin sandstone. The aeromagnetic highs along the Vergeles-Zayante fault were discussed by Ross (1984), and he attributes them to hornblende-rich gabbroic rocks in the subsurface. Hachured area represents the estimated late Miocene extent of the Santa Margarita Formation in the southern Diablo Range. The stippled region represents the original extent of Etchegoin deposition. Approximately 220 km of right-lateral movement has been restored along the San Andreas fault.

plutonic detritus are contained in these strata. One type is rich only in green and brown hornblendes and the other is rich in hornblendes, zircon, sphene, epidote, and garnet. The latter source is suspected to contain reworked material, and it probably was a plutonic-rich sedimentary source.

To assess the relative importance and relative direction of these two source terranes, the abundance of quartz and of the heavy mineral association of factor 1 are plotted for each of the four stratigraphic sections (fig. 16). The plutonic detritus that is reflected by abundant green and brown hornblendes is most abundant in the Warthan Canyon section. This detritus decreases in abundance eastward, and it is found only in the lower part of the Reef Ridge section and in lower and middle parts of the Anticline Ridge section. Little of this detritus is found in the Sulphur Creek section. The fact that this detritus decreases to the east in the Coalinga region suggests that the source lay to the west, across the San Andreas fault. Two distinct pulses of this detritus are found in the Warthan Canyon and Anticline Ridge sections, whereas only one is found in the Reef Ridge section. A source west of the San Andreas fault could produce such an effect as it was moved northwestward away from the Reef Ridge section as a result of fault movement.

Possible source terranes west of the San Andreas fault are the Montara Mountain Granodiorite, the Ben Lomond Granodiorite, and the plutonic basement of the Gabilan Range (fig. 15). The Montara Mountain and Ben Lomond plutonic rocks are composed primarily of quartz diorite, which contain only minor amounts of brown hornblende (Ross, 1972). Plutonic rocks of Montara Mountain contain apatite, zircon, and sphene as significant accessory minerals, whereas those in Ben Lomond contain zircon (Spotts, 1962). Sphene is inversely correlated with the suspected plutonic source rocks, and zircon, although not used in the factor analysis, is present only in trace amounts in samples that have high positive loadings on factor 1 (Appendix III and IV). These heavy mineral data suggest that neither the Montara Mountain nor the Ben Lomond plutonic rocks are likely candidates as the source of plutonic detritus characterized by green and brown hornblendes.

Plutonic rocks of primarily quartz monzonite and granodiorite composition crop out today for almost 900 km^2 in the Gabilan Range (Ross, 1972). No strata correlative in time to Etchegoin strata are found in the Gabilan Range, suggesting that it may have been emergent during deposition of the Etchegoin Formation. Plutonic rocks of the Gabilan Range contain little brown hornblende, and sphene, epidote, and zircon are common accessory minerals (Ross, 1972). The heavy minerals contained in Gabilan Range plutonic rocks are at variance with plutonic detritus in Etchegoin sandstone that is characterized by positive loadings on factor 1, suggesting that the Gabilan Range was not the source of this detritus. In addition, felsic volcanic rocks of the Pinnacles Volcanics are found in the southern part of the Gabilan Range. The lack of felsic volcanic detritus in Etchegoin sandstone further argues against a Gabilan Range source for detritus in the Etchegoin Formation.

A small plutonic body composed of hornblende quartz gabbro is found in the Logan area in the northwesternmost part of the Gabilan Range

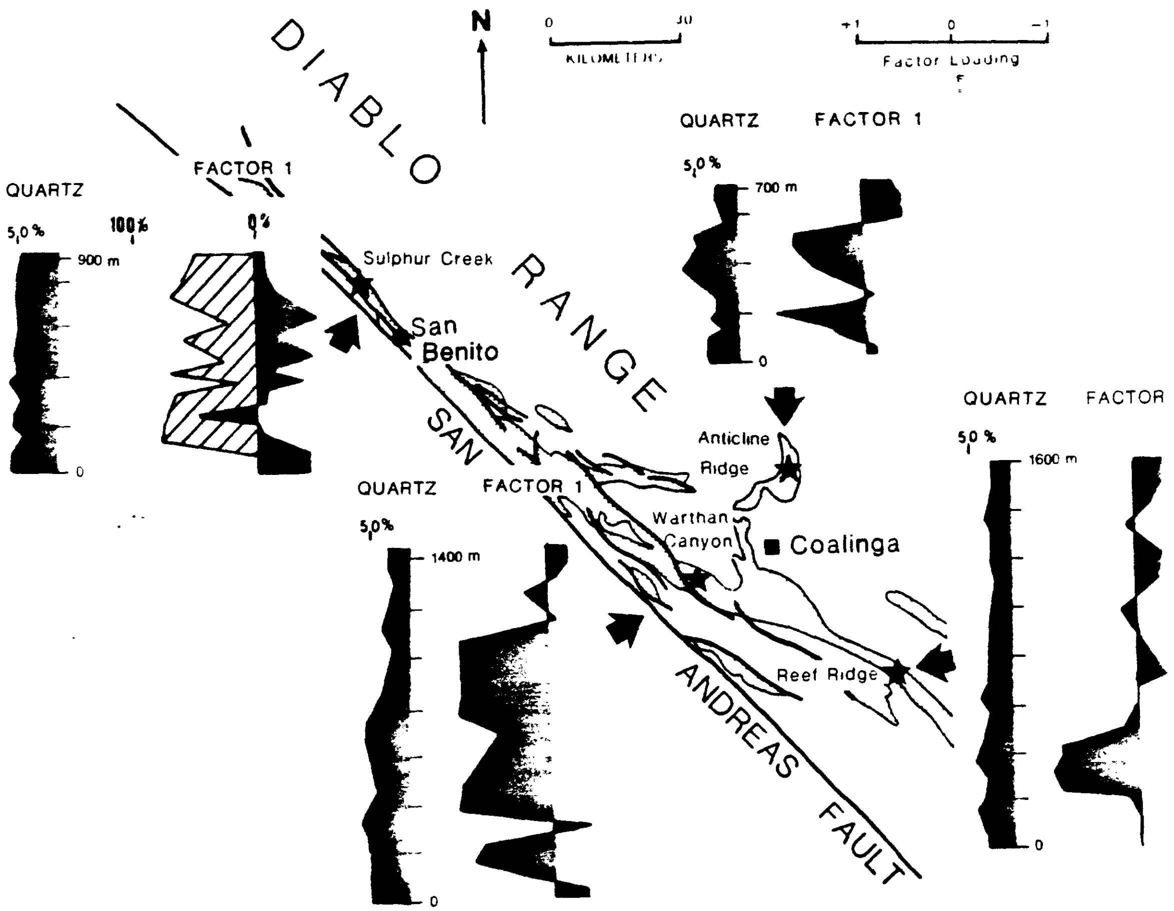


Figure 16. The distribution of plutonic detritus in sandstone in the Etchegoin Formation as reflected by the relative abundance of quartz and the heavy mineral association of green and brown hornblendes (factor 1). The hachured area of the graph of factor 1 in the Sulphur Creek section is the percent of green hornblende in the heavy mineral suite, which represents the relative abundance of plutonic detritus characterized by green and brown hornblendes, zircon, sphene, epidote, and garnet.

(fig. 15), and it contains a heavy mineral suite very similar to that of the proposed source terrane. The plutonic rocks are dominantly hornblende quartz gabbro and they contain an average of about 40 percent hornblende, most of which is green (Ross, 1970, 1972). Minor amounts of apatite, hypersthene, and clinopyroxene are found in these rocks, but they are volumetrically insignificant (Ross, 1972). These plutonic rocks are not covered by strata correlative with the Etchegoin Formation, which suggests that they may have been emergent during the late Miocene. The Logan area plutonic rocks are markedly different from those in the Gabilan Range, because they are part of a small oceanic-floored tectonic block that is distinct from the Gabilan Range block (Ross, 1984). This small tectonic block is bounded by the Vergales-Zayante, San Andreas, Pilarcitos, and La Honda-Ben Lomond faults. The hornblende-quartz gabbro is unique, in that no other rocks of similar composition are exposed west of the San Andreas fault in central California. The mineralogy of these rocks makes them a good candidate for the plutonic detritus found in Etchegoin sandstone characterized by the heavy mineral assocation of green and brown hornblendes. However, the surface exposure of these rocks is less than 10 km^2, which is insufficient to account for the volume of this type of detritus in the Etchegoin Formation. A gravity high surrounds the exposed hornblende-quartz gabbro and encompasses an area of about 60 km^2, but even a source of 60 km^2 probably is insufficient to account for the amount of detritus in Etchegoin sandstone.

The small tectonic block that contains the hornblende-quartz gabbro has two relatively large aeromagnetic highs (Boulder Creek and Corralitos highs) adjacent to the Vergales-Zayante fault that Ross (1984) attributed to hornblende quartz gabbro, or similar rock types, in the subsurface. These two, now-covered plutonic bodies underlie an area of nearly 200 km^2, and, if emergent, could account for the volume of hornblende-rich plutonic detritus in the Etchegoin Formation. Clark and Rietman (1973) suggested that the Vergeles-Zayante fault has undergone down-to-the-north post-Pliocene movement. Therefore, these now-covered plutonic bodies may very well have been exposed during deposition of Etchegion strata. The fact that there are two relatively large plutonic bodies may account for the two pulses of this detritus in strata in the Warthan Canyon and Anticline Ridge regions, whereas only one pulse occurred in the Reef Ridge region. The now-covered gabbroic rocks adjacent to the Vergales-Zayante fault are the only viable source for the exclusively hornblende-rich plutonic detritus in the Etchegoin.

The heavy minerals found in sandstone in the Sulphur Creek section (fig. 16) suggest that a plutonic source distinct from that associated exclusively with hornblende contributed plutonic detritus to the Etchegoin Formation. This second source was distinct from the hornblende-quartz-gabbro terrane, because it contained significant amounts of zircon, sphene, epidote, and garnet. Also, the multiple degrees of rounding and varied crystal shape exhibited by some heavy mineral grains that comprise this assocation make a reworked source likely. The arkosic sandstone of the Santa Margarita Formation, which is rich in plutonic debris, is the most likely source for this detritus, because it is in close proximity and because coarse-grained Santa Margarita detritus is found in Etchegoin conglomerate. To test the mineralogic similarity between arkosic sandstone in the Santa Margarita Formation and plutonic detritus in Sulphur Creek sandstone, the heavy mineral content of six Santa Margarita sandstone samples is compared to that found in Etchegoin sandstone rich in the mineral association of hornblende, zircon, sphene, epidote, and garnet.

Sandstone samples recovered from the Santa Margarita Formation within the southern Diablo Range contain a heavy mineral assemblage similar to that in the Etchegoin Formation (Table 9, fig.17). The

TABLE 9. HEAVY MINERALS IN SANTA MARGARITA SANDSTONE

	Percent									
Sample Number	Green Hornblende	Brown Hornblende	Sphene	Hypersthene	Epidote	Actinolite-Tremolite	Zircon	Garnet	Glaucophane	Augite
SMF-1	45	27	13	0	6	2	2	6	1	0
SMF-2	51	19	14	0	4	1	3	8	0	0
SMF-3	36	48	7	0	3	1	2	2	1	0
SMF-4	39	21	15	0	7	1	2	11	3	1
SMF-5	47	20	17	0	5	0	3	7	1	0
SMF-6	61	4	19	0	3	1	2	8	0	2
Average-Santa Margarita	47	23	14	0	5	1	2	7	1	0
Average-Etchegoin in Sulphur Creek	34	16	10	1	11	3	12	3	7	3

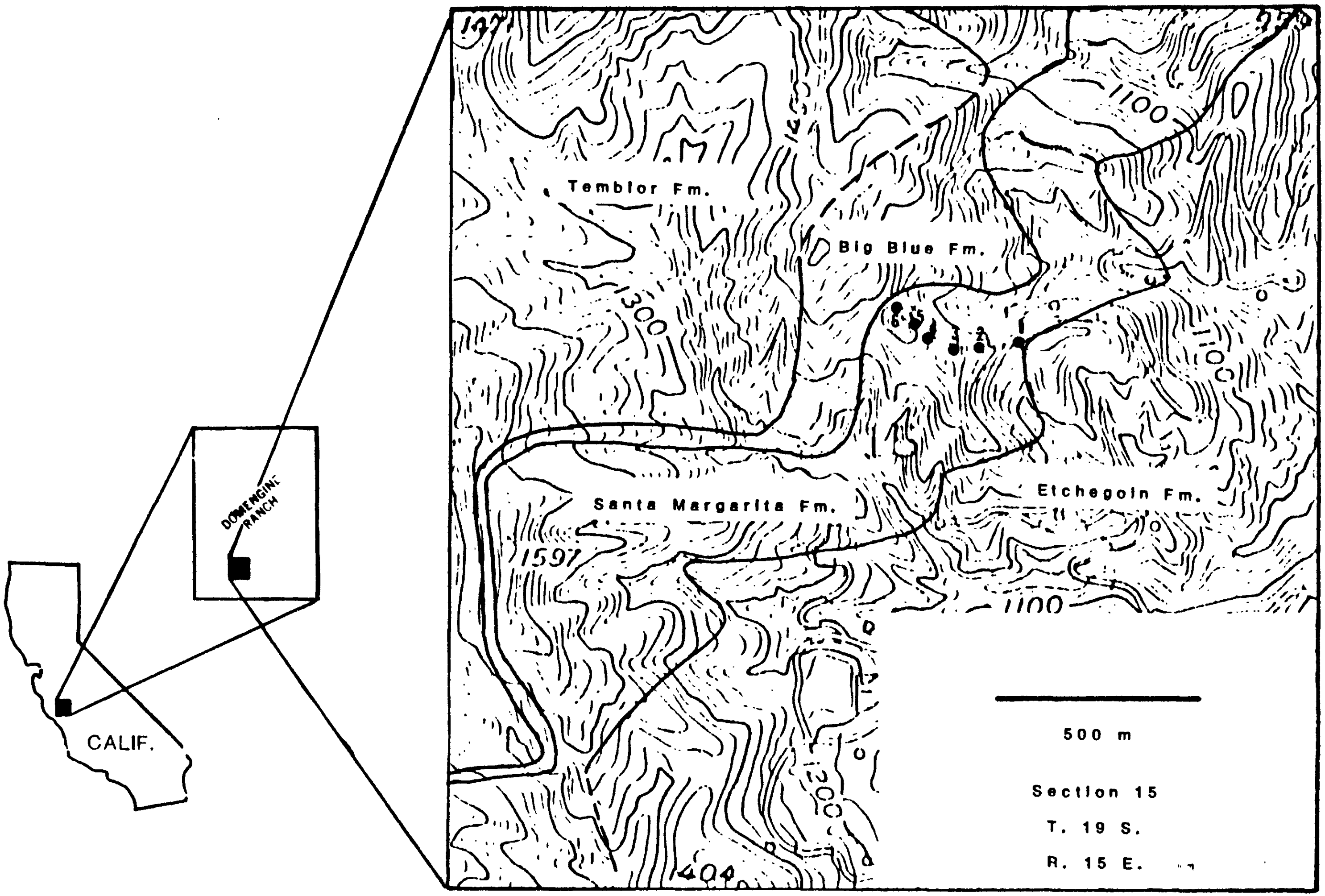


Figure 17. Map showing the locations of sampled Santa Margarita sandstone along Anticline Ridge, with geologic mapping after Adegoke (1969).

heavy mineral suite of the six Santa Margarita sandstone samples average 47 percent green hornblende, 23 percent brown hornblende, 2 percent zircon, 14 percent sphene, 5 percent epidote, and 7 percent garnet. These averages are similar to those of the 9 sandstone samples from the Sulphur Creek section. Therefore, the most likely source of plutonic detritus characterized by hornblendes, zircon, sphene, epidote, and garnet is the Santa Margarita Formation of the southern Diablo Range.

Sandstone in the Santa Margarita Formation, which could have contributed detritus to the Etchegoin Formation, is today found only along the east flank of the southern Diablo Range. However, the restricted distribution of Santa Margarita sandstone does not detract from assigning this source to the plutonic detritus found primarily in the Sulphur Creek section. The Vallecitos Straits, the seaway outboard of the Coalinga region (fig. 15), covered much of the southern Diablo Range during the late Miocene (Addicott, 1970). It is reasonable to assume that during the late Miocene the extent of the Santa Margarita Formation in the Diablo Range was much greater than that found today. A predominantly westward drainage of the newly emergent southern Diablo Range would account for a preponderance of Santa Margarita detritus in the Sulphur Creek region. Thus, the plutonic-rich detritus found primarily in the Sulphur Creek section is attributed to reworking of arkosic sandstone of the Santa Margarita Formation.

The composition of framework grains suggests that a moderate amount of plutonic detritus is present in both the Reef Ridge and Anticline Ridge sections that is not accounted for by the two previously determined source terranes (fig. 16). In the lower and middle parts of the Anticline Ridge section, and throughout much of the Reef Ridge section, the framework composition suggests that plutonic detritus is fairly abundant; however, factor ananlysis failed to yield a heavy mineral association suggestive of a plutonic source. The discrepancy makes it possible that (1) a third plutonic source terrane was present that lacks diagnostic heavy minerals, (2) the framework grains suggestive of plutonic detritus were not derived from a plutonic source, or (3) the diagnostic heavy minerals were not accounted for by factor analysis. Quartz and feldspar are found in abundance in these sandstone samples as are green and brown hornblendes (Appendix II and III). Because green hornblende is characteristic of plutonic rocks, the third possibility listed above is most likely. For example, sandstone samples in the Reef Ridge section that do not have high positive loadings on factor 1 contain an average of 26 percent green hornblende, 25 percent brown hornblende, 2.4 percent epidote, and 2.1 percent zircon. The heavy mineral suite contained in these samples is common in many plutonic rocks, but inferences as to the source of this detritus are difficult.

The most likely source for this detritus in the Reef Ridge and Anticline Ridge section is the plutonic basement of the Sierra Nevada. The Sierra Nevada was chosen because plutonic rocks there commonly contain moderate amounts of hornblendes, epidote, and zircon (Bateman and others, 1962). Sierra Nevada plutonic detritus is expected to be contained within Etchegoin sandstone in the Coalinga region, because less than 50 km east of the Coalinga region Etchegoin strata grade laterally into strata of the the Kern River Formation (Bartow, in press b). Along the east side of the central San Joaquin Valley, the Kern River Formation is restricted to the subsurface, and its composition is poorly known. However, Bartow (oral comm., 1985) suggested that these rocks are similar in composition and mode of origin to Kern River rocks in the southeastern part of the valley that are composed nearly exclusively of plutonic detritus from the Sierra Nevada (Bartow and Pittman, 1984). Because Sierran plutonic detritus is thought to be contained in correlative, nonmarine rocks of the Kern River Formation east of Coalinga, such detritus is expected to be found in Etchegoin sandstone. The plutonic detritus in Etchegoin sandstone samples in the Anticline Ridge and Reef Ridge sections that do not have high positive loadings on factor 1, but whose framework composition suggests abundant plutonic detritus, may have been derived from the plutonic basement of the Sierra Nevada.

Volcanic Source Terranes

Volcanic detritus is abundant in sandstone in the Etchegoin Formation, and VRF account for more than one third of the total framework grains. Three types of volcanic detritus are found in Etchegoin sandstone, two of which, augite and brown hornblende and hypersthene and brown hornblende, account for approximately 40 percent of the variance in the heavy mineral data set. The severely altered volcanic detritus, which is not associated with any heavy mineral association, is abundant in sandstone in the Sulphur Creek region. No variance in the heavy mineral data was accounted for by the severely altered volcanic detritus, because no distinctive heavy minerals are associated with this detritus.

The volcanic detritus in sandstone in the Coalinga region (fig. 18) is thought to have been derived primarily from the Mehrten Formation (Lerbekmo, 1961). The Mehrten Formation crops out today along the foothills of the central Sierra Nevada (fig. 19), and it is found extensively in the subsurface of the northern San Joaquin Valley (American Association of Petroleum Geologists, 1958; Lerbekmo, 1961; Bartow, 1985). The Mehrten Formation is composed of volcaniclastic deposits and lahars derived from coeval volcanoes at the crest of the Sierra Nevada (Curtis, 1954; Wagner, 1981). To test the possibility that both the augite- and hypersthene-rich volcanic detritus in Etchegoin strata was derived from the Mehrten Formation, eight Mehrten sandstone beds were sampled (fig. 20), and they were assayed for their heavy minerals (Appendix V). In addition, the Quien Sabe Volcanics were sampled (fig. 21, Appendix V), because some volcanic detritus may have originated from this source. The heavy minerals in Mehrten sandstone average 7 percent green hornblende, 33 percent brown hornblende, 5 percent sphene, 19 percent hypersthene, and 36 percent augite (Table 10). As seen in Table 10, the heavy mineral content of Mehrten sandstone is similar to that found in Etchegoin sandstone characterized by the heavy mineral associations of augite- and hypersthene-rich volcanic detritus, except that Mehrten sandstone has a relatively high abundance of green hornblende and sphene. The relatively high average of sphene is a result of one sample containing 34 percent sphene. The average of green hornblende is larger than expected for volcaniclastic

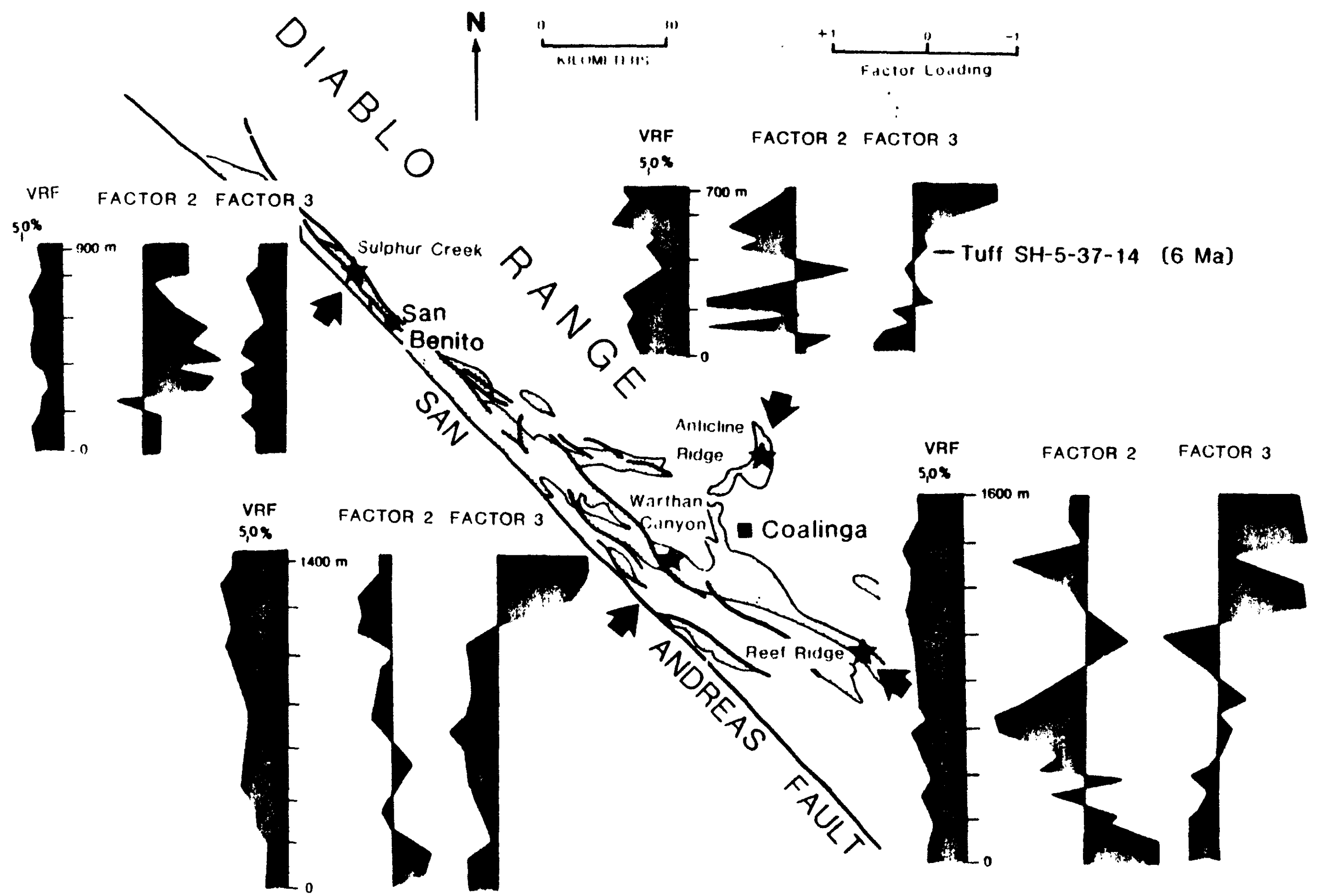


Figure 18. The distribution of volcanic detritus in sandstone in the Etchegoin Formation as reflected by the relative abundance of VRF and by the heavy mineral associations of augite and brown hornblende (factor 2) and hyperthene and brown hornblende (factor 3).

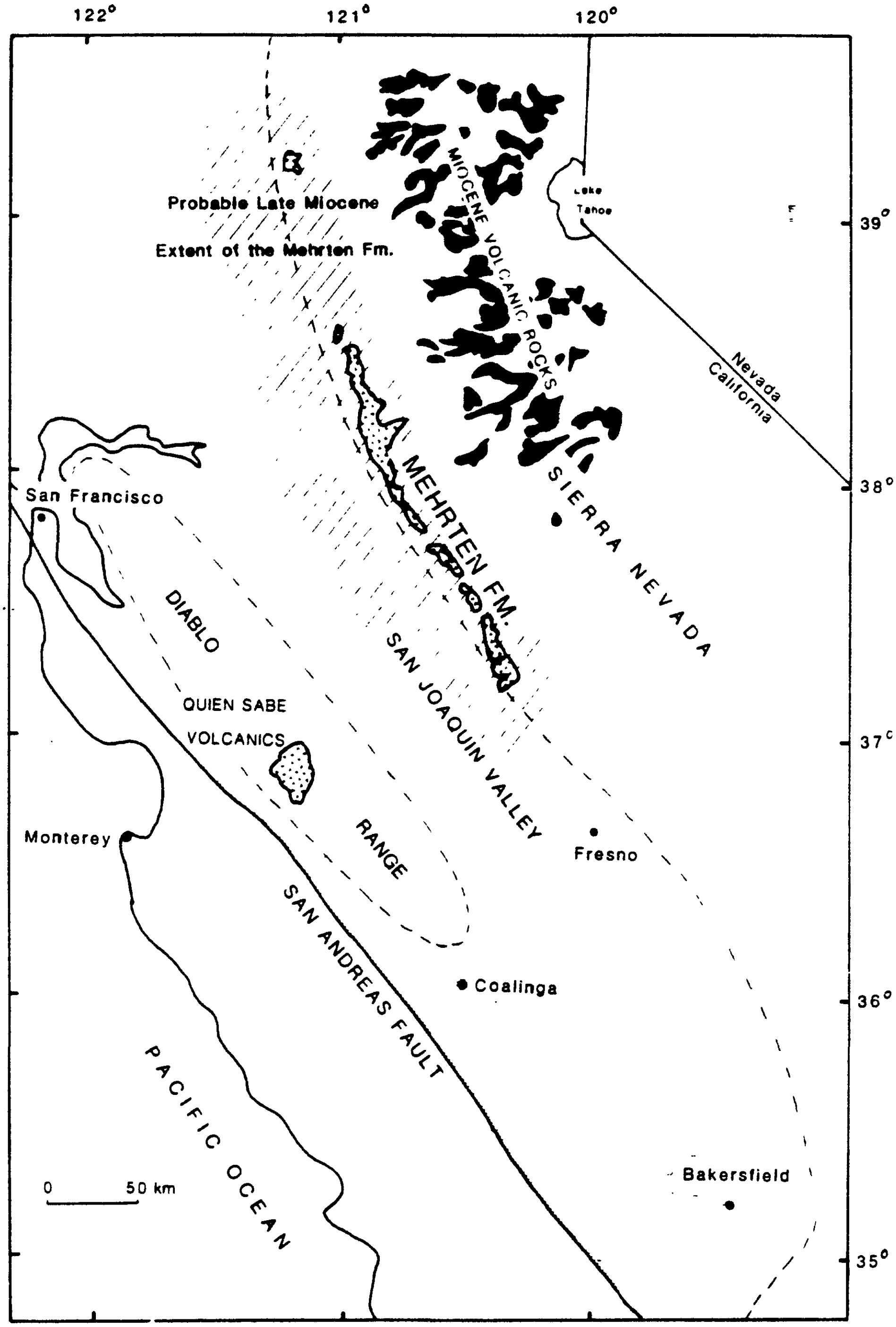


Figure 19. Possible sources for the volcanic detritus found in Etchegoin sandstone. The Mehrten Formation today crops out in the foothills of the western Sierra Nevada (shaded), and it is found extensively in the subsurface of the northern San Joaquin Valley. The minimum late Miocene extent of the Mehrten Formation is estimated to be the region encompassed by hachures. The stippled region represents the original extent of Etchegoin deposition.

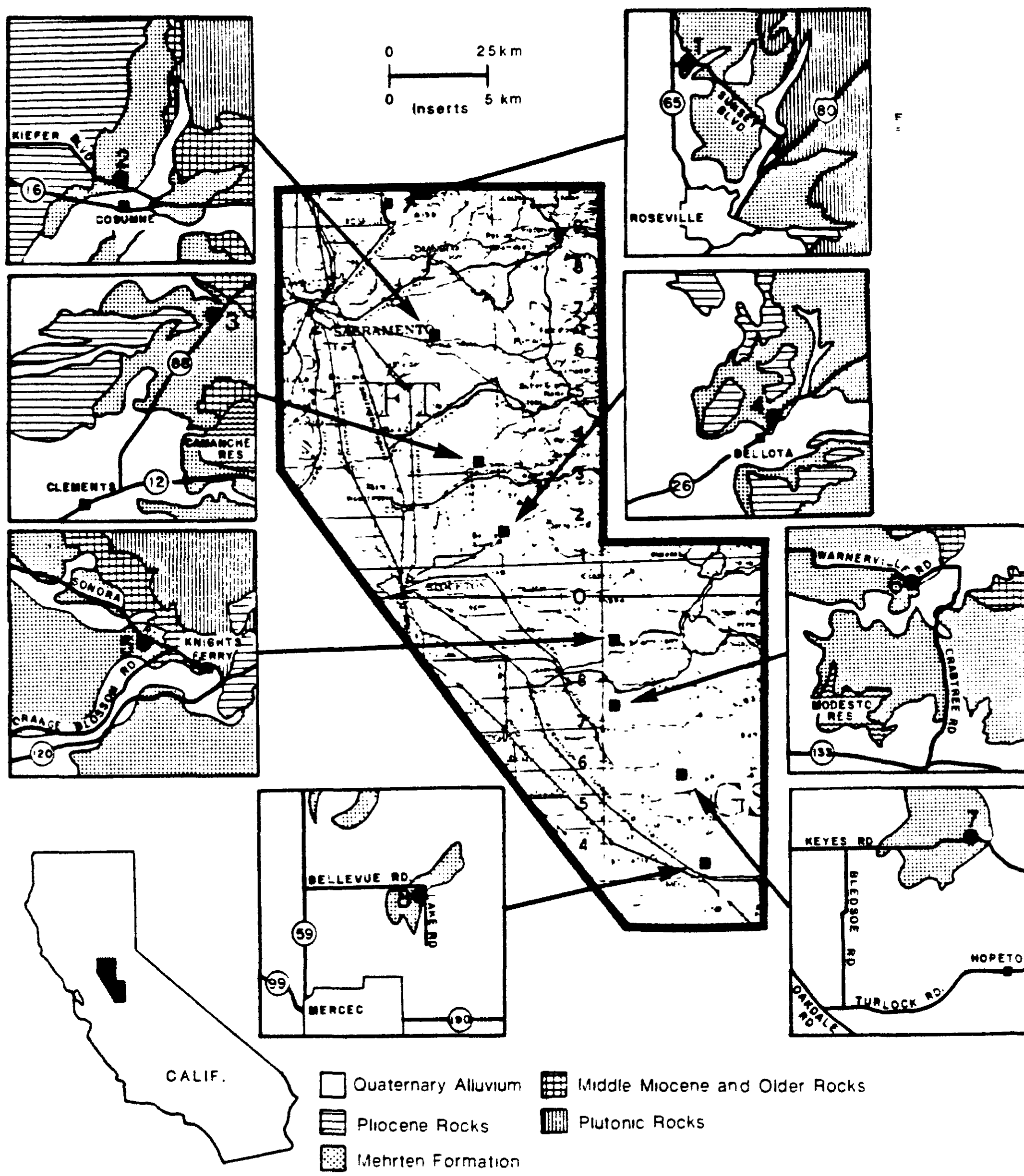


Figure 20. Map showing the locations of sampled Mehrten Formation sandstones, with geologic maps after Wagner and others (1981).

TABLE 10. COMPARISON OF HEAVY MINERALS IN THE ETCHEGOIN FORMATION, MEHRTEN FORMATION, AND QUIEN SABE VOLCANICS

	Percent									
	Green Hornblende	Brown Hornblende	Sphene	Hypersthene	Epidote	Actinolite-Tremolite	Zircon	Garnet	Glaucophane	Augite
Etchegoin Sandstones > 0.7 on Factor 2 (7 samples)	16	36	0	8	1	1	1	0	0	37
Etchegoin Sandstones < -0.7 on Factor 3 (9 samples)	11	21	0	39	1	0	1	0	0	27
Average - Mehrten Fm	7	33	5	19	0	0	0	0	0	36
Average-Quien Sabe Volcanics	1	11	1	35	0	0	0	0	0	52

strata, and it was found in appreciable amounts in two sandstone samples. Both sphene and green hornblende probably were derived from locally exposed plutonic basement areas of the Sierra Nevada, and they suggest that significant areas of basement plutonic rock were exposed during deposition of the Mehrten Formation.

The hypersthene-rich volcanic detritus characteristically is found stratigraphically above the augite-rich volcanic detritus in the Etchegoin Formation (fig. 18), and this fact should be reflected in the source of the volcanic detritus. The lack of knowledge of regional stratigraphy and quantitative mineralogy of the Mehrten Formation precludes the possibility of detailing augite-rich versus hypersthene-rich strata within the Mehrten. However, because Mehrten strata were derived from coeval volcanoes at the crest of the Sierra Nevada, major mineralogical variations in the Mehrten should be similar to those found in correlative volcanic rocks at the crest of the Sierra Nevada. The upper part of the Mehrten Formation is correlative with the Stanislaus Formation at the crest of the Sierra Nevada (Slemmons, 1966), and the Stanislaus is composed of augite-rich andesites extruded between 10 Ma and 8 Ma (Dalrymple, 1964, old constants). Also correlative with the upper part of the Mehrten Formation are andesites and hypersthene basalts that crop out northwest of Lake Tahoe (Hudson, 1951). The hypersthene basalts reach a thickness of over 300 m and overlie andesitic agglomerates that attain a thickness of about 600 m (Hudson, 1951; Dalrymple, 1964). An age of about 7 Ma is assigned to the lower part of the hypersthene basalt (Dalrymple, 1964, old constants). These data suggest that augite-rich volcanoes were succeeded by hyperthene-rich volcanoes, and that the change from augite-rich to hypersthene-rich extrusions occurred around 7 Ma. Because Mehrten strata were derived from these volcanic rocks, a similar succession should occur in the Mehrten Formation.

The mineralogic change from augite-rich to hypersthene-rich volcanic activity, at the crest of the Sierra Nevada about 7 Ma, is concordant with the change from augite-rich to hypersthene-rich detritus found in Etchegoin strata. The change in mineralogy of volcanic detritus occurred at about 5 Ma in the Anticline Ridge section (fig. 18). A time lag of about 2 m.y. is reasonable between extrusion of hypersthene basalt in the Sierra and deposition of hypersthene-rich detritus in the San Joaquin basin, over 400 km to the southwest. The temporal relationship between origin and deposition of augite-rich and hypersthene-rich volcanic detritus further argues for a Sierra Nevada source for volcanic detritus in Etchegoin strata.

The assignment of the Mehrten Formation as the primary source of the volcanic detritus in Etchegoin sandstone does not preclude the possibility of a substantial contribution by the late Miocene andesitic rocks of the Quien Sabe Volcanics. Rocks of the Quien Sabe Volcanics crop out today for about 250 km^2 in the central Diablo Range (fig. 19), and detritus originating from this source may be present in Etchegoin sandstone. Sand samples that were recovered from streams draining the Quien Sabe Volcanics have a heavy mineral assemblage characterized by brown hornblende, augite, and hypersthene, which is similar to that found in the Mehrten Formation samples (Table 10, fig. 21, Appendix V). Because the heavy mineral content of the Mehrten Formation and Quien Sabe Volcanics is similar, heavy minerals cannot be used to discriminate between volcanic detritus from these two sources. However, the Quien Sabe Volcanics are about 100 km from the Coalinga region, and if this source contributed significant amounts of sand-sized detritus it should have also contributed significant amounts of coarse-grained detritus. Little, if any, Quien Sabe Volcanics detritus is found in Etchegoin conglomerate (Table 2); therefore, it is unlikely that the Quien Sabe Volcanics contributed significant sand-sized detritus to the Etchegoin Formation.

Volcanic detritus in Etchegoin sandstone in the Sulphur Creek region is characterized by a paucity of augite and hypersthene, indicating that neither the Mehrten Formation nor the Quien Sabe Volcanics contributed the volcanic detritus found in these strata. Opaques are common in VRF in these sandstone samples, and they probably are the alteration products of volcanic accessory minerals. The degree of alteration in the VRF is much greater than that found in other framework grain types in Sulphur Creek sandstone, which suggests that this volcanic detritus was reworked. The most likely source of reworked volcanic detritus is the Franciscan of the Diablo Range, because it contains abundant altered or metamorphosed mafic volcanic detritus that occurs as framework grains in sandstone, as clasts in conglomerate, and as mafic volcanic intrusions (Leith, 1949; Dibblee, 1981; Page, 1981).

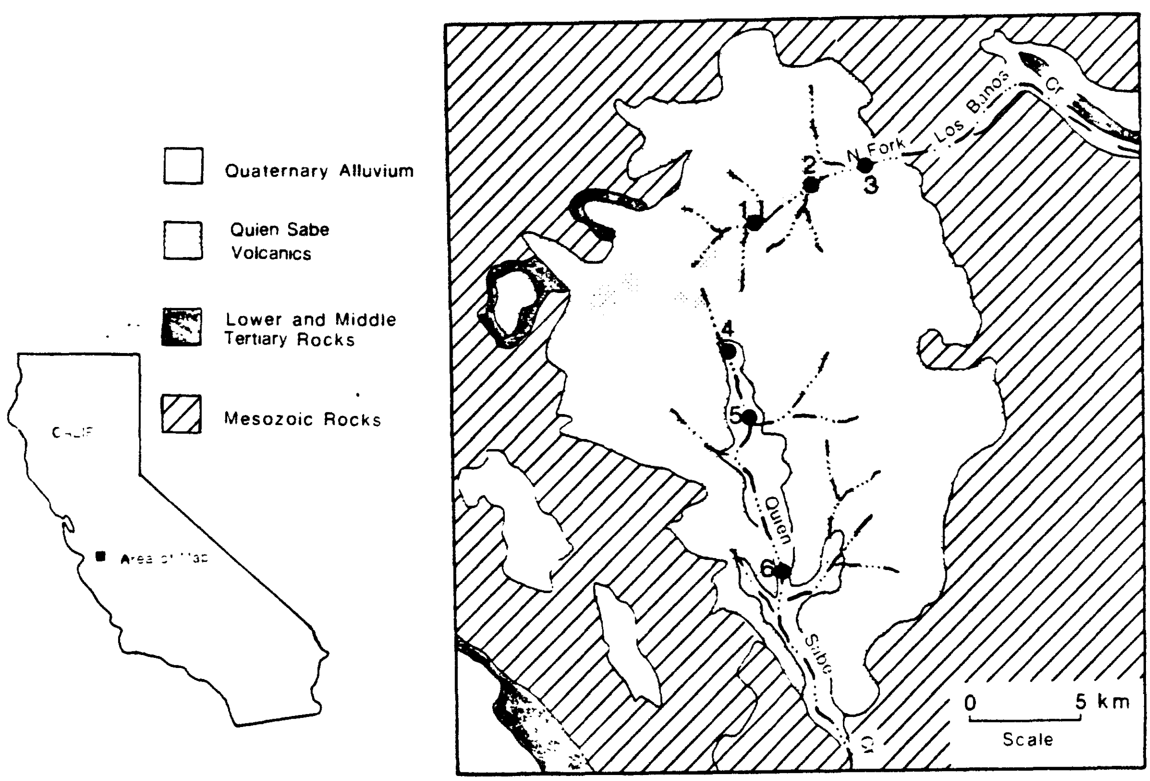


Figure 21. Map showing the locations of sand samples from streams draining the Quien Sabe Volcanics, with geologic map after Dibblee (1971).

Metamorphic Source Terranes

A moderate amount of metamorphic detritus is found in sandstone of the Etchegoin Formation (fig. 22). MRF are most abundant in sandstone in the Sulphur Creek section, and they are present in moderate amounts throughout the three sections of the Coalinga region. Nearly all of the MRF detritus in the Sulphur Creek section, and most of the MRF detritus in the lower part of the Warthan Canyon section, is associated with the heavy mineral association of actinolite-tremolite and glaucophane. Actinolite-tremolite and glaucophane schist fragments are found as MRF in Etchegoin sandstone. A nearby source of actinolite, tremolite, and glaucophane schist are the blueschist facies rocks of the Franciscan in the Diablo Range (Wilson, 1943; Leith, 1949; Dibblee, 1979). The Franciscan is assigned as the source of metamorphic detritus, because of its close proximity and similar lithology, and because it contributed coarse-grained detritus and altered volcanic detritus to the Etchegoin Formation.

Sandstone in the upper part of the Warthan Canyon section, and in most of the Reef Ridge and Anticline Ridge sections, contains a moderate amount of MRF that is not associated with actinolite-tremolite or glaucophane. Inferences as to the source of this detritus are difficult, because the sandstone lacks diagnostic heavy minerals from which specific source terranes may be determined. The class MRF is composed dominantly of polycrystalline quartz; therefore, it is possible that some framework grains here grouped as MRF are not of metamorphic origin. A plutonic origin for such detritus is possible because protoclastic deformation and multiple intrusive events, both of which are common in plutonic terranes, may alter the original plutonic texture so as to mimic that which characterizes metamorphic rocks. Alternatively, because the Franciscan of the Diablo Range is highly variable, many Franciscan rocks lack actinolite, tremolite, and glaucophane. MRF in Etchegoin sandstone that is not associated with these heavy minerals could have been derived from such Franciscan rocks. Additional data are necessary to assess the origin of this detritus in the Etchegoin Formation.

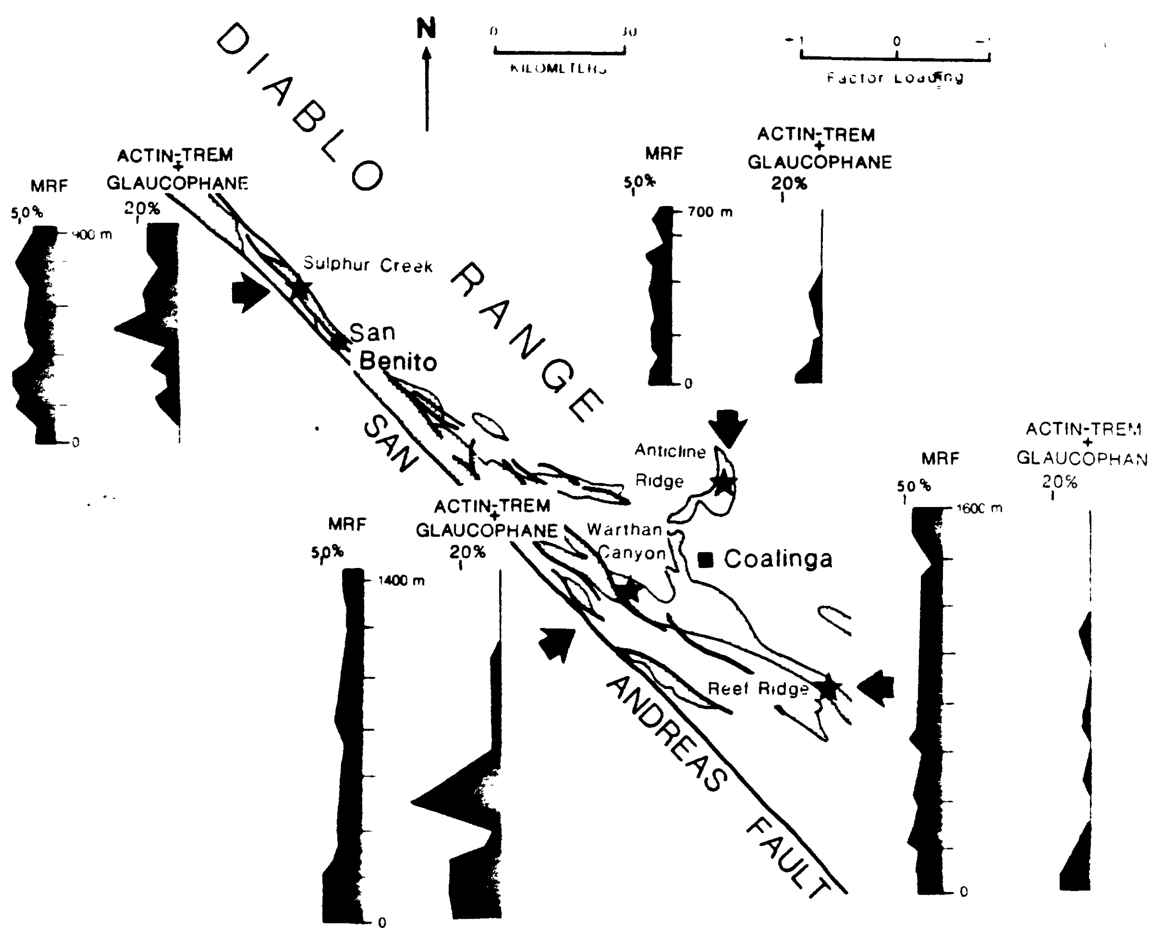


Figure 22. The distribution of metamorphic detritus in sandstone in the Etchegoin Formation as reflected by the relative abundances of MRF and actinolite-tremolite plus glaucophane.

PALEOGEOGRAPHY AND TECTONICS

Provenance of the Etchegoin Formation coupled with regional stratigraphic correlations allow fairly detailed reconstructions of the paleogeography of much of central California. Constraints imposed by the depositional environments of Etchegoin strata augment the reconstructions. Tectonism, most probably associated with the evolution of the San Andreas fault, is inferred to account for some of the marked changes in paleogeography.

"Pre-Etchegoin" Paleogeography

Volcanic detritus is lacking in the upper Miocene rocks of the San Joaquin Valley that are older than the Etchegoin Formation, indicating significant amounts of volcanic detritus did not enter the San Joaquin basin during that part of the late Miocene. The lack of volcanic detritus is most notable in the coarse clastics rocks, such as the arkosic Santa Margarita and Chanac Formations. Active volcanism was occurring in the central Sierra Nevada, and it produced a tremendous amount of andesitic detritus that was transported westward into the San Francisco Bay region (Louderback, 1924; Lerbekmo, 1961; Graham and others, 1984).

The "pre-Etchegoin" paleogeography of central California (fig. 23) was characterized by a deep-water San Joaquin basin (Bandy and Arnal, 1969) that was connected to the Pacific Ocean by at least three seaways (Phillips, 1984). Fine-grained sediment of the Monterey Formation and associated rocks was deposited in the central part of the basin, and shallow-marine and nonmarine, arkosic, clastic detritus of the Santa Margarita and Chanac Formations was deposited around its margin. The Gabilan Range was emergent and shed plutonic and volcanic detritus eastward into the southern part of the basin (Huffman, 1972). Arkosic detritus was shed eastward by the emergent Santa Cruz Mountains region (Phillips, 1984). The areal extent of the emergent Santa Cruz Mountains region is poorly known, but it may have extended to the southern border of the Vallecitos Straits. Emergent regions that were far to the west of the San Andreas fault probably had little effect on deposition in the San Joaquin basin. The plutonic-rich rocks along the eastern margin of the valley, which were deposited as alluvial fans built westward into the San Joaquin basin, reflect that the Sierra Nevada were emergent.

The central Diablo Range was emergent, as reflected in the composition of the upper Miocene Carbona and Oro Loma Formations that are found along the east flank of the range (Raymond, 1969; Bartow, 1985). Both of these formations have been interpreted as alluvial fan deposits that were built eastward from the Diablo Range (Bartow, in press a).

To the north of the emergent central Diablo Range, the Contra Costa basin (Creely and others, 1982) received the volcanic detritus that was transported westward from the Sierra Nevada (Lerbekmo, 1961; Graham and others, 1984). Deposition of the volcanic detritus occurred primarily in the shallow-marine eastern part of the basin (Neroly and Cierbo

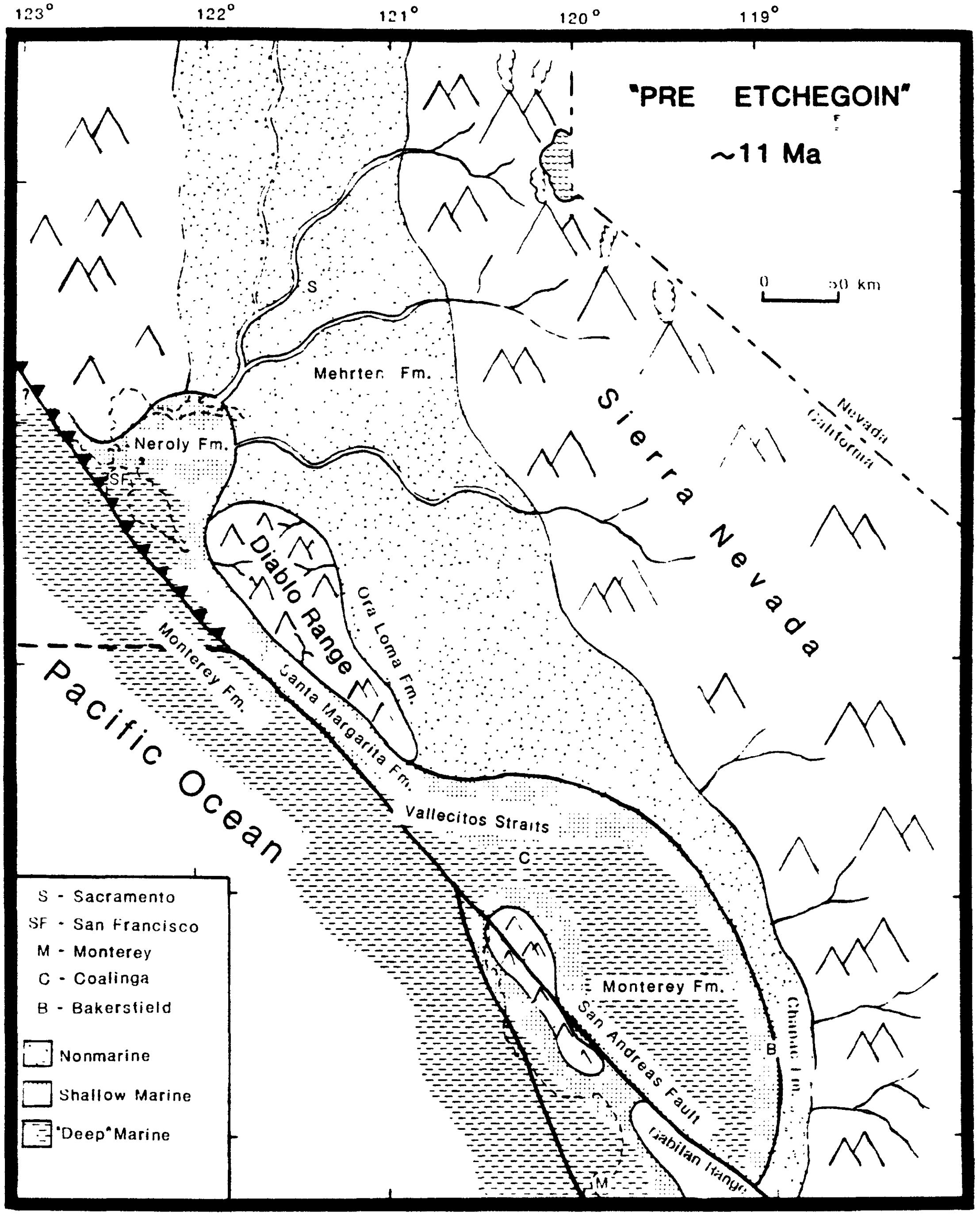


Figure 23. Paleogeographic reconstruction for central California at about 11 Ma. The "pre-Etchegoin" paleogeography is modified from Bartow (in press a), Greene and Clark (1979), and Graham and others (1984). Approximately 250 km of right-lateral movement has been restored along the San Andreas fault.

formations), whereas further outboard, fine-grained hemipelagic sediment of the Monterey Formation was deposited (Graham and others, 1984).

"Early Etchegoin" Paleogeography

With onset of deposition of the Etchegoin strata between 10 and 9 Ma the entire San Joaquin basin had shallowed and marked changes had occurred in the paleogeography surrounding the basin. A shallowing throughout much of the basin is reflected by the change from predominantly fine-grained, organic-rich sediment deposited in bathyal water depths (Bandy and Arnal, 1969) to the predominantly coarse-grained shallow-marine and nonmarine sediment of the Etchegoin Formation. The shallowing of the basin may have started prior to the deposition of Etchegoin strata, because some Santa Margarita strata are thought to have been deposited as regressive sandstone (Foss, 1972). The shallowing of the basin may be related to a drop in sea level of about 100 m that occurred around 10 Ma (Vail and Hardenbol, 1979). It is possible that the drop in sea level shallowed the basin, initiated regression of Santa Margarita sandstone and created the unconformity at the base of the Etchegoin Formation found along the margins of the San Joaquin Valley. However, much better stratigraphic and age control are necessary to assess this possibility.

The influx of volcanic detritus into the San Joaquin basin probably was a result of tectonic activity in the northern Diablo Range (fig. 24). The drop in sea level that may be associated with the onset of deposition of the Etchegoin strata could not have been responsible for the influx of Sierran volcanic detritus to the San Joaquin basin. A drop in sea level would have entrenched the rivers that transported the volcanic detritus to the San Francisco Bay region, thereby inhibiting major shifts in transport direction. Graham and others (1984) suggested that coastal uplift occurred in the San Francisco Bay region during the late Miocene. Such uplift did not induce the shift in transport direction, because it would have effectively ponded the detritus entering the San Francisco Bay region and resulted in extensive volcanic-rich lacustrine and nonmarine deposits farther inboard. No such deposits have been reported in the vicinity of the northern Diablo Range (Wagner, 1978; Creely and others, 1982; Bartow, 1985). Uplift did not occur in the central part of the northern Diablo Range, because it remained at sea level after local uplift had started to the west (Liniecki and Andersen, 1984). To account for the shift in deposition of Sierran volcanic detritus from the San Francisco Bay region to the San Joaquin Valley, uplift in the eastern part of the northern Diablo Range is required.

Other major paleogeographic changes around the basin that accompanied onset of deposition of Etchegoin strata were the emergence of the southern part of the Diablo Range and submergence of the Gabilan Range and most the Santa Cruz Mountains region. The presence of Santa Margarita detritus in Etchegoin strata, and the dominantly nonmarine Etchegoin strata found north of Coalinga, indicate the southern Diablo Range became emergent. The central part of the Diablo Range remained emergent and contributed Franciscan detritus to the Etchegoin Formation. Both Santa Margarita Formation and Franciscan detritus are

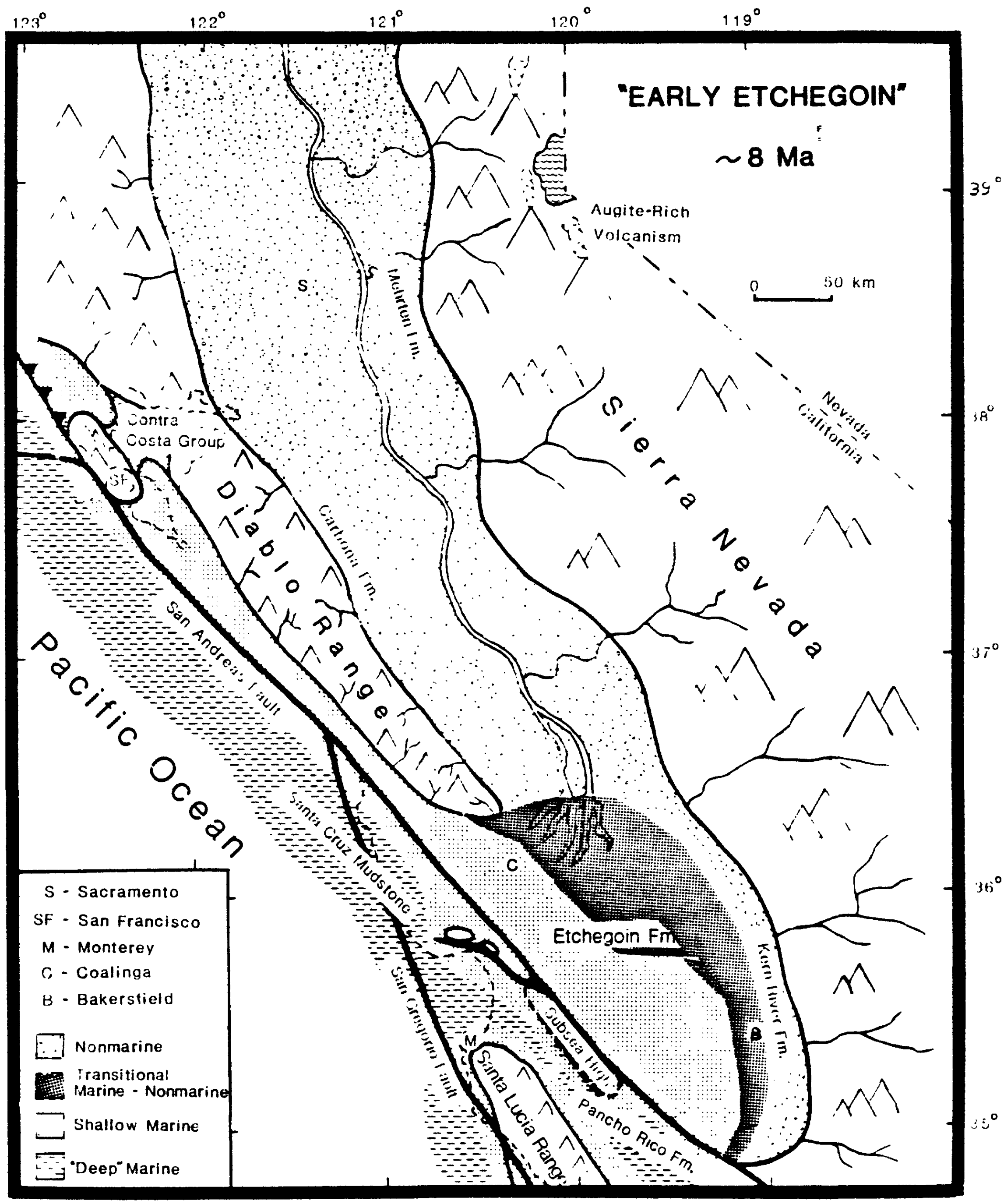


Figure 24. Paleogeographic reconstruction for central California at about 8 Ma. The "early Etchegoin" paleogeography is detailed by provenance of the Etchegoin Formation, depositional environments of lower Etchegoin strata, and stratigraphic correlations with coeval strata. Approximately 210 km of right-lateral movement has been restored along the San Andreas fault.

most abundant in Etchegoin strata in the San Benito region, which suggests that drainage of the newly emergent southern Diablo Range was primarily westward. Volcanic and plutonic detritus that is characteristic of the Gabilan Range is lacking in Etchegoin sandstone, suggesting that it had submerged prior to deposition of Etchegoin strata. However, the Gabilan Range probably remained a subsea high, which inhibited detritus from the emergent Santa Lucia Range from entering the San Joaquin basin. Only the small tectonic block northeast of the Vergales-Zayante fault remained emergent in the Santa Cruz Mountains region, and it contributed the hornblende-quartz-gabbroic detritus found in Etchegoin sandstone. If much of the Santa Cruz Mountains region had remained emergent, plutonic detritus from the Ben Lomond or Montara Mountain regions would be found in Etchegoin sandstone, but this is not the case. The southern and south-central Sierra Nevada contibuted large amounts of plutonic detritus to the nonmarine Kern River Formation (Bartow and Pittman, 1984) and to the Etchegoin Formation. Mather and others (1975) reported that Etchegoin strata in the southern San Joaquin Valley were in part derived from rocks along the southern margin of the San Joaquin basin.

The fact that the hornblende-quartz-gabbroic source terrane is found west of the San Andreas fault makes possible a calculation of a long-term slip rate for the fault. The lower parts of all three sampled stratigraphic sections in the Coalinga region contain detritus originating from this source, suggesting that it was adjacent to, and outboard of, the Coalinga region during the deposition of lower Etchegoin strata. The Reef Ridge section contains only one interval rich in this type of detritus, whereas the two northern sections contain two intervals, which suggests that initially this source was closest to the Reef Ridge section. Assuming that the plutonic terrane was positioned just northwest of the Reef Ridge section, approximately 210 km of movement along the San Andreas fault has occurred since deposition of the lowest interval of hornblende-rich plutonic detritus. The age for the lowest interval of this detritus in the Anticline Ridge section is about 7.5 Ma. The 7.5 Ma age was determined on the basis of projection of an 140 m/m.y. sedimentation rate from tuff SH-5-37-14, downsection to the lowest interval of hornblende-rich detritus. An age of about 7.5 Ma and a displacement of about 210 km yields an average rate of slip for the San Andreas fault of around 28 mm/yr during the past 7.5 Ma.

"Late Etchegoin" Paleogeography

The later stage of deposition of the Etchegoin strata was characterized by continued deposition of Sierra Nevada and Diablo Range detritus into a shallow and restricted San Joaquin basin (fig. 25). The relative amount of Sierran volcanic detritus deposited in the San Joaquin basin increased with time, and during the later stage of Etchegoin deposition it comprised over half of the total clastic sediment deposited in the Coalinga region. Whether the volume of volcanic detritus actually increased, or the volume of non-volcanic detritus decreased, is difficult to determine. In the southern part of

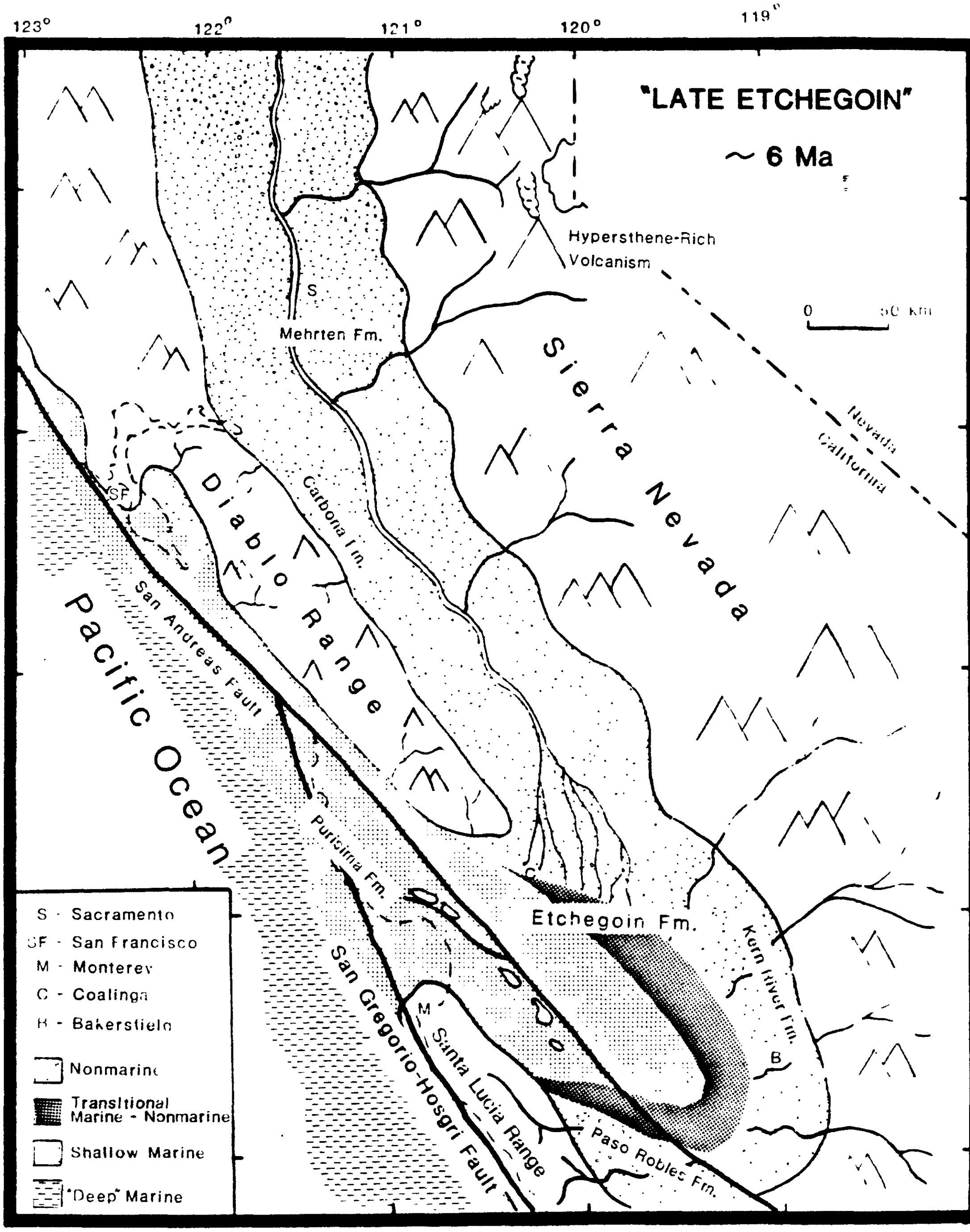


Figure 25. Paleogeographic reconstruction for central California at about 6 Ma. The "late Etchegoin" paleogeography is detailed by provenance of the Etchegoin Formation, depositional environments of upper Etchegoin strata, and stratigraphic correlations to coeval strata. Approximately 160 km of right-lateral movement has been restored along the San Andreas fault.

the basin, Sierran plutonic detritus continued to be transported into the basin, as did a significant amount of detritus from the southern Salinas Valley. Salinas Valley detritus is not reflected in the composition of sampled Etchegoin strata in the Coalinga region, but Galehouse (1967) reported that the rivers that deposited the Paso Robles Formation emptied into the southern San Joaquin basin.

A significant shallowing had occurred during deposition of the Etchegoin strata, which probably was a result of restricted connections to the Pacific Ocean. The basin restriction probably resulted from the closure of the southern seaway, which occurred at about 6 Ma (Addicott and Galehouse, 1973), and by a partial blockage of the northern seaway, which occurred as a result of positioning of the Gabilan Range subsea high outboard of the Coalinga region by movement along the San Andreas fault. Closure of the southwestern seaway probably was a result of uplift in, and outboard of, the Temblor Range. At about 6 Ma, the Gabilan Range subsea high might have been locally emergent, because by 4 Ma it was totally emergent and shed detritus westward into the Salinas Valley (Dohrenwend, 1979). Restricting connections to the Pacific Ocean affected deposition of Etchegoin strata by decreasing the areal extent of marine deposition and increasing the areal extent of nonmarine deposition.

SUMMARY AND CONCLUSIONS

The framework composition and heavy minerals contained in sandstone of the upper Miocene and Pliocene Etchegoin Formation suggest that many source terranes contributed detritus to Etchegoin sandstone. One type of plutonic detritus found in the Etchegoin Formation is characterized by quartz associated with green and brown hornblendes, and this detritus is thought to have been derived dominantly from now-covered, hornblende-quartz-gabbro rocks adjacent to the Vergales-Zayante fault. A second type of plutonic detritus is characterized by quartz associated with green and brown hornblendes, zircon, sphene, epidote, and garnet. The source of this detritus is attributed to the arkosic Santa Margarita Formation of the southern Diablo Range. A Santa Margarita Formation source is likely, because it contains a heavy mineral suite similar to that which characterizes Etchegoin sandstone rich in this type of plutonic detritus, and, on the basis of grain morphology, a reworked origin for this detritus is suspected. Also, Etchegoin conglomerate contains Crassostrea and felsic volcanic detritus that most likely were derived from nearby Santa Margarita strata. A third type of plutonic detritus that is reflected by quartz associated with green and brown hornblendes, epidote, and zircon, may be present in the sandstone. The source of this detritus is difficult to assess, but it may have been the plutonic basement of the Sierra Nevada. Sierran plutonic detritus is expected in Etchegoin strata because, east of Coalinga (inboard), Etchegoin strata grade laterally into Kern River strata, which are thought to have been deposited as alluvial fans built westward from the plutonic basement of the Sierra Nevada.

Three types of volcanic detritus are found in Etchegoin sandstone, and they are characterized by volcanic rock fragments associated with augite and brown hornblende, volcanic rock fragments associated with hypersthene and brown hornblende, and severely altered VRF not associated with a distinctive suite of accessory heavy minerals. The first two types of volcanic detritus are thought to have been derived from the Sierra Nevada, because aguite-rich and hypersthene-rich volcanic rocks are common in the Sierra Nevada and volcanic activity in the Sierra was augite-rich prior to about 7 Ma and hypersthene-rich after that time. A succession of augite-rich to hypersthene-rich detritus is found in Etchegoin sandstone and the influx of hypersthene-rich detritus occurred at about 4 Ma in the Coalinga region. The volcanic detritus that is characterized by severely altered VRF and no distinctive accessory heavy minerals probably was derived from altered or metamorphosed Franciscan sandstone, conglomerate, and mafic intrusive rocks in the Diablo Range. The Franciscan was chosen as the source because it is the most proximal source of severely altered volcanic detritus and it contributed a preponderance of coarse-grained detritus to Etchegoin conglomerate. Volcanic detritus from the Quien Sabe Volcanics evidently is not abundant in Etchegoin sandstone or conglomerate.

Metamorphic detritus found in Etchegoin sandstone is characterized primarily by metamorphic rock fragments associated with actinolite-tremolite and glaucophane. A blueschist-facies Franciscan source is inferred for the metamorphic detritus.

Understanding the provenance of the Etchegoin Formation makes it possible to develop paleogeographic reconstructions of central California for part of the late Miocene and early Pliocene. The late Miocene of central California was characterized by two marine embayments: one in the San Francisco Bay region and the other in the central and southern parts of the San Joaquin Valley. Emergent regions were the Gabilan Range, Santa Cruz Mountains, central Diablo Range, and the Sierra Nevada. Paleogeographic changes that accompanied the onset of deposition of the Etchegoin Formation are uplift of the northeastern and southern parts of the Diablo Range and submergence of the Gabilan Range and all of the Santa Cruz Mountains region, except for the small tectonic block northeast of the Vergales-Zayante fault. Uplift in the northeastern part of the Diablo Range is inferred to account for the change in locus of deposition of Sierran volcanic detritus from the San Francisco Bay region to the San Joaquin basin. Emergence of the southern Diablo Range is reflected in Etchegoin strata by the presence of Santa Margarita detritus. The Gabilan Range was submergent, because detritus that characterizes these rocks is lacking in Etchegoin sandstone. However, the Gabilan Range probably remained a subsea high that prevented detritus that originated in the emergent Santa Lucia Range from entering the San Joaquin basin. The lack of detritus that is characteristic of the Santa Cruz Mountains region south of the Vergales-Zayante fault or west of the La Honda-Ben Lomond fault suggests that much of the Santa Cruz Mountains region was submerged.

The later stage of deposition of Etchegoin strata is marked by continued deposition of Sierran volcanic and Diablo Range detritus in a restricted San Joaquin basin. Uplift in, and outboard of, the Temblor Range probably closed the southern seaway and allowed Salinas Valley detritus to enter the southern San Joaquin Valley. The northern seaway was restricted by movement along the San Andreas fault that positioned the Gabilan Range subsea high outboard of the Coalinga region. A marked shallowing of the San Joaquin basin occurred in response to the decreased connection to the Pacific Ocean.

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APPENDIX I: DATA PERTAINING TO TUFFS

Summarized below are data pertaining to chemical analyses of tuffs found in Etchegoin and related strata along Anticline Ridge. Chemical analyses were provided by Sarna-Wojcicki of the U.S. Geological Survey in Menlo Park. The sample preparation and analytical techniques used in tephrachronologic studies here are given in Sarna-Wojcicki and others (1979). Some tuffs were recovered by Steve Werner of California State University, Fresno. The locations of tuffs are shown in figure 26.

SUMMARY OF CHEMICAL DATA RELATED TO TEPHRA

Tuff SW-C -- Etchegoin Formation

Raw Probe Data - Percent		Recalculated to 100%	
SiO_2	66.935	SiO_2	72.85
Al_2O_3	13.469	Al_2O_3	14.66
Fe_2O_3	1.819	Fe_2O_3	1.98
MgO	0.389	MgO	0.42
MnO	0.064	MnO	0.07
CaO	1.482	CaO	1.61
TiO_2	0.381	TiO_2	0.41
Na_2O	4.186	Na_2O	3.43
K_2O	3.152	K_2O	3.43
Total	91.878	Total	99.99

Raw Probe Data - Percent		Recalculated to 100%	

Tuff 15-27 -- Etchegoin Formation

SiO_2	72.590	SiO_2	77.06
Al_2O_3	12.321	Al_2O_3	13.08
Fe_2O_3	1.025	Fe_2O_3	1.09
MgO	0.182	MgO	0.19
MnO	0.038	MnO	0.04
CaO	0.949	CaO	1.01
TiO_2	0.154	TiO_2	0.16
Na_2O	3.741	Na_2O	3.97
K_2O	3.195	K_2O	3.39
Total	94.196	Total	99.99

Tuff SW-A -- Etchegoin Formation

SiO_2	73.012	SiO_2	76.98
Al_2O_3	12.450	Al_2O_3	13.13
Fe_2O_3	1.012	Fe_2O_3	1.07
MgO	0.179	MgO	0.19
MnO	0.055	MnO	0.19
CaO	0.976	CaO	1.03
TiO_2	0.154	TiO_2	0.16
Na_2O	3.574	Na_2O	3.77
K_2O	3.435	K_2O	3.62
Total	94.847	Total	100.01

Tuff SH-5-37-14 -- Etchegoin Formation

SiO_2	70.467	SiO_2	75.89
Al_2O_3	12.616	Al_2O_3	13.59
Fe_2O_3	1.402	Fe_2O_3	1.51
MgO	0.052	MgO	0.06
MnO	0.012	MnO	0.01
CaO	0.537	CaO	0.58
TiO_2	0.101	TiO_2	0.11
Na_2O	4.649	Na_2O	5.01
K_2O	3.017	K_2O	3.25
Total	92.852	Total	100.01

Raw Probe Data - Percent / Recalculated to 100 percent

Tuff SW-B -- San Joaquin Formation

	Raw Probe Data - Percent		Recalculated to 100 percent
SiO_2	69.705	SiO_2	75.50
Al_2O_3	12.460	Al_2O_3	13.50
Fe_2O_3	1.627	Fe_2O_3	1.76
MgO	0.020	MgO	0.02
MnO	0.024	MnO	0.03
CaO	0.605	CaO	0.66
TiO_2	0.118	TiO_2	0.13
Na_2O	4.355	Na_2O	4.72
K_2O	3.405	K_2O	3.69
Total	92.320	Total	100.01

Tuff SW-D -- Tulare Formation

	Raw Probe Data - Percent		Recalculated to 100 percent
SiO_2	72.093	SiO_2	77.65
Al_2O_3	11.827	Al_2O_3	12.74
Fe_2O_3	0.660	Fe_2O_3	0.71
MgO	0.095	MgO	0.10
MnO	0.047	MnO	0.05
CaO	0.636	CaO	0.69
TiO_2	0.104	TiO_2	0.11
Na_2O	3.411	Na_2O	3.37
K_2O	3.967	K_2O	4.27
Total	92.840	Total	99.99

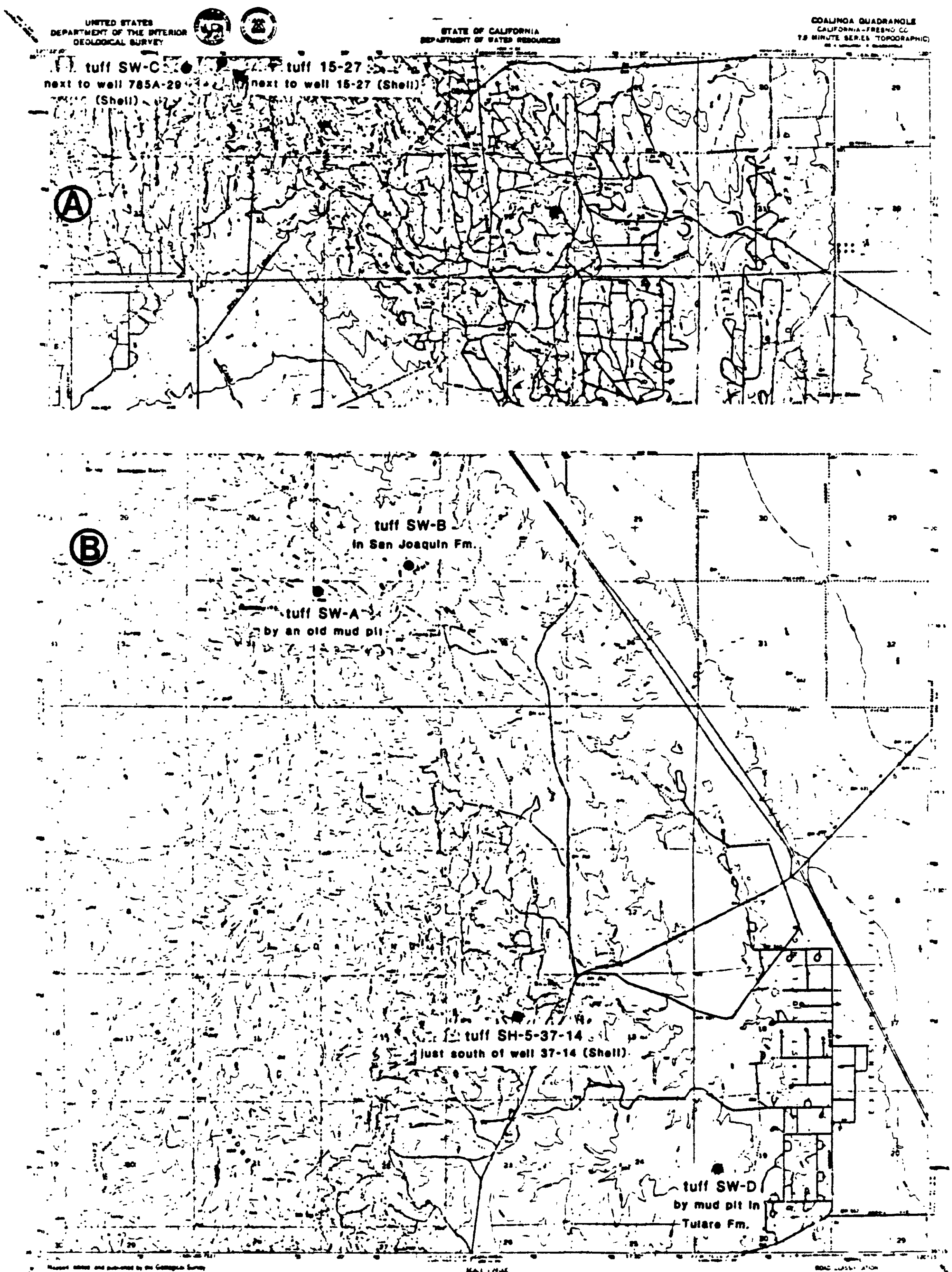

Figure 26. Maps showing the sample locations of tuffs found in Etchegoin strata (A) in the northern part of the Coalinga 7 1/2 minute quadrangle and (B) in the central and southern parts of the Domengine Ranch 7 1/2 minute quadrangle.

APPENDIX II: FRAMEWORK COMPOSITION DATA

Listed below are data resulting from the assay of 300 framework grains in thin sections of sandstone in the Etchegoin Formation. Samples are listed in stratigraphic order for each of the sampled stratigraphic sections; CAS - Coalinga Anticline, WCS - Warthan Canyon, SCS - Sulphur Creek, and RRS - Reef Ridge. The locations of the sampled sections are given in the text (fig. 10). The median grain size for some sampled sandstone is also given in phi units.

	Qz	Feldspar	Chert	VRF	PRF	MRF	Grain Size
CAS- 1	67	38	12	126	8	49	1.75
- 8	58	73	6	133	12	18	2.75
- 9	37	37	14	163	5	44	2.0
-12	53	84	9	114	3	37	1.75
-15	49	30	18	158	1	44	1.75
-19	44	29	3	171	17	36	1.75
-21	86	97	40	42	0	35	4.0
-25	89	53	9	102	7	40	1.75
-27	78	104	15	54	2	47	3.5
-29	30	63	4	180	9	14	2.25
-33	49	70	5	134	1	41	2.25
-35	57	37	5	167	5	29	1.75
WCS-22	86	55	7	53	3	96	2.75
-20	107	42	0	84	0	67	4.25
-18	87	79	13	67	9	45	2.75
-16	74	26	10	124	8	58	1.75
-14	110	33	5	102	4	46	3.25
-12	107	35	0	104	5	49	3.75
-10	58	39	5	119	11	68	2.25
- 8	40	29	6	159	16	50	1.0
- 6	54	75	8	122	6	35	1.75
- 4	50	54	0	160	0	36	2.25
- 2	32	43	2	173	11	39	2.5
- 0	55	32	10	144	7	52	1.5

	Qz	Feldspar	Chert	VRF	PRF	MRF	Grain Size
SCS-14	101	68	8	42	12	69	-
-13	91	84	10	31	19	65	-
-12	74	70	13	88	4	51	-
-11	87	83	14	67	6	43	-
-10	83	76	17	81	15	28	-
- 9	77	74	8	91	8	42	-
- 8	92	65	8	61	10	64	-
- 7	81	89	23	32	13	62	-
- 6	85	71	9	59	1	75	-
- 5	89	73	4	64	8	62	-
- 4	91	72	11	58	2	66	-
- 3	83	74	2	56	10	75	-
- 2	86	67	8	96	6	41	-
- 1	87	60	16	61	13	63	-
RRS- 1	77	33	20	104	0	66	-
- 2	90	32	15	93	10	60	-
- 3	60	46	16	86	17	75	-
- 4	62	51	11	112	1	63	-
- 5	90	57	12	87	3	51	-
- 6	80	45	7	102	0	66	-
- 7	64	54	2	111	11	58	-
- 8	56	29	8	147	8	52	-
- 9	75	35	8	96	12	74	-
-10	57	46	12	116	7	62	-
-12	51	46	3	138	5	57	-
-14	43	32	2	166	3	54	-
-16	54	27	2	155	9	53	-
-17	47	31	5	152	13	52	-
-18	61	46	6	160	0	27	-
-19	51	40	6	123	6	74	-

APPENDIX III: HEAVY MINERAL DATA

Summarized below are data resulting from the assay of 300 non-opaque heavy mineral grains in grain mounts of sandstone in the Etchegoin Formation. Frequency data are given in the number of grains encountered during assay. Sandstone samples are listed in stratigraphic order for each of the sampled stratigraphic sections; CAS - Coalinga Anticline, WCS - Warthan Canyon, SCS - Sulphur Creek, and RRS - Reef Ridge. The locations of the sampled stratigraphic sections are given in the text (fig. 10).

	Green Hornblende	Brown Hornblende	Sphene	Hypersthene	Epidote	Actinolite-Tremolite	Zircon	Garnet	Glaucophane	Augite
CAS - 1	76	104	37	11	11	10	16	10	25	0
- 8	132	81	7	12	19	11	26	0	5	7
- 9	63	144	2	6	3	6	3	1	0	72
-12	135	142	0	6	4	6	3	1	0	3
-15	26	149	0	16	2	0	3	0	0	104
-19	48	115	0	10	4	5	2	2	1	113
-21	175	75	0	16	6	7	5	0	5	11
-25	81	146	0	19	7	0	2	0	0	45
-27	112	105	1	15	7	0	5	0	1	54
-28	18	55	0	5	1	0	2	0	0	219
-33	31	48	2	104	2	0	6	0	1	106
-35	17	40	0	142	1	1	2	0	0	97
WCS -26	25	50	25	0	101	0	25	0	74	0
-24	155	110	3	8	2	6	5	3	5	3
-22	136	86	2	14	4	0	23	2	2	31
-20	56	44	11	0	11	0	44	0	134	0
-18	135	143	0	0	7	3	7	2	3	0
-16	141	128	5	5	3	5	6	1	1	5
-14	139	121	3	0	18	12	5	2	0	0
-12	129	121	4	4	9	4	11	0	7	11
-10	116	160	6	0	5	0	2	2	4	5
- 8	147	131	5	2	13	2	0	0	0	0
- 6	148	43	2	1	1	1	0	0	0	104

		Green Hornblende	Brown Hornblende	Sphene	Hypersthene	Epidote	Actinolite-Tremolite	Zircon	Garnet	Glaucophane	Augite
WCS	- 4	33	129	0	91	0	1	1	0	0	45
	- 2	49	82	1	88	1	1	2	0	0	76
	- 0	49	55	0	120	1	2	2	0	3	68
SCS	-14	0	0	87	0	49	0	140	24	0	0
	-13	0	0	120	0	80	0	84	16	0	0
	-12	131	104	15	0	8	19	13	6	4	0
	-11	115	113	4	0	2	25	19	7	6	9
	-10	98	120	14	3	8	2	14	2	14	25
	- 9	164	47	14	7	38	14	7	2	7	0
	- 8	161	39	18	4	12	9	13	7	30	7
	- 7	41	12	71	5	70	0	65	6	30	0
	- 6	175	34	15	3	38	3	9	6	13	4
	- 5	82	2	17	3	43	10	42	16	85	0
	- 4	159	21	0	15	25	11	10	1	31	27
	- 3	63	7	29	7	42	2	67	12	48	23
	- 2	113	98	5	0	13	27	12	11	0	21
	- 1	117	70	9	13	22	6	10	0	33	20
RRS	- 1	183	17	0	8	27	6	21	2	34	2
	- 2	149	81	0	1	2	21	28	2	6	10
	- 3	187	105	1	2	1	0	1	0	1	2
	- 4	107	160	0	2	3	0	2	0	2	24
	- 5	181	104	0	1	5	4	2	0	0	3
	- 6	92	180	0	2	0	4	5	0	1	16
	- 7	118	80	1	8	4	2	2	0	0	85
	- 8	51	112	1	8	1	1	1	0	0	125
	- 9	52	123	0	0	12	4	1	1	1	106
	-10	56	71	1	20	4	1	2	0	1	144
	-12	131	89	23	1	24	11	14	2	5	0
	-14	24	40	0	155	0	0	1	0	1	79
	-16	29	46	2	118	2	0	2	0	0	101
	-17	73	108	1	9	4	0	4	1	3	97
	-18	44	60	0	123	5	0	0	0	0	68
	-19	28	55	0	115	2	1	1	1	0	97

APPENDIX IV: FACTOR LOADINGS

Listed below are factor loadings that resulted from a Q-mode factor analysis of Etchegoin heavy mineral data.

	Factor 1	Factor 2	Factor 3	Factor 4
CAS - 1	-0.11580	-0.12016	0.42755	0.25042
- 8	0.23800	-0.43962	0.32494	0.47498
- 9	0.35179	0.90265	0.01707	0.24709
-12	0.90606	0.04475	0.23440	0.32663
-15	0.17635	0.93808	-0.22453	-0.14002
-19	-0.11923	0.92830	-0.11606	0.13284
-21	0.52052	-0.58461	0.13410	0.36724
-25	0.71908	0.63973	-0.14706	-0.20203
-27	0.69365	0.34020	-0.10599	-0.28455
-29	-0.43974	0.66190	-0.19233	-0.12190
-33	-0.35236	0.23883	-0.86639	-0.16138
-35	-0.33462	0.12463	-0.92696	-0.09290
WCS -26	-0.33864	-0.08931	0.26649	-0.63026
-24	0.77459	-0.34599	0.30234	0.41030
-22	0.69624	-0.30937	0.05354	-0.14968
-20	-0.37579	-0.36812	0.19553	-0.62518
-18	0.94609	0.03367	0.28695	0.09615
-16	0.91602	-0.08070	0.27192	0.26633
-14	0.51808	-0.17410	0.48103	0.53169
-12	0.92638	-0.00730	0.28943	0.10350
-10	0.90434	0.22898	0.23724	-0.10912
- 8	0.92505	-0.12269	0.30776	-0.09253
- 6	-0.06609	-0.01151	0.02096	-0.06033
- 4	0.25169	0.42458	-0.81614	-0.06895
- 2	-0.08833	0.31492	-0.93191	-0.10978
- 0	-0.20346	0.03341	-0.97645	-0.04559
SCS -14	-0.55775	-0.22479	0.31944	-0.33126
-13	-0.54498	-0.21290	0.33731	-0.51727
-12	0.09335	-0.21756	0.45429	0.79862
-11	0.00328	-0.04705	0.33620	0.90034
-10	0.77058	0.32696	0.36699	-0.19810
- 9	-0.12143	-0.65927	0.44278	0.25303
- 8	-0.12305	-0.77705	0.45787	0.33607
- 7	-0.51819	-0.28460	0.32326	-0.60977
- 6	-0.08065	-0.79529	0.47418	-0.26588
- 5	-0.60689	-0.47197	0.39550	0.05422
- 4	-0.22775	-0.66837	0.20553	0.31229

	Factor 1	Factor 2	Factor 3	Factor 4
SCS - 3	-0.66831	-0.37694	0.32236	-0.34388
- 2	-0.18550	-0.09728	0.38570	0.85346
- 1	0.08511	-0.51464	0.33592	0.08899
RRS - 1	-0.03301	-0.83335	0.28458	0.04711
- 2	0.08697	-0.24334	0.27978	0.85346
- 3	0.82826	-0.36972	0.19830	-0.01697
- 4	0.89506	0.41822	0.10603	-0.08501
- 5	0.78846	-0.38392	0.27938	0.17597
- 6	0.81999	0.32721	-0.05085	-0.04043
- 7	0.17472	0.32721	-0.05085	-0.04043
- 8	-0.03191	0.87269	-0.17827	-0.09872
- 9	-0.01138	0.95925	0.02900	-0.02735
-10	-0.32888	0.95925	-0.29048	-0.13578
-12	0.16000	-0.43630	0.62138	0.24847
-14	-0.25949	0.02943	-0.95720	-0.11088
-16	-0.32899	0.17756	-0.90253	-0.15254
-17	0.12263	0.80923	-0.13314	-0.21067
-18	-0.17413	0.05887	-0.96781	-0.16589
-19	-0.32293	0.21059	-0.90691	-0.10060

APPENDIX V: HEAVY MINERAL DATA FOR THE MEHRTEN FORMATION AND THE QUIEN SABE VOLCANICS

Summarized below are data resulting from the assay of 300 non-opaque, heavy mineral grains from grain mounts of sandstone from the Mehrten Formation, and from sand samples from streams draining the Quien Sabe Volcanics. See text for sample locations (figs. 20 and 21).

		Green Hornblende	Brown Hornblende	Sphene	Hypersthene	Epidote	Actinolite-Tremolite	Zircon	Garnet	Glaucophane	Augite
MEHRTEN FORMATION											
	MF-1	1	86	0	64	0	0	0	0	0	149
	-2	14	132	1	57	1	0	0	0	0	95
	-3	3	30	103	0	0	0	0	0	0	164
	-4	72	196	1	12	2	0	0	0	0	17
	-5	0	73	0	99	1	0	0	0	0	127
	-6	75	176	6	28	2	0	0	0	0	13
	-7	0	70	0	116	0	0	0	0	0	114
	-8	14	38	0	71	0	0	0	0	0	177
QUIEN SABE VOLCANICS											
	QS-1	0	26	0	96	0	0	0	0	0	178
	-2	2	40	0	149	0	0	2	0	0	147
	-3	10	39	0	100	0	0	0	0	0	151
	-4	1	22	0	78	0	0	1	0	0	198
	-5	2	27	3	136	0	0	0	0	0	133
	-6	12	47	1	116	0	0	0	0	0	124