Distribution and Juxtaposition of Mesozoic Lithotectonic Elements in the Basement of the Santa Maria Basin, California

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Chapter B

Distribution and Juxtaposition of Mesozoic Lithotectonic Elements in the Basement of the Santa Maria Basin, California

By HUGH McLEAN

U.S. GEOLOGICAL SURVEY BULLETIN 1995

EVOLUTION OF SEDIMENTARY BASINS—SANTA MARIA PROVINCE

U.S. DEPARTMENT OF THE INTERIOR
MANUEL LUJAN, JR., Secretary

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Distribution and Juxtaposition of Mesozoic Lithotectonic Elements in the Basement of the Santa Maria Basin, California

By HUGH McLEAN

Abstract

Approximately 150 wells in the Santa Maria basin have been drilled to basement. Core samples from more than 80 wells indicate that basement is composed mainly of mélange of the Mesozoic Franciscan assemblage, ophiolitic rocks, and smaller areas underlain by Great Valley sequence sedimentary rocks. Upper Cretaceous sandstone and mudstone underlie the western part of the Santa Maria Valley oil field and most of the Guadalupe oil field. The latter is on structural trend with outcrops of lithologically similar rocks of the Point San Luis slab, located approximately 25 km to the northwest.

Petrographic data from surface rocks exposed around the margin of the basin define three sandstone petrofacies: (1) a quartz- and feldspar-rich assemblage that contains abundant K-feldspar and ranges in age from Turonian(?) to Maestrichtian; (2) a lithic-rich assemblage that contains a low percentage of K-feldspar and locally ranges in age from Tithonian to Cenomanian; and (3) Franciscan sandstone (so-called graywacke) that lacks K-feldspar and overlaps the quartz-feldspar-lithic (QFL) detrital modes of the two Great Valley sequence petrofacies. Petrologic similarities between sandstone knockers in Franciscan mélange and Great Valley sequence sandstones suggest that the Franciscan rocks may represent variably metamorphosed Upper Jurassic to Upper Cretaceous Great Valley sequence rocks.

The distribution of basement petrofacies does not constrain the direction and amount of offset on the concealed Lompoc fault (the Santa Ynez Valley fault), but shows that the lower and upper part of the Great Valley sequence exists on both sides of the fault. The Pezzoni-Casmalia fault juxtaposes the Point Sal ophiolite and the conformably overlying lower Great Valley sequence petrofacies on its south side against an outlier of the upper petrofacies of the Great Valley sequence on the north side. The juxtaposition of different petrofacies suggests lateral offset along the fault, but provides no piercing points. Areally restricted subcrops of the lower Miocene Lospe Formation suggest that Neogene motion on the Pezzoni-Casmalia fault has been mainly dip slip with the north side down.

Manuscript approved for publication, May 3, 1991.

INTRODUCTION

The Santa Maria basin (SMB) is an onshore and offshore Cenozoic structural depression located along the central California coast (fig. 1). Several fields within the basin produce oil from the Miocene Monterey and Miocene and Pliocene Sisquoc Formations. Economic and acoustic basement in the SMB and adjacent areas consists of several late Mesozoic lithotectonic units. According to data published by the State of California Division of Oil and Gas, approximately 150 wells in the SMB bottomed in basement rocks variously described as the Franciscan assemblage, Knoxville Formation, Jurassic rocks, Cretaceous rocks, serpentine, and granite (wells used in this study are shown in fig. 2). Most of these names (except granite, which is unknown west of the Sur-Nacimiento fault) apply to either a heterogeneous assemblage of chaotically mixed rock bodies (mélange) of the Franciscan assemblage (also called the Franciscan Complex by some workers), or to the more structurally coherent submarine-fan complex called the Great Valley sequence by Bailey and others (1964), and the Great Valley Group by some workers (see Ingersoll, 1990); the Great Valley sequence overlies the Point Sal ophiolite described by Hopson (1977). Outliers of Great Valley sequence strata and a tectonic sliver of dismembered ophiolitic rocks locally overlie Franciscan mélange.

Using the Mesozoic sandstone petrofacies west of the Sur-Nacimiento fault zone described by previous workers such as Gilbert and Dickinson (1970), Gilbert (1973), and Dickinson and others (1982), this report expands the pioneering work of Gray (1980) and further delineates the distribution and composition of the Franciscan, Great Valley sequence, and ophiolitic units in the subsurface of the SMB. Tectonic implications suggested by the petrographic similarities of Great Valley sequence sandstones and sandstone knockers in the Franciscan mélange are also explored herein.

Acknowledgments

The pioneering work of Lynn Gray provided the foundation for this study. Terry Buddin, Reon Moag, and Vic Rosato of UNOCAL, Larry Knauer of the California Core Repository; and Larry Beyer of the U.S. Geological Survey provided access to core material. Caroline Isaacs and M. Clark Blake, Jr., also provided helpful and timely assistance. The early Miocene age for the Lospe Formation was kindly provided by R.G. Stanley. Early drafts of the manuscript were reviewed by T.C. MacKinnon and J.G. Vedder. Later versions profited from critical reviews by R.V. Ingersoll, J.A. Miller, M.E. Milling, T.H. Nilson, and an anonymous reviewer.

Previous Work

Gray (1980) petrographically examined 117 thin sections sampled from approximately 50 wells using

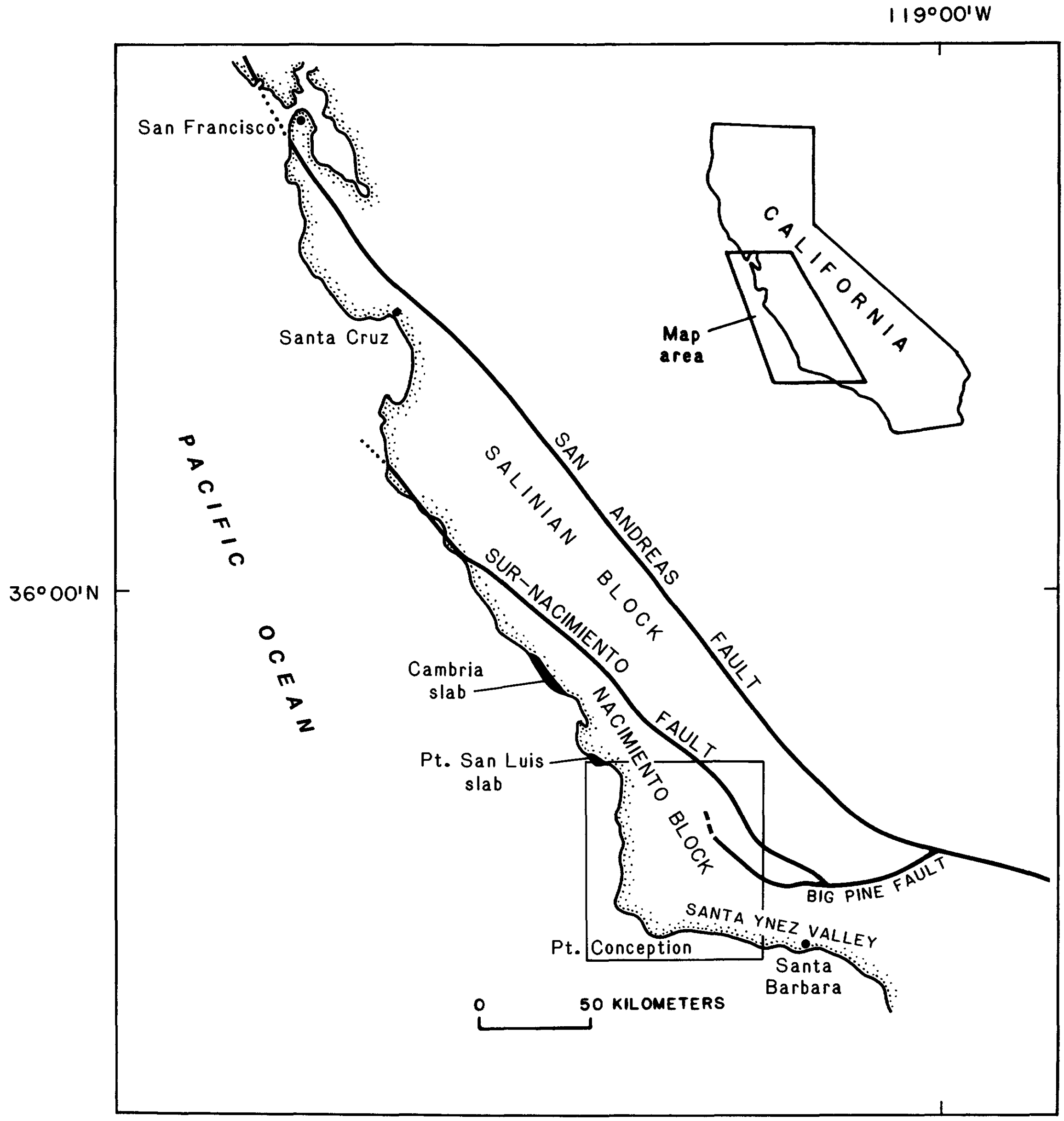

Figure 1. Index map of Salinian and Nacimiento blocks, Cambria and Point San Luis slabs, and Santa Maria basin (outlined) as shown in figures 2, 3, and 8. Faults dashed where approximate; dotted where concealed.

core collections of the UNOCAL Corporation. Also reported were Late Cretaceous fossils, and textures of ophiolitic basement rocks. Detrital modes of 19 Cretaceous Great Valley sequence sandstone samples were also reported. Hall (1982) subsequently published a map of the pre-Miocene subcrops using generalized lithologies reported by the California State Division of Oil and Gas. Lithologies listed in the DOG reports, however, do not generally recognize the subtle differences in composition between rocks of the upper and lower parts of the Great Valley sequence and sandstones in the Franciscan mélange.

Visual inspection of basement core from 42 wells in this study augments the work of Gray (1980). Microfiche records from 77 wells that were drilled to basement provide additional data.

Mesozoic sandstone petrofacies described in the Nacimiento block by Brown (1968), Gilbert and Dickinson (1970), MacKinnon (1978), Lee-Wong and Howell (1977), Smith (1978), Nelson (1979), Dickinson

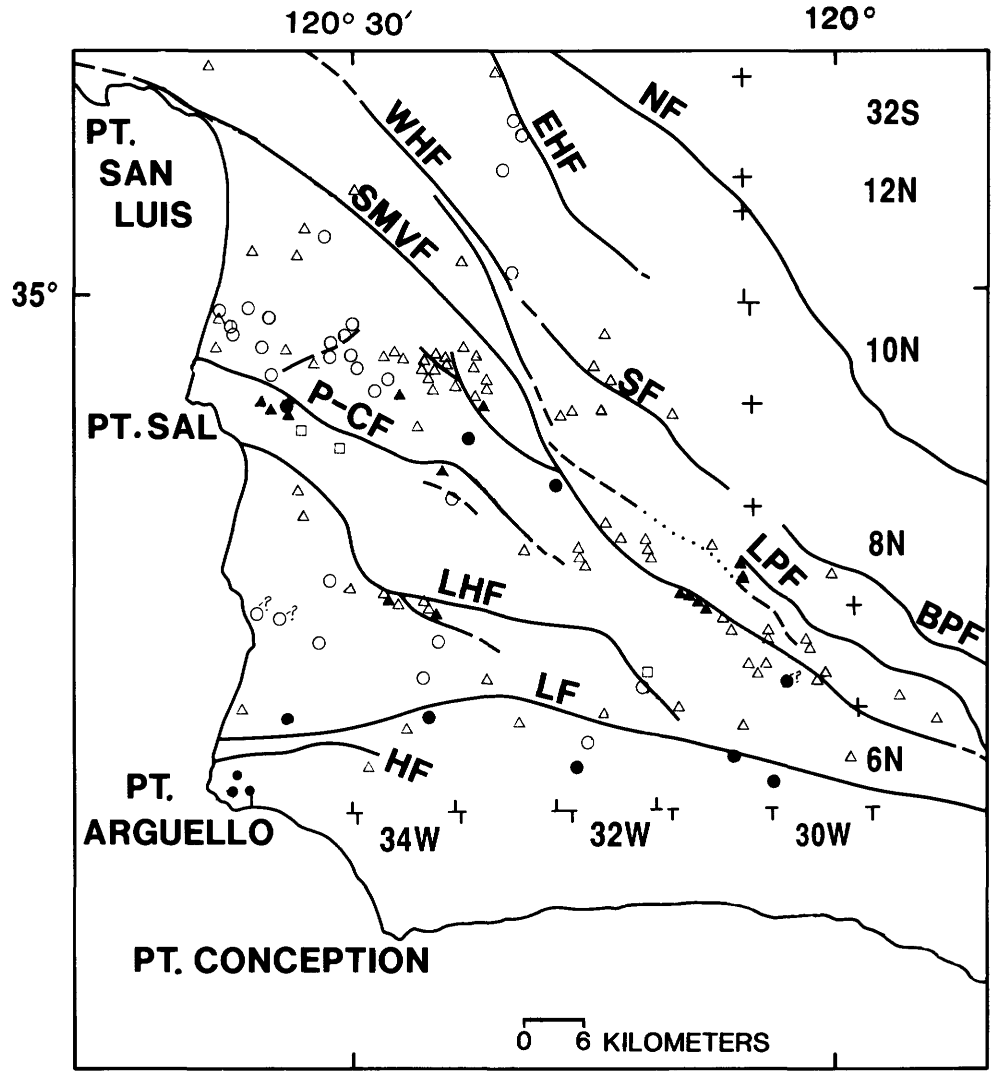

Figure 2. Locations of basement wells used in this study, and traces of major faults. Map symbols indicating rock unit at total depth of exploratory wells: open squares, lower Miocene Lospe Formation; open circles, upper Great Valley sequence petrofacies; solid circles, lower Great Valley sequence petrofacies; open triangles, Franciscan assemblage; solid triangles, ultramafic or ophiolitic(?) volcanic rocks, and (or) serpentine. Queries indicate uncertain lithologic affinity. Fault symbols: BPF, Big Pine Mountain fault; EHF, East Huasna fault; HF, Honda fault; LF, Lompoc fault (also called Santa Ynez River fault); LHF, Lions Head fault; LPF, Little Pine fault; NF, Sur-Nacimiento fault; P-CF, Pezzoni-Casmalia fault; SF, Suey fault; SMVF, Santa Maria Valley fault; WHF, West Huasna fault. Faults dashed where approximate; dotted where concealed. Fault names and locations from Gray (1980) and Hall (1981). Numbers indicate township and range.

and others (1982), Seiders (1983), and Toyne (1987) were used to identify the various Mesozoic lithotectonic units of this study. The published detrital modes consistently show that composition varies with age and that the concept of petrofacies as applied to the Great Valley sequence of the Sacramento and San Joaquin Valleys of California by Ojakangas (1968), Ingersoll (1978), and Dickinson and Rich (1972) also applies to the Great Valley sequence west of the Sur-Nacimiento fault.

Petrologic studies of sandstone knockers in the Franciscan mélange in the SMB area are less numerous; however, Brown (1968), Gilbert (1973), Ernst (1980), Dickinson and others (1982), and Seiders (1983) have reported on some of the Franciscan rocks. The most comprehensive geologic map of the SMB is by Woodring and Bramlette (1950); adjacent areas have been mapped by Dibblee (1950), Hall and Corbató (1967), Hall (1973, 1978, 1981), Hall and others (1979), and Vedder and others (1989).

Methods Of Study

The petrofacies established by the previous workers cited above indicate that detrital modes of quartz (Q), feldspar (F), and lithic fragments (L) provide a reliable means of differentiating Upper Jurassic to middle Upper Cretaceous Great Valley sequence rocks from uppermost Cretaceous (mainly Campanian and Maestrichtian) rocks in the Nacimiento block. To correctly identify Great Valley sequence and Franciscan sandstones in the subsurface of the SMB (fig. 3), QFL modes were determined for 45 Great Valley sequence and 17 Franciscan knocker outcrop samples from previously unstudied areas adjacent to the SMB (table 1). To insure consistency with previous studies, outcrop samples from the Point San Luis slab (fig. 1) of Lee-Wong and Howell (1977) and Gray (1980) were recounted.

The suite of outcrop sandstones was then compared with 39 subsurface sandstones selected from 24 wells. Detrital modes for this study were obtained using a slightly modified version of the point-counting techniques outlined by Dickinson (1970). Standard thin sections were stained for K-feldspar. Furthermore, because this study focused on comparing petrofacies rather than provenance, the Gazzi-Dickinson method described by Ingersoll and others (1984) was not used. However, medium-grained samples were counted where possible to reduce the effects of grain-size variation on composition. A minimum of 300 grains of quartz, feldspar, and rock fragments were counted in each specimen and plotted on ternary diagrams (figs. 4-8). Q includes monocrystalline and coarsely polycrystalline quartz (grains with up to four crystals). F includes plagioclase and potassium feldspar. L includes all rock fragments including chert and quartzite, which in most cases are minor components. Grains of mica, epidote, and opaque oxides were counted in addition to the minimum 300 QFL grains.

Other detrital modes such as QmPK—monocrystalline quartz (Qm), plagioclase feldspar (P), potassium feldspar (K)—and QmFLt—monocrystalline quartz (Qm), plagioclase feldspar (F), and total lithic fragments (Lt)—were not deemed relevant to the purposes of this study, because potassium feldspar was not detected in any of the Franciscan sandstones. QFL as used herein is essentially the same as QmFLt because chert and quartzite are included with lithic fragments (L).

Outcrop samples were collected during geologic mapping by the U.S. Geological Survey in the Los Padres National Forest and the Santa Lucia Wilderness. Subsurface core samples were obtained from the California Core Repository (Bakersfield); from UNOCAL Corp., Brea, California; and from L.A. Beyer of the U.S. Geological Survey, Menlo Park. The thin-section collection used by Gray (1980) was also examined, and several samples were restained for K-feldspar and recounted.

PETROGRAPHIC CHARACTERISTICS AND DETRITAL MODES OF OUTCROP SAMPLES

To simplify the terminology used herein, Upper Jurassic (Tithonian) to lower Upper Cretaceous (possibly as young as Turonian) quartz-poor sandstones are informally called the *lower* Great Valley sequence petrofacies. These rocks are mapped locally as either the Espada Formation of Dibblee (1950) or the Toro Formation. Upper Cretaceous rocks that are largely Campanian and Maestrichtian in age and tend to contain abundant quartz and plagioclase, as well as abundant K-feldspar, are informally called herein the *upper* Great Valley sequence petrofacies. In contrast to the well-documented age constraints of Great Valley sequence petrofacies, little is known about the relationship between age and composition of sandstone (so-called graywacke) knockers in Franciscan mélange. As shown below, however, the QFL modes of Great Valley sequence rocks and knockers of Franciscan sandstone closely overlap.

General Textural Characteristics

Great Valley sequence and Franciscan sandstones in the area around the SMB share several general textural characteristics. Quartz and most lithic fragments tend to be subangular to subrounded, whereas feldspar grains tend to be more angular. Framework grains are moderately poor to moderately well sorted and tend to be tightly packed. Grain contacts are mainly long and concavo-convex, and sutured grains are rare. Intergranular clayey matrix in most rocks ranges from 10 to approximately 15 percent. Figure 4 compares the QFL modes of the upper and lower Great Valley sequence sandstone petrofacies. Sandstone knockers in Franciscan mélange typically contain less than 15 percent intergranular matrix and do not classify as graywacke as defined by Pettijohn and others (1972, p. 159)

Lower Petrofacies

Mean detrital modes for the lower Great Valley sequence petrofacies sandstones are approximately Q16, F21, and L63 (table 1). Percentages of K-feldspar, biotite, and epidote are comparatively low, commonly less than 1 percent for each component. Rock fragments consist mainly of aphanitic andesite and basaltic andesite in

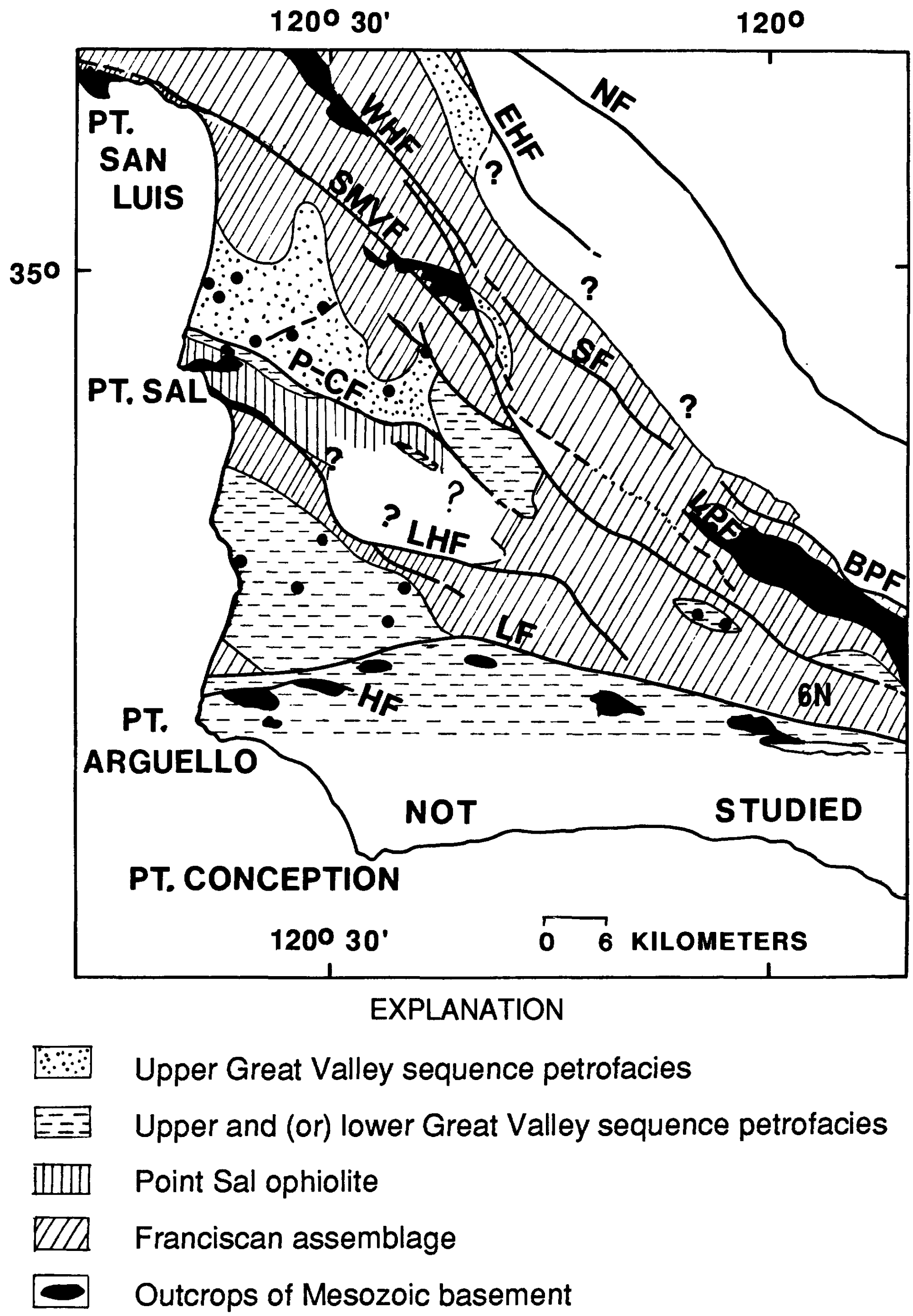

Figure 3. Distribution of Mesozoic rocks in the subsurface of the Santa Maria basin. Solid dots represent locations of wells yielding Cretaceous palynomorphs as reported by Gray (1980). Fault symbols as shown in figure 2.

Table 1. Composition of Mesozoic sandstones of the Santa Maria Basin

[Detrital modes for QFL and QmPK; average percentages for K-feldspar, mica, and epidote, for sandstones of the Great Valley sequence, for Jurassic and Cretaceous Franciscan assemblage (KJf), and for well cores. *n* is the size of the sample population except as follows: (') *n*=3, (") *n*=11,(*) *n*=14. QFL is quartz, feldspar, and lithic fragments including microcrystalline quartz and chert. QmPK is monocrystalline quartz, plagioclase, and potassium feldspar. Mica includes muscovite and biotite. Ku, Upper Cretaceous rocks; Kl, Lower Cretaceous rocks]

	n	Q	F	L	Qm	P	K	K-spar	Mica	Epidote
Ku-outcrop	27	36.5	44	19.5	42.3	42.8	14.9	10.2	5.9	0.5
Ku-wells	21	30.4	39.9	29.7	39.7	49.1	11.2	6.8	5.5	0.8
Kl-outcrop	18	15.6	21.3	63.1	31.4*	67.7*	0.9	0.2	1.1	1.2
Kl-wells	7	19.1	26.8	54.1	45.3'	50.6'	4.1	1.1	1.8	3.5
KJf-outcrop	17	24.7	32.2	43.1	40.4"	59.6"	0	0	4.8	0.3
KJf-wells	11	27.7	35	37.3	45.2	54.6	0	0	4.6	1.9
Point San Luis slab	8	33.5	45.3	21.2	38.8	45.4	15.8	10.8	5.6	0.9

which the glassy groundmass is altered to a paste of semiopaque clay minerals. Sedimentary rock fragments include very fine grained quartzofeldspathic sandstone, siltstone, and argillite. Other lithics include rare microgranitic fragments (chiefly diorite), quartz-mica schist, quartzite, and assorted (recrystallized?) lime clasts.

Lower petrofacies rocks, mapped as the Espada Formation south of the Lompoc fault by Dibblee (1950), contain unusually high percentages of little-altered mafic volcanic rock fragments and abundant clinopyroxene, components that are notably absent in the lower petrofacies rocks mapped as the Espada Formation on the east side of the basin. The abundance of clinopyroxene-rich volcanic debris suggests proximity to a volcanic (arc?) source.

Upper Petrofacies

Upper Great Valley sequence petrofacies sandstones characteristically contain abundant quartz and feldspar, and significant percentages of K-feldspar and biotite. Mean detrital modes of the upper Great Valley sequence petrofacies suite are approximately Q36, F44, and L20 (table 1). Coarse-grained sandstones contain abundant granitic rock fragments, and weathered coarse-grained rocks often have a grussy texture, similar to that of a decomposed granitic rock.

QFL modes from the Cambria and Point San Luis slabs (fig. 1) correspond closely with the QFL modes of the other upper petrofacies outcrop samples (fig. 5); textures and accessory-mineral assemblages are also similar. Paleontologic age control in the Cambria slab is poor, but rare palynomorphs and dinoflagellates suggest a Late Cretaceous (no younger than Campanian) age (Smith, 1978, p. 21). Fossils have not been reported from the Point San Luis slab, but a Late Cretaceous age is supported by the petrographic data of Lee-Wong and Howell (1977), Smith (1978), Gray (1980), and Gray's samples recounted in this report.

Franciscan Petrofacies

Hsü (1968) noted that so-called graywacke sandstone knockers in the Franciscan mélange of the San Francisco Peninsula range widely in color, composition, degree of deformation, and metamorphic grade. Sandstone knockers in the Franciscan mélange in areas adjacent to the SMB exhibit similar kinds of variation. Some knockers superficially resemble upper and (or) lower Great Valley sequence petrofacies sandstones in color and texture; however, the Franciscan rocks tend to be harder, denser, and more highly fractured, with abundant calcite- or quartz-filled veins. Deformation in knockers ranges from mild fracturing to penetrative deformation with complex shearing and development of incipient S1 foliation.

Figure 6 compares QFL modes for Franciscan sandstone knockers with upper and lower petrofacies outcrop suites. The Franciscan rocks overlap most of the lower petrofacies suite, and the relatively quartz-poor upper petrofacies suite. Although ages of individual knockers of Franciscan sandstone are unknown, their QFL modes overlap more with the lower petrofacies suite than with the upper petrofacies suite. Possible implications of the overlapping QFL modes of Franciscan and Great Valley sequence sandstones are discussed below (see section "Discussion and Conclusions").

SUBSURFACE DISTRIBUTION OF MESOZOIC ROCKS

Several SMB wells that contain K-feldspar-bearing sandstones also contain Late Cretaceous palynomorphs (Gray, 1980) (figs. 3, 7). Similar upper Great Valley sequence petrofacies rocks were found in this study to underlie significant parts of the Guadalupe and Santa Maria Valley oil fields (stippled pattern of fig. 3). Basement rock cores indicate that Great Valley sequence strata structurally overlie Franciscan assemblage mélange and that the Great Valley sequence is locally truncated by protrusions of serpentinite and (or) serpentinized

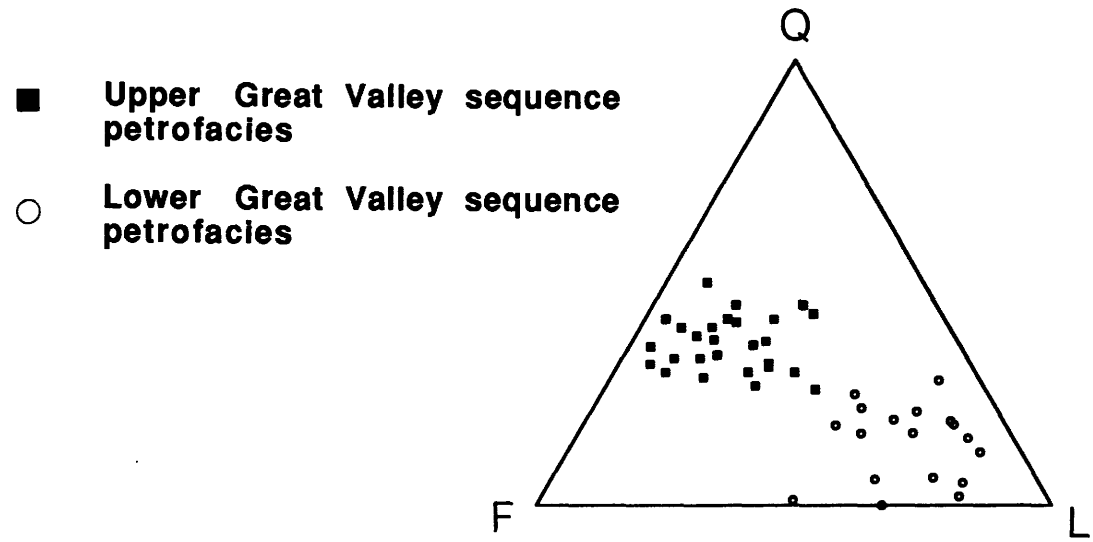

Figure 4. Detrital modes of Great Valley sequence outcrop samples. Q-monocrystalline and polycrystalline quartz; F-plagioclase and potassium feldspar; L-lithic rock fragments including chert.

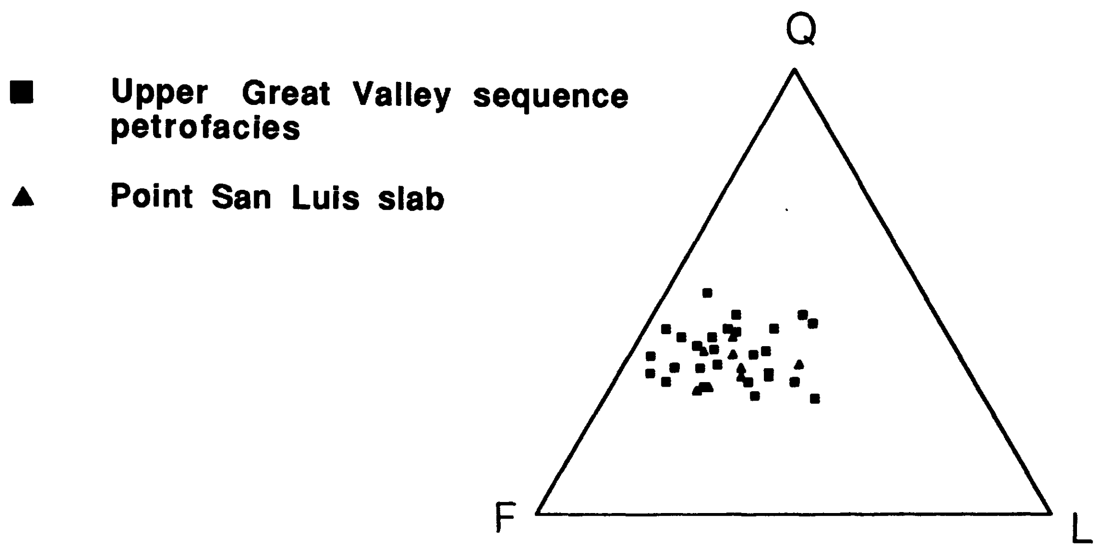

Figure 5. Detrital modes of sandstone in outcrops from the Point San Luis slab (fig. 1) and from the upper part of the Great Valley sequence.

mélange that contains incorporated fragments of ultramafic and spilitic volcanic rocks (Brown, 1968; Vedder and others, 1989). The subsurface relations in the Guadalupe and Santa Maria oil fields are similar to field relations visible in the Cambria and Point San Luis slabs.

Upper Jurassic and Lower Cretaceous sandstone, mudstone, and shale exposed in the seacliffs of Point Sal were mapped as the Knoxville Formation by Woodring and Bramlette (1950) and are part of the lower Great Valley sequence petrofacies as defined herein. These Knoxville strata overlie a succession of chert, pillow basalt, and ultramafic rocks of Jurassic age called the Point Sal ophiolite, (fig. 3) The lower petrofacies (Knoxville) and the ophiolitic rocks are in turn unconformably overlain by up to 800 m of lower Miocene sandstone, conglomerate, mudstone, and tuff, called the Lospe Formation by Stanley and others (1990). Much of the reddish and greenish colored sedimentary detritus in the Lospe is derived from Franciscan and ophiolitic rocks.

Data from widely spaced wells in the coastal lowlands between the Lions Head fault and Lompoc faults indicate that the Franciscan mélange is locally overlain by both upper and lower petrofacies rocks that are in turn unconformably overlain by local deposits of the Lospe Formation (figs. 2, 3, 8).

The results of this study indicate that the SMB is largely underlain by Franciscan mélange with smaller areas underlain by Great Valley sequence and tectonic slivers of ophiolitic rocks (fig. 3). Franciscan sandstone,

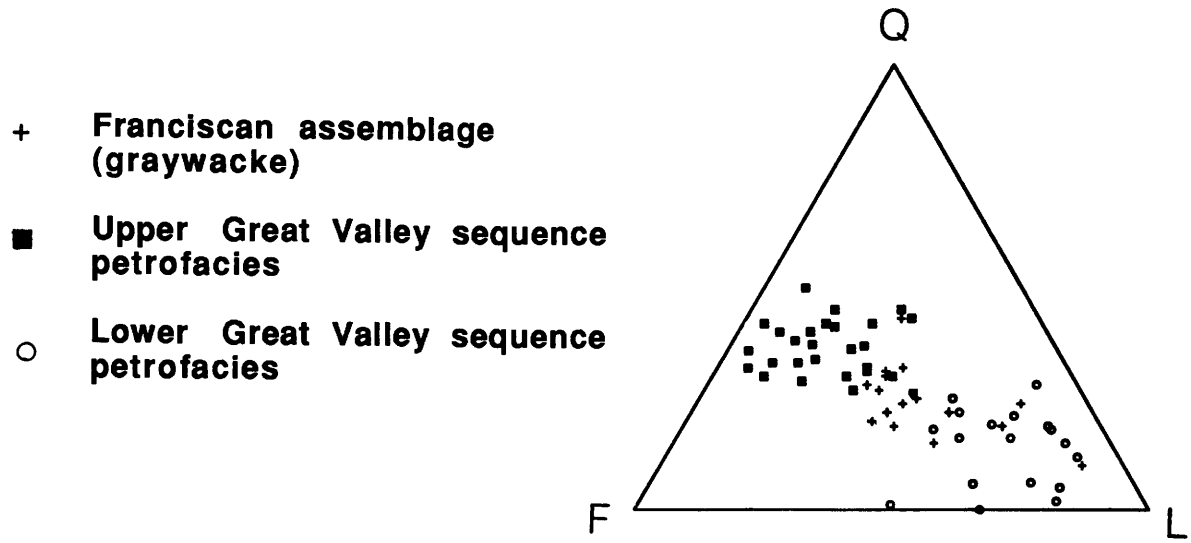

Figure 6. Detrital modes of graywacke in outcrops of Franciscan assemblage mélange added to data shown in figure 4.

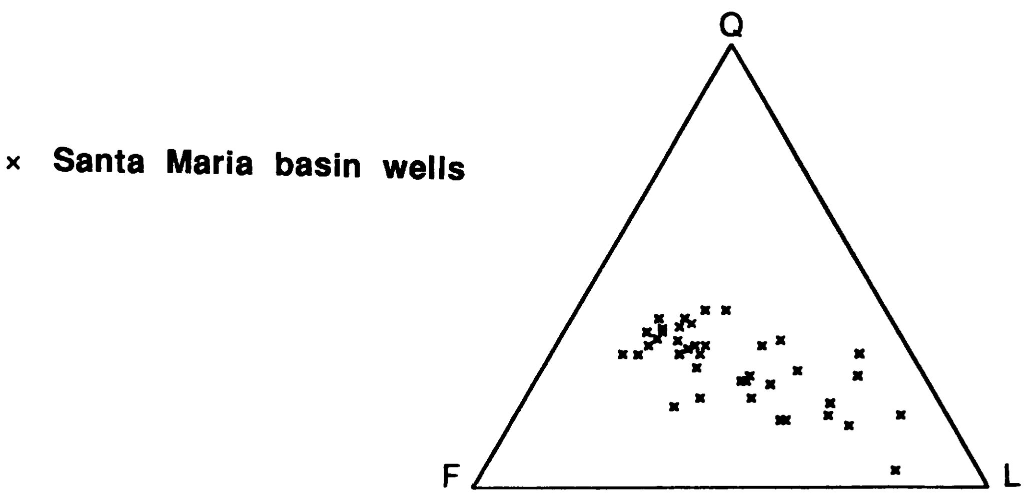

Figure 7. Detrital modes of sandstone samples from subsurface core samples.

presumably enclosed in subsurface mélange, was identified in only 8 wells. The QFL modes of 11 specimens of rocks interpreted to be Franciscan sandstone overlap the fields of both upper and lower Great Valley sequence petrofacies (fig. 9). The Franciscan rocks that plot in the upper petrofacies field represent four wells within a radius of 5 km located in the southeasternmost part of the basin, whereas sandstones that plot in the lower petrofacies field represent widely spaced wells located along the eastern edge of the basin.

COMMENTS ON THE ABSENCE OF K-FELDSPAR IN SANDSTONE KNOCKERS OF FRANCISCAN MÉLANGE

Although the Franciscan and Great Valley sequence sandstones studied here share similar grain shapes, size sorting, accessory minerals, and framework modes, none of the Franciscan rocks contain K-feldspar. Conversely, upper Great Valley sequence petrofacies sandstones generally contain 5 to 10 percent orthoclase, and even lower petrofacies rocks commonly contain at least trace amounts of detrital K-feldspar (table 1). Thus, in subsurface rocks, the absence of K-feldspar is an important criterion for distinguishing Franciscan from Great Valley sequence sandstones, especially in rocks that plot in the upper petrofacies field. Feldspar grains in the Franciscan suite, however, commonly display chessboard texture suggesting that albite has replaced detrital K-feldspar as reported by Walker (1984). Parallel extinction of albite twins suggests that detrital plagioclase has likewise been albitized. Trends of increasing albitization of K-feldspar with depth have been documented in the Denver Basin by Walker (1984) and in the North Sea adjacent to Norway by Saigal and others (1988). Increasing albitization of plagioclase with burial depth has also been reported by Pittman (1988). Neither detrital K-feld-

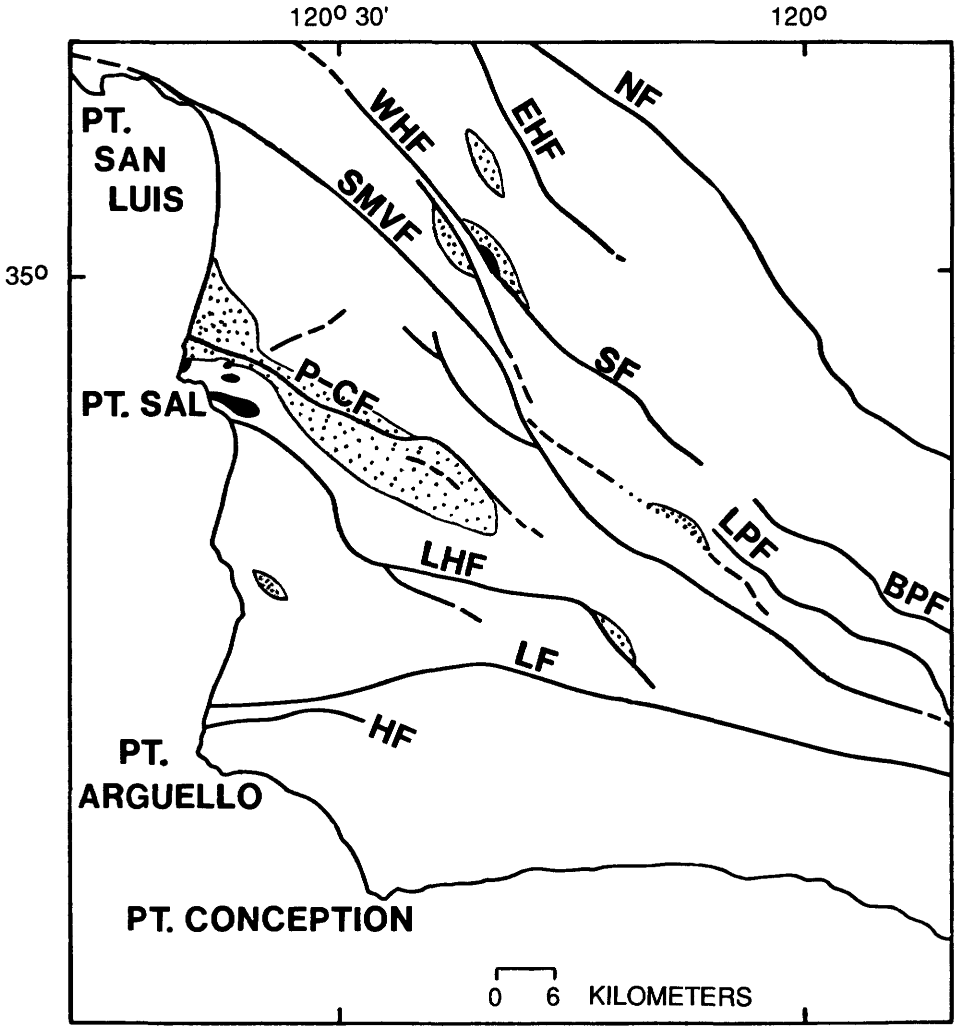

Figure 8. Subsurface distribution map of lower Miocene Lospe Formation (stippled area); outcrops shown as dark shaded areas. Fault symbols as shown in figure 2.

spar nor calcic plagioclase would be expected to survive in sandstone knockers in Franciscan mélange, which are commonly metamorphosed to greenschist facies and in some cases blueschist facies, although textural evidence in some rocks indicates that K-feldspar may have existed prior to metamorphism.

DISCUSSION AND CONCLUSIONS

The SMB is floored mainly by mélange of the Franciscan assemblage and locally by strata of the upper and (or) lower petrofacies of the Great Valley sequence. Slivers of altered ophiolitic rocks are probably enclosed in mélange (fig. 3). The lower Miocene Lospe Formation contains abundant Franciscan and ophiolitic detritus and overlaps the Pezzoni-Casmalia fault, which suggests that Neogene movement on the fault has been mainly vertical with the north side down relative to the south side.

Mesozoic sandstone petrofacies established by previous workers for rocks in the Nacimiento block and elsewhere in California provide a useful means of differentiating Franciscan and Great Valley sequence rocks in the subsurface. The overall petrographic similarities of sandstone knockers in Franciscan mélange and sandstone of the lower part of the Great Valley sequence suggest that quartz-poor, lithic-rich Franciscan sandstone may represent the subducted lower Great Valley sequence petrofacies. Conversely, quartz and feldspar-rich Franciscan sandstone knockers may represent the subducted upper Great Valley sequence petrofacies. Although the Franciscan rocks no longer contain K-feldspar, their range in composition and associated feldspar textures suggest (but do not prove) that the mélange sandstones may represent subducted Great Valley sequence that ranges in age from Late Jurassic and (or) Early Cretaceous to middle Late Cretaceous. Analogs of quartz- and feldspar-rich Campanian and Maestrichtian Great Valley sequence sandstone petrofacies are unknown in the Franciscan mélange of the Santa Maria basin area. Conversely lithic-rich lower petrofacies rocks are unknown in the Cambria and Point San Luis slabs and in the northern floor of the SMB. The observed distribution of Great Valley sequence petrofacies suggests that a depocenter located on the continental slope may have moved progressively seaward during Mesozoic subduction in central California. Previous workers such as Howell and others (1977), Smith (1978), and Smith and others (1979) interpreted the Cambria and Point San Luis slabs as trench or slope-basin deposits that accumulated outboard from the main fore-arc basin. Complex isoclinal folds, faults, and broken formation in the two slabs suggest that sediment accumulated on a structurally active zone of accretion. Preservation of abundant detrital K-feldspar in the Cambria and Point San Luis slabs suggests that although the rocks were tectonically "kneaded," they were not subducted into the subjacent accretionary complex, which is now represented by Franciscan mélange.

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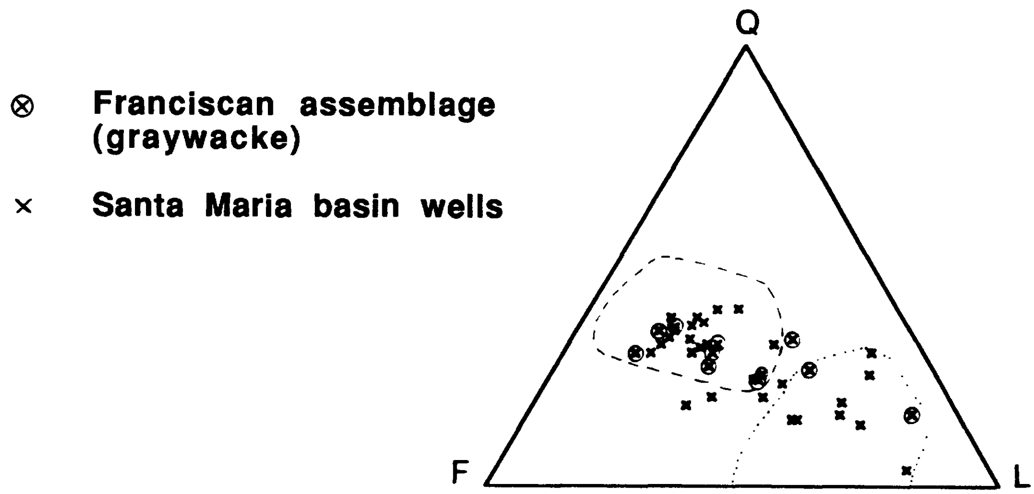

Figure 9. Subsurface samples interpreted as Franciscan assemblage graywacke. Dashed line is upper Great Valley sequence petrofacies field and dotted line is lower Great Valley sequence petrofacies field shown in figure 3.

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