The American Association of Petroleum Geologists Bulletin
V. 67, No. 4 (April 1983), P. 624-645, 12 Figs.

Cretaceous Sinistral Strike Slip Along Nacimiento Fault in Coastal California[1]

WILLIAM R. DICKINSON[2]

ABSTRACT

The San Andreas and Nacimiento faults of coastal California both separate granitic and metamorphic basement rocks of the Salinian block from partly coeval but contrasting Mesozoic terranes underlain by the Franciscan subduction complex. By analogy with Neogene dextral strike slip along the San Andreas fault, Cretaceous sinistral strike slip can be inferred along the Nacimiento fault in preference to hypotheses for tectonic erosion during subduction or for dextral strike slip of unspecified amount. Following restoration of known San Andreas and inferred proto-San Andreas dextral displacements, reversal of about 560 km (350 mi) of postulated sinistral slip on the Nacimiento fault brings four major Mesozoic lithotectonic belts of California and Baja California into simple alignment as subparallel terranes related to Mesozoic subduction along the continental margin.

Neogene deformation within the San Andreas transform system involved (a) elongation of the Salinian block by dextral slip along subsidiary faults that branch from the San Andreas fault, and (b) dextral rotation of crustal panels within the Transverse Ranges. Latest Cretaceous and/or earliest Paleogene dextral slip along a proto-San Andreas fault followed the San Andreas course in central California, but diverged westward in southern California. Nacimiento sinistral displacements occurred in mid-Cretaceous to early or medial Late Cretaceous time, after Cretaceous emplacement of plutons now within the Salinian block but prior to deposition of uppermost Cretaceous sedimentary sequences in central California. Available data on Mesozoic relative and absolute plate motions in the Mesoamerican region support the likelihood of Cretaceous sinistral strike slip subparallel to the California continental margin.

Paleotectonic reconstruction of crustal blocks in California and Baja California to their inferred mid-Cretaceous relative positions shows the Salinian block inserted on a bias between the flanking Mojave and Peninsular Ranges blocks. Salinian granitic rocks thus formed an interior part of the Mesozoic batholith belt, and their initial strontium isotopic ratios are compatible with the gradients displayed by values from the adjoining blocks. The similar Mesozoic terranes that now lie east and west of the Salinian block were then adjacent to one another west of the Sierra Nevada block. Available paleomagnetic data neither support nor preclude the reconstruction, but additional work together with future detailed lithotectonic comparisons potentially can confirm or refute the hypothesis it represents. A correct interpretation of the Nacimiento fault is important for understanding the overall tectonic framework of petroliferous basins both onshore and offshore in coastal California.

INTRODUCTION

Of all the puzzling structural discontinuities in coastal California, none is more difficult to interpret than the Nacimiento fault. At present, there is no consensus on the dominant sense of slip along the fault, on the timing of the principal displacements, or on its significance as a structural feature in the tectonic evolution of the continental margin. This paper develops the hypothesis that the Nacimiento fault had its origin in the Cretaceous as a sinistral or left-lateral strike-slip fault. The argument is based fundamentally on the observed geometric pattern of coastal terranes in California and Baja California. Consequently, the core of this paper is a series of tectonic and paleotectonic maps. Descriptions of the rock masses involved are confined to salient aspects that directly influence the arguments presented.

The central terrane of the California Coast Ranges is the Salinian block (Fig. 1), whose basement is composed of Cretaceous granitic plutons intrusive into metamorphic rocks of generally amphibolite facies. This basement is similar to the bedrock of the Sierra Nevada block farther east. To either side of the Salinian block, the basement is the Franciscan assemblage, a subduction complex of oceanic and related facies of late Mesozoic and early Cenozoic age.

The eastern side of the Salinian block is the San Andreas fault. The western side is generally termed the Nacimiento fault, although there is wide recognition that various segments of the contact have different characters that reflect tectonic overprints of several kinds.

Radiometric dates showing that the granitic plutons of the Salinian block are Cretaceous in age (Curtis et al, 1958) strengthened the hypothesis that hundreds of kilometers of dextral or right-lateral strike slip occurred along the San Andreas fault during the Cenozoic (Hill and Dibblee,

[1]Manuscript received, April 1, 1982; accepted, August 30, 1982.

[2]Laboratory of Geotectonics, Department of Geosciences, University of Arizona, Tucson, Arizona 85721.

I thank T. H. Anderson, B. C. Burchfiel, R. F. Butler, P. J. Coney, J. C. Crowell, J. K. Crouch, G. A. Davis, T. W. Dibblee, David Engebretson, W. G. Ernst, R. G. Gastil, S. A. Graham, C. A. Hall, W. B. Hamilton, D. G. Howell, R. V. Ingersoll, R. W. Kistler, M. H. Link, B. P. Luyendyk, T. H. Nilsen, B. M. Page, E. A. Silver, L. T. Silver, J. E. Spencer, A. G. Sylvester, J. G. Vedder, and D. W. Weaver for helpful discussions and/or preprints. This research was supported by the Earth Sciences Division of the National Science Foundation with NSF Grant EAR 76-22636, and by the Laboratory of Geotectonics in the Department of Geosciences at the University of Arizona.

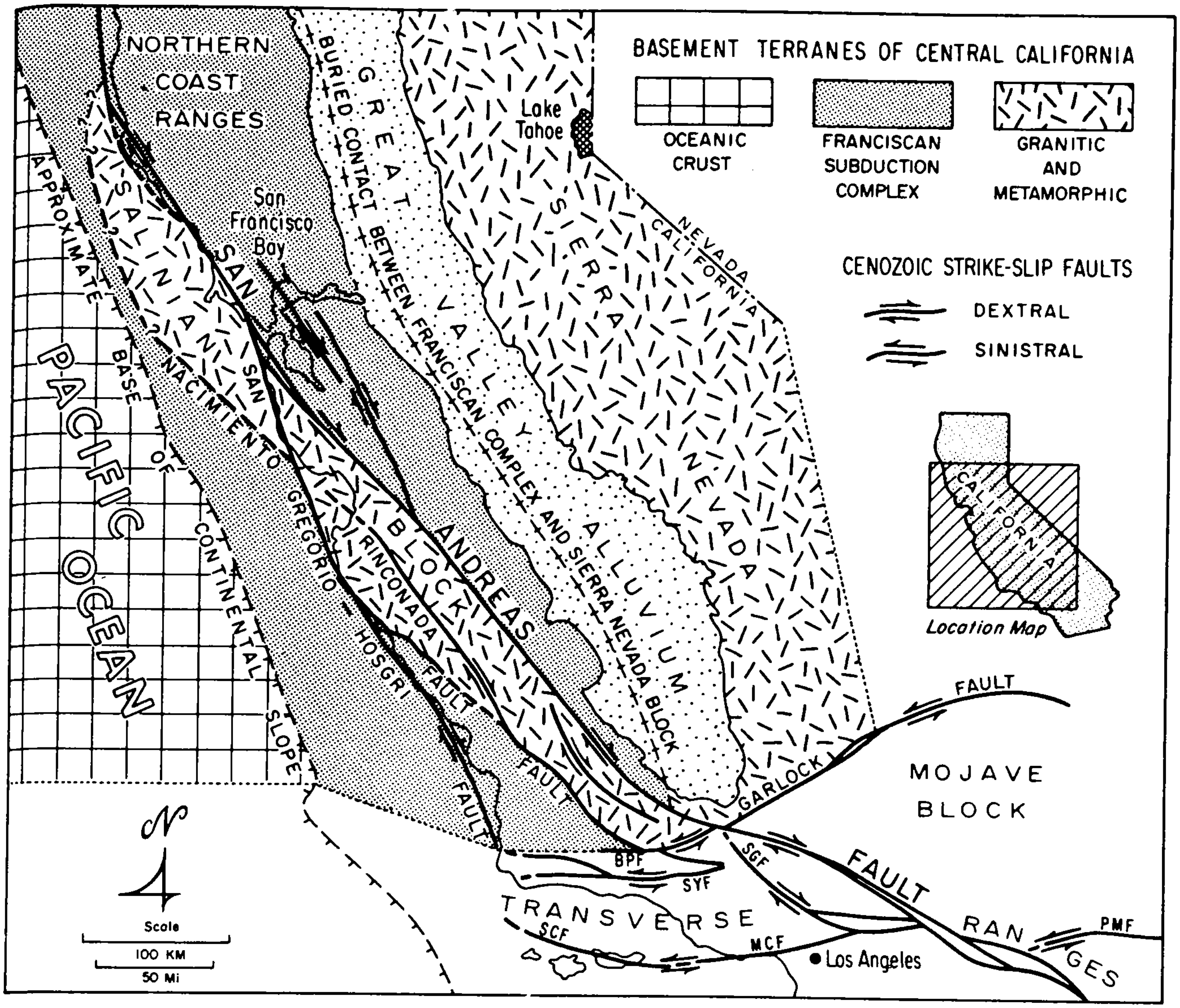

FIG. 1—Tectonic relations of Salinian block in coastal California. Fault abbreviations: BPF, Big Pine; MCF, Malibu Coast, PMF, Pinto Mountain; SCF, Santa Cruz Island; SGF, San Gabriel; SYF, Santa Ynez. Offshore relations modified after Silver et al (1971) and Hoskins and Griffiths (1971). See Figure 6 for course of San Gregorio–Hosgri fault and Figure 7 for detail in western Transverse Ranges.

1953). Large lateral displacement is required to explain the occurrence of Cretaceous plutons in contact with Franciscan rocks to the east along the whole length of the Salinian block. Coeval and older strata of the Franciscan assemblage show no hint of the thermal effects that would be expected from intrusive emplacement of the granitic plutons in their present positions.

It probably has occurred to almost every California geologist that the same line of reasoning could be used to argue for a comparable amount of sinistral strike slip along the Nacimiento fault (e.g., Gastil, 1968). However, as Crowell (1962) wrote, the idea that two subparallel faults as close together as the San Andreas and Nacimiento could have experienced such great strike slips in opposing senses was "so startling that it is *at present* unacceptable" (italics added). Twenty years later, we are not so startled by cases of astounding crustal mobility.

It is still inconceivable that the two great faults could have moved simultaneously in opposing senses. Instead, the sinistral displacements along the Nacimiento fault are inferred here to have occurred during the Cretaceous, prior to the dextral displacements that occurred along the San Andreas fault and its subsidiary strands within the San Andreas transform system of Neogene age (Atwater, 1970). Alternative explanations for the juxtaposition of disparate terranes across the Nacimiento fault contact involve some combination of (a) tectonic erosion during pre-Oligocene subduction, and (b) dextral strike slip of such magnitude that offset counterparts of the California terranes cannot yet be identified with certainty anywhere along the Cordilleran margin (Page, 1981, 1982). These alternatives are here considered less attractive than the concept of Cretaceous sinistral slip (Dickinson, 1981a). Several lines of thought suggest that important sinistral truncations of the California continental margin occurred during the Mesozoic prior to the better known dextral offsets during the Cenozoic (Burchfiel and Davis, 1981).

Restoration of inferred sinistral slip along the Nacimiento fault permits a more satisfactory reconstruction of basement terranes in coastal California than existing ideas have allowed. The hypothesis presented here thus leads to an improved tectonic model whose specific predictions can be tested by future work. Better understanding of the tectonic evolution of California is important to improve knowledge of the structural framework of petroliferous basins both onshore and offshore in coastal California (Blake et al, 1978).

MESOZOIC LITHOTECTONIC BELTS

The regional setting of the Salinian block can be understood best in relation to four key lithotectonic belts of Mesozoic rocks in California and Baja California (Fig. 2). The present geographic pattern of the four belts is complex in the coastal region occupied by the Salinian block, and also in the region immediately south of the Salinian block. This complex region in southern California includes the Transverse Ranges (Fig. 1) onshore and the offshore California continental borderland. However, in central California east of the Salinian block and in Baja California south of the Transverse Ranges, the configuration of the four subparallel belts is basically simple. The kinds of terranes that form the belts are described briefly here as they occur from east to west (Fig. 2). Together, the four belts can be interpreted as the geologic record of a Mesozoic arc-trench system along the Cordilleran margin of North America (Hamilton, 1969).

Batholith Belt

The easternmost belt is composed dominantly of granitic plutons, although pendants and septa of metamorphic wall rocks are also extensive in some areas. The batholiths of the Sierra Nevada and the Peninsular Ranges (Fig. 2) belong to this belt, as does all the exposed portion of the Salinian block. The plutons are inferred to represent the roots of a Mesozoic magmatic arc, although remnants of the volcanic phase of arc magmatism have survived erosion only sparingly in isolated areas. Most of the granitic rocks yield Cretaceous radiometric ages, but Jurassic intrusives are also widespread in lesser volume (Evernden and Kistler, 1970; Armstrong and Suppe, 1973; Krummenacher et al, 1975; Silver et al, 1979; Miller and Norton, 1980).

Within the main batholith belt, there is a crude but persistent zonation from east to west in the nature of the dominant granitic rocks and in the character of the metamorphic country rock (Gastil, 1968, 1975). On the east, mainly felsic plutons are intrusive into chiefly Paleozoic metasedimentary rocks of generally miogeoclinal affinity, and are emplaced locally into Precambrian basement that represents a westward projection of the craton in the southern California region. Scattered plutons occur far east of the edge of the main batholith belt in some areas. On the west, more mafic plutons were intruded into so-called eugeosynclinal strata that include large proportions of metavolcanic rocks and represent oceanic terranes accreted to the continental block during the Mesozoic (Coney et al, 1980). The zone of eugeosynclinal country rocks expands in width northward in the northern Sierra Nevada and adjacent regions as the contact with miogeoclinal rocks curves eastward into central Nevada. The boundary between the batholith belt and the foothills belt (Fig. 2) is gradational, and many individual plutons occur within the latter.

Foothills Belt

In the Sierra Nevada foothills and along the western flank of the Peninsular Ranges lies a structurally complicated metamorphic belt of varied lithology. Metavolcanic and metavolcaniclastic rocks, tectonic slices of ophiolitic successions, and intensely deformed successions of slate and metachert are perhaps most characteristic. Tectonite fabrics and melange-like structures of the sort whose origin is now commonly attributed to processes of subduction are widespread (e.g., Duffield and Sharp, 1975; Criscione et al, 1978). Rare fossils indicate that the metamorphosed terranes of the foothills belt are partly late Paleozoic, but are largely Triassic to Jurassic in age. Tectonostratigraphic correlations along the length of the foothills belt from California into Baja California are still uncertain in detail.

The foothills belt evidently represents a collage of exotic island arcs, associated oceanic crust, and overlying sedimentary sequences that were assembled and accreted along the continental margin by subduction and obduction during the middle part of the Mesozoic. The climax of deformation probably came at the time when the crustal blocks of major island-arc terranes collided with the continental margin. This episode occurred in the Late Jurassic in central California (Schweickert and Cowan, 1975; Hietanen, 1981), but may have been as late as the Early Cretaceous in Baja California (Rangin, 1978; Gastil et al, 1978). The position of the foothills belt can be regarded as the location of an early to middle Mesozoic subduction zone that was operative along the continental margin prior to the evolution of the Franciscan subduction complex in late Mesozoic and early Cenozoic time farther west.

Great Valley Belt

The Great Valley sequence of central California was deposited in a major fore-arc basin of latest Jurassic and Cretaceous age (Ingersoll, 1978a; 1979). Similar fore-arc sedimentation continued into the Paleogene (Dickinson et al, 1979). Where thickest, the strata are dominantly turbidites (Ingersoll, 1978c) and lie depositionally upon an ophiolite sequence now commonly termed the Coast Range ophiolite (Bailey et al, 1970). Eastward, the flank of the Great Valley basin onlaps the foothills belt where shelf deposits occur above the angular unconformity. The clastic detritus in the Great Valley sequence was derived mainly from granitic plutons of the batholith belt and from erosion of arc volcanics that once capped the batholith belt (Dickinson and Rich, 1972; Ingersoll, 1978b,

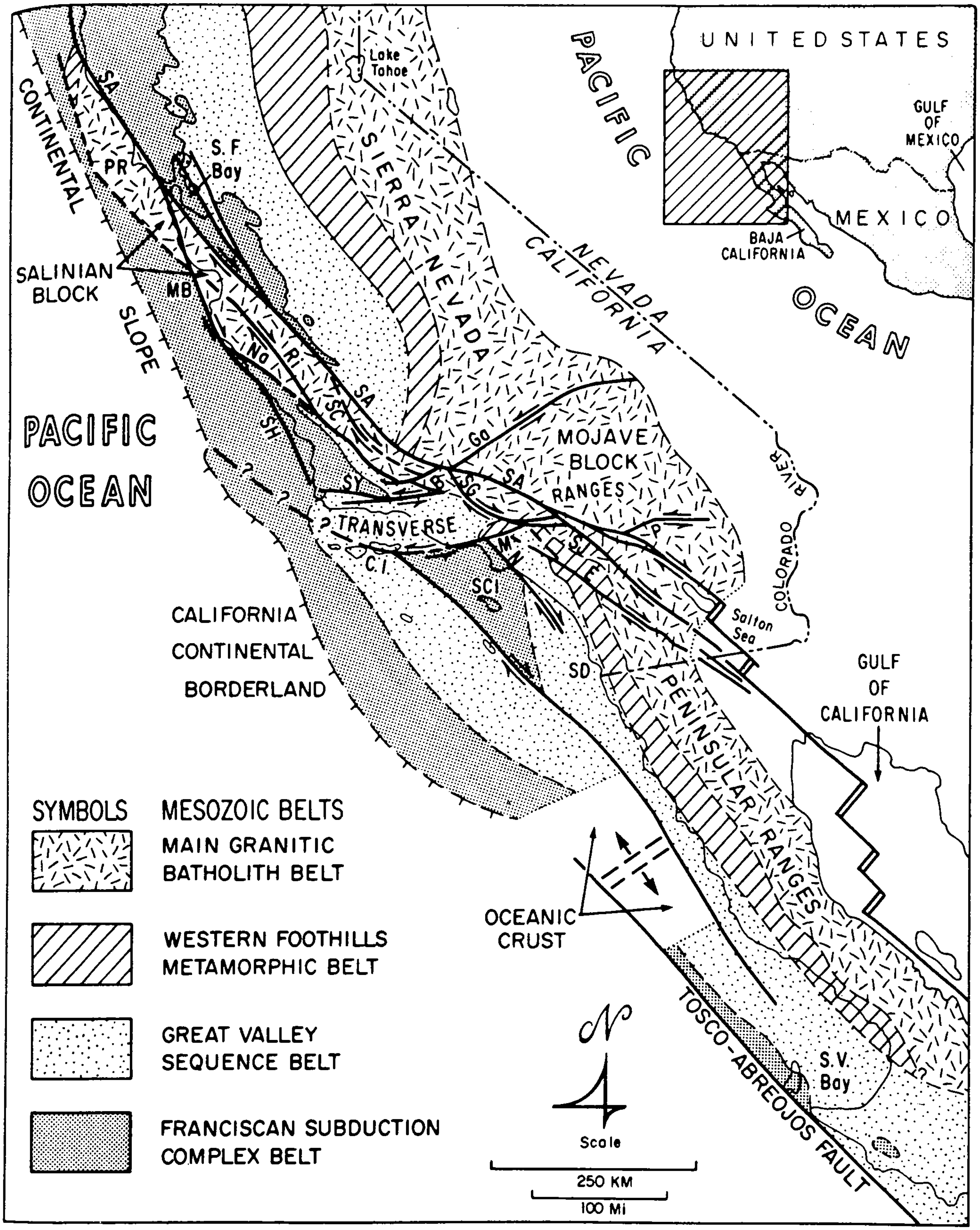

FIG. 2—Regional distribution of principal Mesozoic lithotectonic belts in California and Baja California (see inset for location). Geographic keys along coast (north to south): PR, Point Reyes; S.F. Bay, San Francisco Bay; MB, Monterey Bay; C.I., Channel Islands; SCI, Santa Catalina Island; SD, San Diego; S.V. Bay, Sebastian Vizcaino Bay. Relations in California continental borderland and offshore Baja California adapted from Crouch (1981) and Spencer and Normark (1979), respectively. Relations within Baja California interpreted from Gastil et al (1975). Spreading pattern schematic in Gulf of California. Fault abbreviations: B, Big Pine, E, Elsinore; Ga, Garlock; M, Malibu Coast; N. Newport-Inglewood; Na, Nacimiento; P, Pinto Mountain; Ri, Rinconada; SA, San Andreas; SC, San Juan–Chimeneas; SG, San Gabriel; SH, San Gregorio–Hosgri; SJ, San Jacinto; SY, Santa Ynez.

1983; Mansfield, 1979). Detrital contributions from the metamorphic terranes of the foothills belt and the batholithic wall rocks are also present. Although affected by burial metamorphism, the Great Valley sequence is not as strongly deformed as the rocks in the lithotectonic belts to the east and west.

Late Cretaceous analogs of the Great Valley strata are present south of the Transverse Ranges along the coast of southern California and in the adjacent borderland offshore (Nilsen and Abbott, 1981). These analogs extend southward into Baja California at least as far as the region of Sebastian Vizcaino Bay (Jones et al, 1976), where Late Jurassic strata are also present (Boles, 1978). The Great Valley sequence is also present within the Transverse Ranges (MacKinnon, 1978) and west of the Salinian block (Gilbert and Dickinson, 1970). Occurrences in those two areas are discussed further in a later section, as are partly coeval strata that lie unconformably on the basement rocks of the Salinian block.

Franciscan Belt

The westernmost belt is composed of intricately deformed graywacke, argillite, chert, greenstone, serpentinite, and rare limestone of the Franciscan assemblage (Bailey et al, 1964). The terrane represents an incrementally accreted subduction complex that developed in association with a trench which existed along the continental margin in late Mesozoic and early Cenozoic times (Ernst, 1970; Travers, 1972). Melanges and multiple thrust panels are characteristic of the structural style, and blueschist metamorphism of variable grade is widespread (Ernst, 1975). On the east, the Franciscan terrane is thrust beneath the Coast Range ophiolite and the Great Valley sequence along the Coast Range thrust (Bailey et al, 1970), which was active during subduction. On the west, the contact with undeformed oceanic crust is inferred to be a dormant trench, now buried beneath Neogene cover and possibly modified by Neogene faulting (Page et al, 1978; Ross and McCulloch, 1979).

Although much of the Franciscan terrane in central California is latest Jurassic to Cretaceous in age, the coastal belt in northern California is composed largely of Cenozoic rocks (Bachman, 1978). Most of the Cenozoic Franciscan rocks are Paleogene (Evitt and Pierce, 1975), but some components are locally as young as Miocene (Beutner et al, 1980; McLaughlin et al, 1982). Age data from south of the Transverse Ranges are sparse, but lithologic correlations suggest that part of the Franciscan assemblage offshore from southern California is also of Cenozoic age (Crouch, 1981). Figure 2 does not reflect differences in age because the position of the contact between Mesozoic and Cenozoic components of the Franciscan assemblage is still poorly known in many areas.

Salinian Block Restoration

Restoration of the Salinian block to its pre-fault position in relation to other tectonic elements depends partly on the interpretation of structural details within the Transverse Ranges. Nevertheless, it is clear that any restoration that involves the reversal of inferred sinistral slip on the Nacimiento fault, as well as reversal of dextral slip on the San Andreas fault, must achieve one key result. By those two paired reversals of fault movement, the Salinian block will be inserted on a bias between the Mojave block and the Peninsular Ranges (Fig. 2). This is an attractive reconstruction, because the granitic terrane of the Salinian block is well known to have more affinities with the interior parts of the batholith belt than with its margin (Gastil, 1968, 1975). In this respect, the configuration thus achieved is bound to be superior, regardless of details, to those reconstructions by which the Salinian block is placed in an initial position along the western edge of the batholith belt (e.g., Suppe, 1970, Fig. 1; Howell, 1975, Fig. 2; Ernst, 1980, Fig. 6).

Unslipping both a dextral San Andreas fault and a sinistral Nacimiento fault will also produce another salient result of key importance. Regardless of the detailed operations involved in such a reconstruction, the belts with Franciscan basement that now lie on either side of the central Salinian block will remain close together after restoration is complete. In the next section, the Mesozoic geology of those two belts is compared as a gross test of the viability of the hypothesis for sinistral strike slip on the Nacimiento fault. A subsequent section discusses details of the structural geometry of the Salinian block and the Transverse Ranges. These details and other information are then used to restore the Mesozoic lithotectonic belts of California and Baja California to their inferred mid-Cretaceous configurations.

CENTRAL CALIFORNIA TERRANES

Although large areas of the central Salinian block are masked by Cenozoic cover, its entire width is exposed on land (Fig. 3). Contrasts between the Mesozoic substratum within the block and on either side are thus well displayed on the outcrop. Beyond the steeply dipping San Andreas fault along the northeast edge of the Salinian block lies the Diablo Range. Franciscan and Great Valley rocks are extensively exposed there in the dissected cores of en echelon anticlines. The folds formed during Neogene wrench deformation that accompanied San Andreas displacements (Harding, 1976). The Coast Range thrust contact between the Franciscan assemblage and the Great Valley sequence was strongly folded and dislocated by steep faults during the Neogene deformation.

Nacimiento Fault Contact

The fundamental geometry of the Nacimiento fault along the southwest side of the Salinian block is difficult to interpret, partly because of modification during Neogene deformation (Page, 1970a). Beyond it lies a second terrane of Franciscan and Great Valley rocks, here termed the Obispo belt. Where the Nacimiento fault is not masked by Neogene cover, it trends mostly through rugged forested country as a relatively obscure contact between Cretaceous sandstones, which nearby lie unconformably on basement rocks of the Salinian block, and Mesozoic graywackes of the Franciscan assemblage in the Obispo belt.

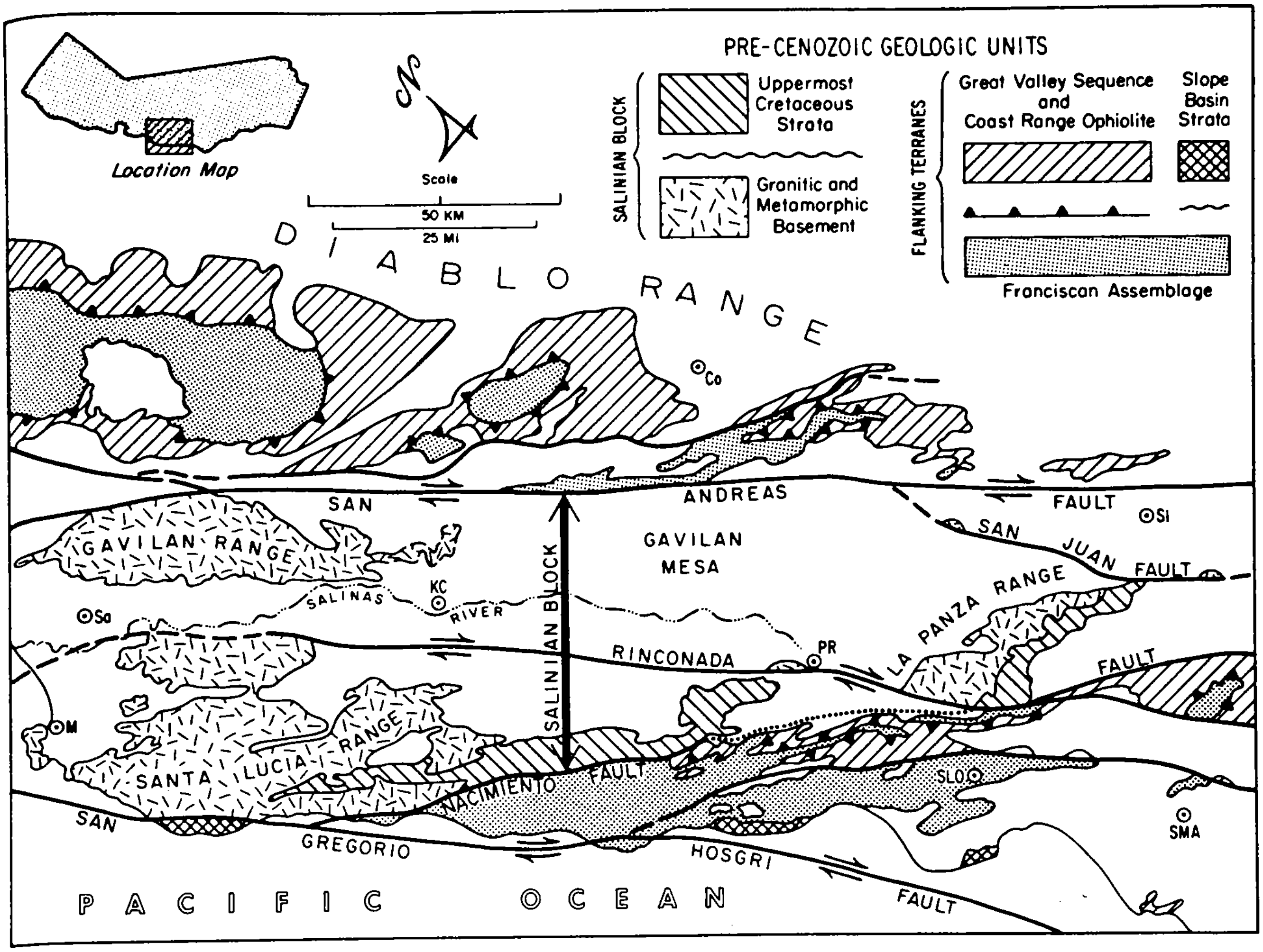

FIG. 3—Distribution of pre-Cenozoic geologic units in central Salinian block and within flanking terranes underlain by Franciscan basement: Diablo Range northeast of San Andreas fault, and Obispo belt southwest of Nacimiento fault. Thrust symbol denotes Coast Range thrust of late Mesozoic age, or equivalent lithologic contact as modified by local Cenozoic faulting associated with Coast Range folding during the Neogene. Key cities and towns: Co, Coalinga; M, Monterey; KC, King City, PR, Paso Robles; Sa, Salinas; Si, Simmler; SLO, San Luis Obispo; SMA, Santa Maria.

This contact is steeply dipping for most if not all of its course. More gently dipping fault contacts between similar Cretaceous sandstones and Franciscan graywackes farther to the southeast are interpreted here as folded imbricate splays of the Coast Range thrust between units that are both part of the Obispo belt. Strata above this folded thrust system locally pass downward into the Coast Range ophiolite at the base of the Great Valley sequence (Page, 1972).

The time at which the Salinian block and the Obispo belt were first brought into contact along the Nacimiento fault has long been in dispute (Page, 1970b). Recent evidence indicates that little or no displacement occurred between the two terranes after upper Oligocene to lower Miocene beds of peculiar and regionally unique barnacle limestone were deposited in nearby areas on both sides of the fault contact (Graham, 1978). This relationship seemingly precludes speculation that the Nacimiento fault might be an early strand of the Neogene San Andreas transform system.

Strong circumstantial evidence indicates that the Salinian block and the Obispo belt were brought into close juxtaposition before the end of the Late Cretaceous (Vedder and Brown, 1968; Vedder et al, 1977). Adjacent to the Rinconada fault (Fig. 1), Upper Cretaceous red beds of probable Campanian age (about 75 m.y.B.P.) lie along the eastern margin of the Obispo belt, but contain coarse clastic detritus of apparently Salinian provenance. However, the juxtaposition could not have occurred before emplacement of the offset granitic plutons in the Salinian block. Complicated cooling histories make the interpretation of radiometric dates a difficult exercise, but the best current estimate for the time span of emplacement based on U-Pb and Rb-Sr isotopic measurements is about 105 to 115 m.y.B.P. (Mattinson, 1978). This age is late Early Cretaceous (Aptian-Albian). Thus, the indicated time window for possible sinistral offset of terranes along the Nacimiento fault is roughly mid-Cretaceous to early Late Cretaceous time. Recent indications (Mattinson, 1982) that some of the plutons in the eastern part of the Salinian block may be as young as about 85 m.y. imply a much narrower time window for offset, which thus might have been

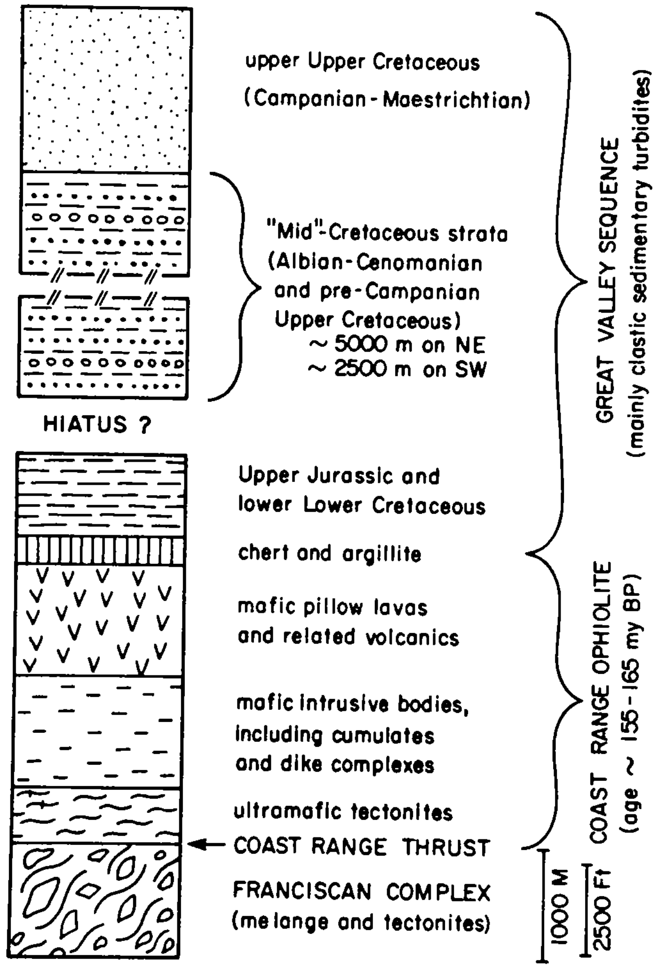

FIG. 4—General tectonostratigraphic column of Mesozoic units in Diablo Range northeast of central Salinian block and Obispo belt southwest of central Salinian block (see Fig. 3). Modified after Rose and Colburn (1963), Hall and Corbato (1967), Gilbert and Dickinson (1970), Hart (1976), MacKinnon (1978), Mansfield (1979), and Hopson et al (1981).

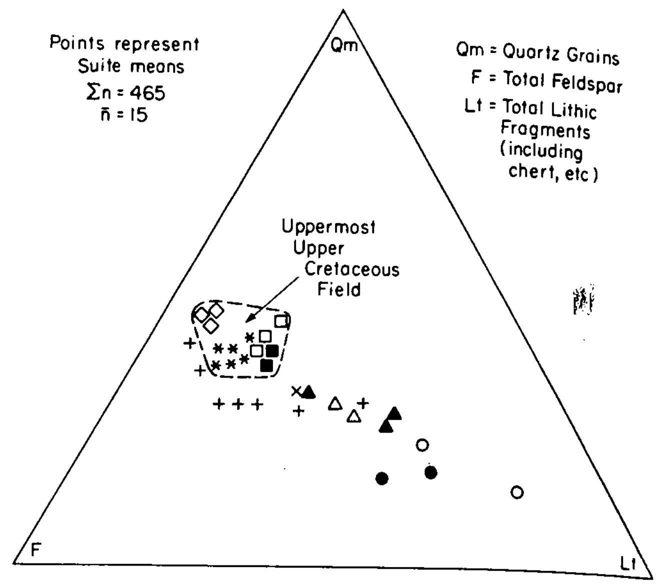

FIG. 5—Mean detrital modes of 31 Mesozoic sandstone suites from central California calculated from 465 point counts of individual samples. Diamonds are uppermost Cretaceous (Campanian-Maestrichtian) suites from borderland basins on the Salinian block (Fig. 3). Other open symbols are Great Valley sequence suites from adjoining Obispo belt, whereas solid symbols are Great Valley sequence suites from Diablo Range east of San Andreas fault; circles are Upper Jurassic to Lower Cretaceous suites, triangles are pre-Campanian Upper Cretaceous suites, and squares are uppermost Cretaceous (Campanian-Maestrichtian) suites. Asterisks are uppermost Cretaceous (Campanian-Maestrichtian) slope-basin suites from the Franciscan assemblage of the Obispo belt (Fig. 3). Older Jurassic-Cretaceous suites from the Franciscan Complex include examples from the Diablo Range (crosses) east of the San Andreas fault, and from the Obispo belt (X's) west of the Nacimiento fault. Data from compilations by Lee-Wong and Howell (1977), Jacobson (1978), and Dickinson et al (1982).

confined to some medial part of Late Cretaceous time.

Comparison of Terranes

The Mesozoic terranes of the Diablo Range and the Obispo belt are more similar to one another than to any other Mesozoic terranes now known from the Cordilleran region. This remarkable similarity is compatible with tectonic reconstructions involving restoration of major sinistral displacements along the Nacimiento fault, as noted in the previous section. Clear-cut differences between the two terranes exist only for latest Cretaceous strata that were deposited after the time of postulated sinistral movements along the Nacimiento fault. Similarities in the Franciscan assemblage, Coast Range ophiolite, and Great Valley sequence of the two areas are reviewed briefly here (Fig. 4).

Except for latest Cretaceous, hence post-Nacimiento, slope-basin deposits along the coast, the Franciscan terranes of the southern Diablo Range and the northern Obispo belt (Fig. 3) are virtually indistinguishable. Both include especially well-developed melange belts with megablocks of graywacke, chert, greenstone, and blueschist set in a matrix of pervasively dislocated argillite and graywacke (Dickinson, 1966; Hsu, 1968). Metamorphic mineral parageneses and zonations are essentially the same (Ernst, 1965, 1980). Detrital modes of Franciscan graywackes from the two terranes are closely comparable (Fig. 5). In both areas, the Franciscan rocks are overlain structurally along the Coast Range thrust by the Coast Range ophiolite, which yields essentially the same age range of radiometric dates from both areas (Hopson et al, 1981).

The Great Valley sequence, which lies depositionally upon the Coast Range ophiolite or structurally upon the underthrust Franciscan assemblage, displays both petrologic and stratigraphic congruence between the two belts. Stratigraphic variations in mean sandstone composition define essentially the same overall trend for both areas (Fig. 5). Moreover, the plots of detrital modes of rocks from different stratigraphic zones within the two areas show that coeval Great Valley sandstones have approximately the same compositions in the two belts.

Also striking is the probable existence of a mid-Lower Cretaceous hiatus or period of apparently slow deposition in the Great Valley sequence of both areas. It has long been known that dated post-Valanginian, pre-Albian strata are absent from the Great Valley sequence of the Diablo Range (Bailey et al, 1964). The same interval is evidently quite thin in the Obispo belt (Hall and Corbato, 1967; Gilbert and Dickinson, 1970; MacKinnon, 1978). By contrast, Great Valley strata occupying the same stratigraphic interval north of San Francisco Bay in the northern Coast Ranges aggregate to a thickness of perhaps 4,000 m (13,000 ft) (Dickinson and Rich, 1972).

Uppermost Cretaceous Strata

Uppermost Cretaceous (Campanian-Maestrichtian) sandstones in the Diablo Range, Salinian block, and Obispo belt all display similar detrital modes (Fig. 5). They represent a regional petrofacies of arkosic sandstones whose appearance in the column recorded final unroofing of the large Cretaceous plutons in the batholith belt. Younger Paleogene sandstones in the region have generally similar compositions.

The uppermost Cretaceous strata of the Salinian block lie unconformably on the granitic and metamorphic basement rocks. No older Mesozoic strata are present. The Salinian Cretaceous sequence was deposited in a region of complex bathymetry having the character of a faulted borderland (Howell et al, 1977; Howell and Vedder, 1978). It is inferred here that the borderland had been created by Cretaceous slip on the Nacimiento fault. No such irregular bathymetry is suggested by stratigraphic relations within the main Great Valley basin that now lies to the east of the Salinian block (Ingersoll, 1978a, c, 1979). Within the borderland basins, a complex facies suite accumulated. Nonmarine fluvial sediments, shelf deposits, and turbidite successions are all represented.

Uppermost Cretaceous strata of the Great Valley sequence in the Obispo belt are mainly turbidites, but are markedly sandier than underlying parts of the Great Valley sequence. The basal contact is rarely exposed and incompletely studied, but has been described tentatively as an unconformity, a paraconformity, and an abrupt lithologic transition in different places (Hall and Corbato, 1967; Gilbert and Dickinson, 1970; MacKinnon, 1978). It is inferred here that the flood of arkosic sand carried into the Obispo belt near the end of the Cretaceous was triggered by tectonic emplacement of the adjacent Salinian block along the Nacimiento fault. Stratigraphic relationships between the resulting sand-rich arkosic sequence and underlying strata may well be varied, because of different degrees of deformation within the offshore borderland during the faulting. Local thrust contacts between the uppermost Cretaceous strata and older parts of the Great Valley sequence in the Obispo belt imply that subduction continued or was resumed after deposition of the younger strata (Page, 1970a).

Uppermost Cretaceous strata of the Franciscan assemblage in the Obispo belt have no known counterparts in the Diablo Range. They are interpreted to be slope-basin turbidites (Fig. 3), rather than trench-fill or open-ocean turbidites (Howell et al, 1977; Underwood, 1977; Smith et al, 1979). They are markedly less deformed than other parts of the local Franciscan terrane, and form nearly intact slabs within the subduction complex. These slabs are thought to lie depositionally upon a Franciscan substratum, although the basal contacts are everywhere tectonically disturbed. It is here inferred that the Franciscan slope-basin deposits are so distinct from the older Franciscan-rocks because the mid-Cretaceous to Late Cretaceous episode of sinistral slip along the Nacimiento fault caused major changes in the configuration of the subduction complex. Deposition of locally exposed Upper Cretaceous sedimentary breccias composed of melange debris (Cowan and Page, 1975) may have been triggered by the fault movements. Continuation or resumption of subduction later faulted the slope-basin deposits into the underlying subduction complex.

The borderland basins along the flank of the Salinian block and the slope basins farther west are thus interpreted here as the products of Cretaceous sinistral slip along the Nacimiento fault. Both seem to be unique lithotectonic elements in coastal California. If the hypothesis is correct, however, related fault-generated latest Cretaceous basins may also have developed elsewhere along the Nacimiento fault. This would have been in the northern end of the Peninsular Ranges near their juncture with the Transverse Ranges at the southern end of the Salinian block (Fig. 2). Subduction that continued during Nacimiento slip, or resumed later, allowed the offshore development of Cenozoic parts of the Franciscan subduction complex along a continental margin modified by the Nacimiento displacements.

SALINIAN BLOCK GEOMETRY

The present Salinian block is an elongate terrane that extends for about 650 km (404 mi) from just north of Point Arena southward to the Transverse Ranges, yet is only 35 to 65 km (22 to 40 mi) wide (Fig. 1). Neogene dextral movements on subsidiary strands of the San Andreas transform system enhanced the elongation of the Salinian block by shuffling slivers of the terrane in a consistent sense. The most significant effect was produced by slip along the San Gregorio–Hosgri fault zone, which offsets the Nacimiento fault (Graham, 1978). The nature of the continuation of the San Gregorio–Hosgri fault zone into the Transverse Ranges has remained in doubt. Clarification of this point is required here to allow correct restoration of the Salinian block and the Nacimiento fault to their pre-Neogene configurations in relation to other tectonic elements of coastal California.

San Gregorio–Hosgri Fault

The San Gregorio–Hosgri fault zone (Fig. 6) consists of several segments whose linkage to form a single unified fault trend was not established until recently (Silver, 1978). Most of the fault zone lies offshore, and each of the segments on land was originally given a separate name. Prior to the advent of marine surveys, the continuity of the fault could not be documented.

Graham and Dickinson (1978a, b) showed that the San Gregorio fault of the San Francisco Peninsula extends (a)

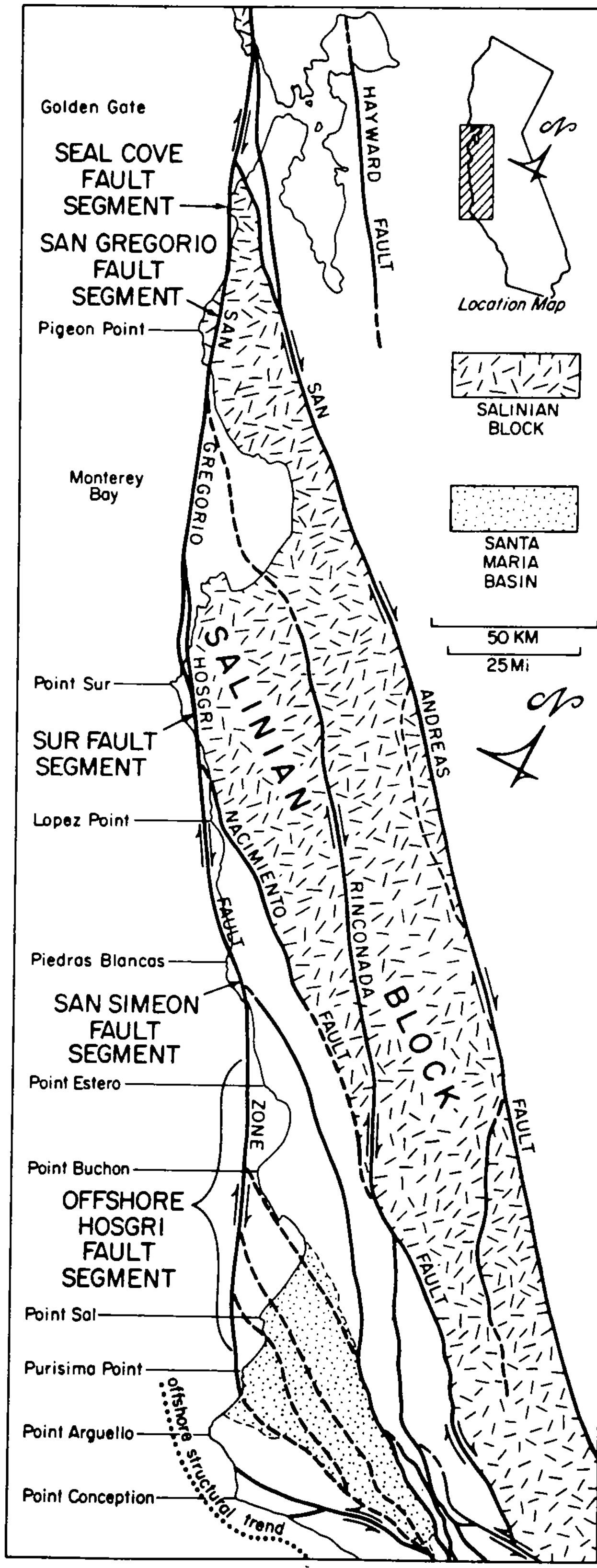

FIG. 6—Tectonic relations of San Gregorio-Hosgri fault zone along central California coast. Salinian block (patterned) is terrane underlain by granitic and metamorphic rocks; flanking terranes are underlain by Franciscan subduction complex. Fault pattern in vicinity of Santa Maria basin (stippled) modified after Hall (1981). Offshore geology west of San Gregorio-Hosgri fault zone not shown.

northward to join the San Andreas fault just beyond the Golden Gate, and (b) southward across the mouth of Monterey Bay (Greene et al, 1973) to appear onshore at intervals as the Sur fault and then the San Simeon fault. Farther south, the connection between the San Simeon fault and the offshore Hosgri fault was first proposed by Hall (1975), and later confirmed by Leslie (1981).

Using apparent offsets of varied geologic features across the San Gregorio-Hosgri fault in central California, Graham and Dickinson (1978a, b) estimated a net dextral displacement of about 115 km (71 mi) along the fault trace. Based on more refined measurements, this best estimate is here revised downward to 110 km (68 mi). For the southernmost or Hosgri segment of the fault, Hall (1981) reported a best estimate of only 95 km (59 mi) of dextral slip. However, the apparent offset of strikingly similar mid-Tertiary nonmarine deposits from Piedras Blancas to Point Sal (Anderson, 1980) is compatible with the higher figure of 110 km (68 mi) used here (Fig. 6). Restoration of that amount of San Gregorio-Hosgri dextral slip would align the onshore and offshore segments of the Nacimiento fault (Fig. 1), and reduce the pre-Neogene length of the Salinian block by 110 km (68 mi). Recent dredge hauls of serpentinite and altered basalt of Franciscan type from a submarine canyon that incises the continental shelf northwest of Monterey Bay seemingly provide direct confirmation of the offset of the Nacimiento fault contact by the San Gregorio-Hosgri fault (Mullins and Nagel, 1981). An independent estimate (Nagel and Mullins, 1983) of the amount of offset implied by the offshore data is about 105 km (65 mi).

The distribution of San Gregorio-Hosgri fault movements through Neogene time is still not well constrained (Hall, 1981). The ages of stratigraphic sequences correlated across the fault as presumed offset pairs imply that the inception of dextral slip was no earlier than middle Miocene time, and that faulting probably began during the late Miocene (Hall, 1975; Graham and Dickinson, 1978a, b). There is little direct evidence on the partitioning of motion between Miocene and Pliocene times. Offsets of Pleistocene and Holocene surfaces and sediments by local fault traces associated with both onshore and offshore segments of the fault show that some activity has continued to the present (Hall, 1975; Coppersmith and Griggs, 1978; Leslie, 1981).

Regional considerations suggest that much of the movement along the San Gregorio-Hosgri fault occurred during the Miocene prior to the opening of the modern Gulf of California beginning about 5 m.y.B.P. (Graham, 1978). Since then, the San Andreas fault proper has been the main strand of the regional San Andreas transform. Hence, only subordinate movements can be inferred along subsidiary faults since the end of the Miocene. Prior to that time, however, appreciable transform motion calculated from global plate reconstructions was apparently taken up along fault strands lying seaward of the present San Andreas fault. The San Gregorio-Hosgri fault zone is an attractive locus for a significant fraction of that older dextral slip.

About 45 km (28 mi) of Neogene dextral slip is also inferred by Graham (1978) for the Rinconada fault (Dibblee, 1976), which apparently intersects and modifies the

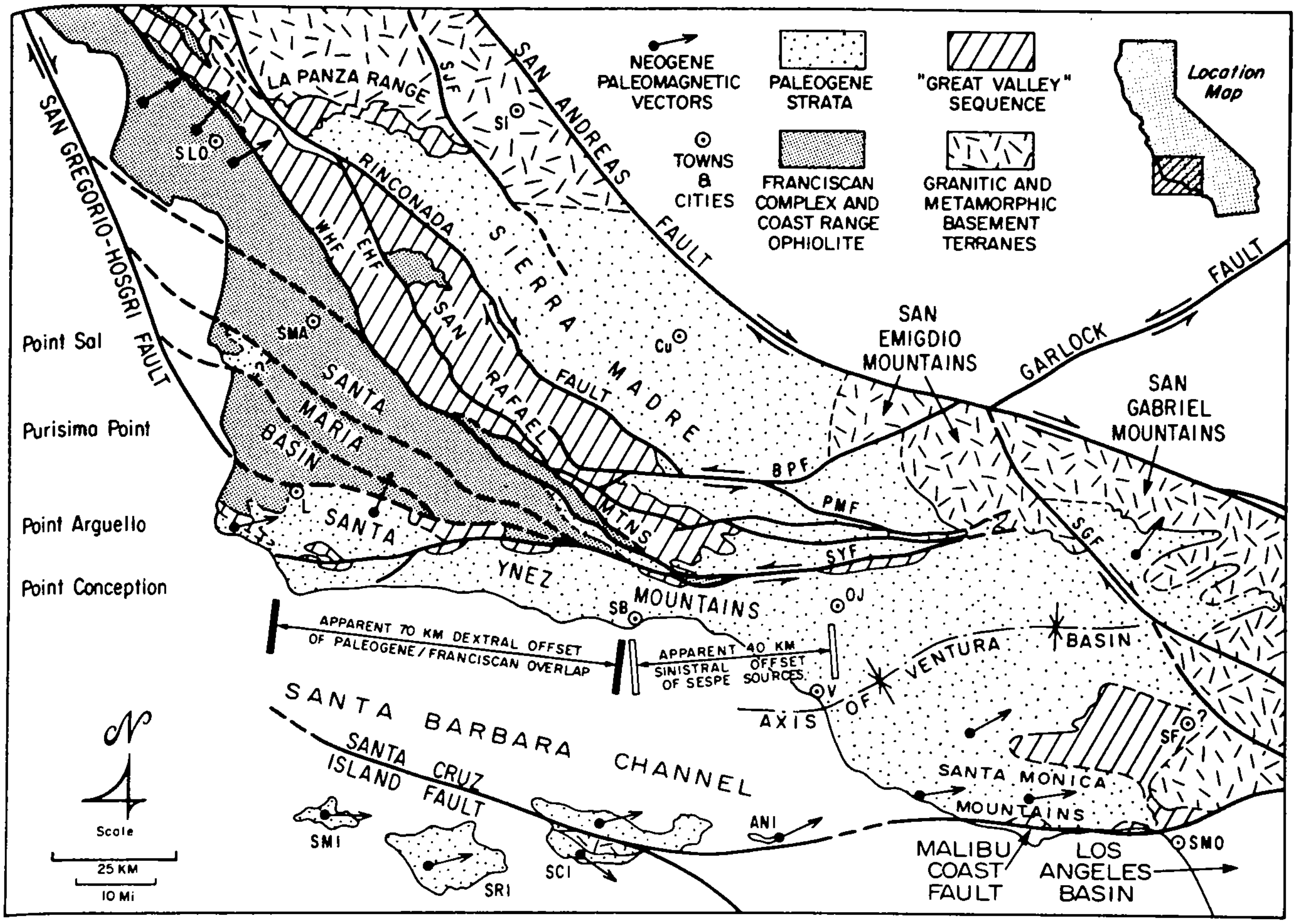

FIG. 7—Combined outcrop and sub-Neogene subcrop map of western Transverse Ranges showing distribution and tectonic relations of pre-Neogene rock units, and pattern of major faults known or suspected to have undergone strike slip, either dextral or sinistral. Dashed traces of inferred faults within and flanking Santa Maria basin adapted after Hall (1981) and Sylvester and Darrow (1979). Paleomagnetic vectors denote observed declination of tectonically rotated remanent magnetization in overlying Neogene volcanics corrected for local fold tilts after Greenhaus and Cox (1979), Kamerling and Luyendyk (1979), and Luyendyk et al (1980). Paleogene strata include Oligocene red beds. "Great Valley" sequence includes Upper Jurassic and Cretaceous sedimentary strata lying either concordantly on the Coast Range ophiolite or unconformably on the "basement" terrane. Rocks of the Franciscan complex and the structurally overlying Coast Range ophiolite are not differentiated because lithologic similarity makes distinctions unreliable in isolated outcrops and subsurface occurrences. "Basement" terrane includes granitic and metamorphic rocks of the Salinian block and the Transverse Ranges. Apparent offsets are discussed in text. Fault abbreviations: BPF, Big Pine; EHF, East Huasna; PMF, Pine Mountain; SGF, San Gabriel; SJF, San Juan–Chimeneas; SYF, Santa Ynez; WHF, West Huasna. Islands abbreviations: ANI, Anacapa; SCI, Santa Cruz; SMI, San Miguel; SRI, Santa Rosa. Key cities and towns: Cu, Cuyama; L, Lompoc; OJ, Ojai; Si, Simmler; SB, Santa Barbara; SF, San Fernando; SLO, San Luis Obispo; SMA, Santa Maria; SMO, Santa Monica; V, Ventura.

older Nacimiento fault on land (Figs. 1, 2, 6). Much, if not all, of the Rinconada displacement was absorbed northward by splay faults and related structures within the Salinian block (Graham, 1978). Southward, the Rinconada trend evidently merges with and follows the basement discontinuity represented by the Nacimiento fault along the western side of the Salinian block. Additional early transform movements may have occurred along or near the continental slope (Atwater, 1970), but any movements that took place there would not have affected the internal geometry of the Salinian block.

Western Transverse Ranges

The location of the southern extension of the San Gregorio–Hosgri fault in the region of the Transverse Ranges (Fig. 7) has been problematical. Marine surveys completed to date do not allow the offshore trace to be mapped with confidence beyond the vicinity of Purisima Point (Payne et al, 1978). Speculation that the fault might continue southward offshore is precluded by observations that curving structural trends detected by marine surveys (Yerkes et al, 1981) arc smoothly, without offset or disruption, around the projection of land that terminates in Point Arguello and Point Conception (Fig. 6).

Branching splays of the San Gregorio–Hosgri fault evidently pass inland (Figs. 6, 7) into the Santa Maria basin (Hall, 1981). Major strike slip on subparallel fault strands within the Santa Maria basin was first suggested by Redwine (1963) on the basis of marked stratigraphic contrasts across buried faults in the subsurface. Because much of the fundamental structure in the area is concealed beneath young basin fill, the underlying fault pattern is depicted variously in detail by different workers. However, none of the faults cross the Santa Ynez Mountains south of the basin (Fig. 7).

Interpretation of the complex fault pattern farther east in the western Transverse Ranges has long been uncertain. In rugged interior mountains, details of the fault geometry are still unclear, but the dominant trends are well established. A tortuous knot of intersecting fault traces is formed by the interference of two sets of strike-slip faults with northwesterly and east-west trends (Fig. 7). Dip-slip thrust and reverse faults are also common.

Faults with northwesterly trends lie subparallel to the San Andreas fault and strike into the western Transverse Ranges from the Coast Ranges to the northwest. These faults can be regarded as subordinate or abandoned strands of the San Andreas transform system. However, the amount of horizontal displacement along subsidiary strands such as the East and West Huasna faults (Fig. 7) is not well controlled. Moreover, these and other faults of the northwesterly trending set have probably undergone some vertical motions as well.

Faults with east-west trends lie subparallel to the sinistral Garlock fault and are among the structures that define the anomalous trend of the Transverse Ranges at an angle to the dominant structural grain of California. Other local structures having east-west trends include major fold axes and several related thrust faults that are dominantly south-vergent. The best known fault of the east-west set is the Big Pine fault (Hill and Dibblee, 1953), along which about 16 km (10 mi) of net sinistral displacement is documented by several offset geologic features. Among the offset features is the Rinconada fault, whose offset continuation is the Pine Mountain fault (Vedder and Brown, 1968). Prominent wrench folds beside the Santa Ynez fault indicate that it is also sinistral (Dibblee, 1950, 1966), but the amount of displacement is still in dispute. At the southern edge of the Transverse Ranges, the Santa Cruz Island fault in the Channel Islands and the Malibu Coast fault form a trend whose connection is speculative (Fig. 7). Onshore along the base of the Santa Monica Mountains, about 60 km (37 mi) of net sinistral slip is inferred (Sage, 1973; Truex, 1976).

Dickinson (1979) inferred that the branching splays of the San Gregorio–Hosgri fault zone turning into the Santa Maria basin (Figs. 6, 7) represent curvature of a through-going dextral fault trend. In concept, such bending of the San Gregorio – Hosgri fault, a subsidiary strand of the San Andreas transform, was envisioned as analogous to the so-called "big bend" of the master San Andreas fault near its juncture with the Garlock fault (Fig. 7). The bent San Gregorio–Hosgri fault was thus seen as (a) merging locally with the east-west structural grain of the Transverse Ranges, (b) being overprinted by sinistral faults and complex folds of the Transverse Ranges, and (c) emerging somehow to the south of the Transverse Ranges in the vicinity of the Los Angeles basin (Fig. 7). This point of view was supported erroneously on the basis of inferred displacements of Paleogene depositional systems, whose apparent offsets in the western Transverse Ranges are actually contradictory in a way that negates the argument.

Paleogene Depositional Systems

Paleogene strata of the western Transverse Ranges occupy two main belts that merge to the east (Fig. 7): (a) a northern belt trends northwesterly as exposures on the northeast side of the Rinconada fault, and extends in the subsurface to the northeast as far as the San Andreas fault (Chipping, 1972); (b) a southern belt trends east-west as exposures along the south side of the Santa Ynez fault, and extends in the subsurface to the south beneath the Santa Barbara Channel and the Ventura basin (Stauffer, 1967; Van de Kamp et al, 1974; Link, 1975). The Paleogene sequences in both belts are dominantly clastic successions that are locally more than 5 km (16,360 ft) thick. Intertonguing facies represent varied environments associated with nonmarine fluvial, deltaic or coastal, shelf, and turbidite depositional systems. Major formational units can be traced from one belt to the other around the plunging anticlinorial nose at the southeast end of the San Rafael Mountains (Page et al, 1951; Vedder, 1972; Vedder et al, 1973; Givens, 1974).

In parts of the western Transverse Ranges, the Paleogene succession lies concordantly on uppermost Cretaceous strata (Fig. 7) of the Great Valley sequence or related units. This substratum represents a southern continuation of the borderland-basin deposits that developed within the fore-arc region during latest Cretaceous time along the flank of the Salinian block and within the adjacent Obispo belt. Deposition of the Paleogene sequence thus buried the contact between these two terranes along the Nacimiento fault, whose exact location in the subsurface can only be inferred.

To the northeast, Paleogene strata onlap granitic and metamorphic basement rocks at the southern end of the Salinian block, and with the latter are truncated at the San Andreas fault. The dominant paleocurrent trends to the south and west imply that sediment sources for the dominantly arkosic sandstones lay mainly within the basement terrane, partly beyond the site of the present San Andreas fault. To the southeast, the substratum beneath Paleogene and Cretaceous strata in the Santa Monica Mountains is the offset northern end of the Peninsular Ranges (Truex, 1976).

Westward, Paleogene strata overlap the underlying Cretaceous section with marked angular unconformity to lie unconformably upon the Franciscan subduction complex of the Obispo belt in the San Rafael Mountains (Plate 3 of Dibblee, 1966). The basal beds are banklike carbonate deposits of the Sierra Blanca Limestone, which probably accumulated atop a submerged offshore sill. By Oligocene time, however, parts of the Franciscan terrane were strongly emergent, and derivative detritus is widespread in fluvial conglomerates of the Sespe and Lospe Formations near the top of the Paleogene succession (McCracken, 1972; Anderson, 1980).

Along the south side of the Santa Maria basin, there is an apparent dextral offset of the overlap of basal Paleogene strata upon the Franciscan by about 70 km (43 mi; Fig. 7). This apparent offset seemingly could be attributed to dextral displacement along a bent southern continuation of the San Gregorio–Hosgri fault through the Transverse

Ranges. The reduced amount of apparent offset, from 110 to 70 km (68 to 43 mi) for the San Gregorio–Hosgri fault, might be attributed to the overprint of later sinistral slip along the Santa Ynez fault.

Farther east, there is an apparent sinistral offset of sources of Sespe clasts by the required 40 km (25 mi; McCracken, 1972). Sespe conglomerates with paleocurrent indicators of southerly flow contain prominent Franciscan detritus as far east as Ojai. However, the nearest Franciscan sources that are not covered by pre-Sespe strata, and thus could have been exposed north of Ojai during Sespe deposition, now lie in the region north of Santa Barbara on the other side of the Santa Ynez fault (Fig. 7).

Nevertheless, summation of the 70 km (43 mi) of apparent dextral offset and 40 km (25 mi) of presumably younger sinistral offset to achieve the nominal 110 km (68 mi) of displacement along the San Gregorio–Hosgri fault is a spurious solution to the problem of the western Transverse Ranges. Restoration of a direct pre-Neogene connection of the Paleogene overlap relationships in the western Santa Ynez Mountains and the San Rafael Mountains would require sliding the Santa Ynez Mountains relatively eastward. However, this reconstruction would also carry the Sespe conglomerates bearing Franciscan clasts far eastward to some initial location south of the San Gabriel Mountains. In that position, no Franciscan sources would be present on the north. Moreover, the operation would also separate by far too much ground the closely comparable Paleogene sandstone units that lie on opposite sides of the Santa Ynez fault near Santa Barbara (Link, 1975).

Paleomagnetic Rotation Indicators

A satisfactory solution to the paradox of the western Transverse Ranges was proposed by Luyendyk et al (1980), based upon paleomagnetic evidence for crustal rotations (Kamerling and Luyendyk, 1979). Remanent paleomagnetic vectors determined from latest Oligocene to middle Miocene volcanics in the region show variable amounts of clockwise rotation from the expected pole (Fig. 7). In extreme cases, the indicated north pole lies nearly due east. Their model suggests that the sinistral faults of the western Transverse Ranges bound east-west crustal panels that were initially oriented nearly north-south. During middle to late Miocene time, these panels are envisioned as rotating clockwise into their present positions about a pivot lying off to the east. Sinistral slip on the faults that now lie east-west would occur as the crustal panels rotated into place. Meanwhile, dextral slip would occur along the San Gregorio–Hosgri fault and subparallel faults lying east of it in order to accommodate the swing of the rotating panels. The cumulative displacement of all the various fault-bounded panels thus rotating or sliding within the deforming region would increase away from the interior of the continental block. The rotation of sites within the San Gabriel Mountains and near San Luis Obispo (Fig. 7) can be attributed to similar behavior of closely spaced faults not shown here for reasons of scale.

This ingenious view of the nature of crustal displacements within a transform zone of finite width accounts for several otherwise puzzling features: (a) the southward termination of the various splays of the San Gregorio–Hosgri and Huasna faults, whose displacements are not required to extend past the north edge of the region of rotating panels; (b) the apparent failure of the Santa Ynez and Pine Mountain faults to continue into the basement toward the pivot, where little or no displacement would be required; and (c) the presence of northerly and northwesterly paleocurrent trends in Paleogene strata of the Channel Islands and the Santa Monica Mountains (Yeats et al, 1974). In their present orientation, these anomalous paleocurrent trends imply an unlikely source within the California continental borderland (Fig. 2), but prior to rotation would indicate a source within the Peninsular Ranges (Crouch, 1979). Finally, the intra-panel deformation required near the pivot region of the rotating panels may explain the occurrence of tightly appressed east-plunging folds in Cretaceous and Paleogene strata between the Santa Ynez and Big Pine faults (Fig. 7).

The attractive Luyendyk et al (1980) model for a semicontinuum of internal deformation within the western Transverse Ranges affords the missing key needed to reconstruct the former course of the four main Mesozoic lithotectonic belts from central California south into Baja California. In effect, the torsional shear indicated by the rotation of crustal panels within the edge of the continental block represented an early stage in the evolution of the San Andreas transform prior to the breakthrough of the master San Andreas fault into the head of the present Gulf of California. Terres and Sylvester (1981) have shown that the Luyendyk et al regional model is kinematically plausible by analogy with the observed rotation of slabs of soil broken into geometrically similar panels by incipient surface rupture along an active fault trace during a modern earthquake in the Imperial Valley of California.

SAN ANDREAS RESTORATION

Before the tectonic effects of Cretaceous sinistral slip on the Nacimiento fault can be discerned, the Cenozoic slip on faults of the San Andreas system must be reversed. Figure 8 is a mid-Tertiary reconstruction of the Mesozoic lithotectonic belts prior to Neogene displacements associated with evolution of the San Andreas transform between the Pacific and American plates. The reconstruction was derived from Figure 2 by performing the following operations.

Subsidiary Faults

East of the San Andreas fault, the Garlock fault was reversed to restore 60 km (37 mi) of sinistral slip (Davis and Burchfiel, 1973). Most of this net displacement on the Garlock fault is inferred to have occurred during the Neogene because it is thought to have been associated with Neogene extension in that part of the Basin and Range province lying north of the Garlock fault (Wright, 1976). Simultaneously, the western edge of the Mojave block was allowed to deform in the manner described by Garfunkel (1974) to straighten the San Andreas fault by eliminating the "big bend" (Bohannon and Howell, 1982). The reconstruction also accommodates 16 km (10 mi) of sinistral displacement (Crowell and Ramirez, 1979) on the Pinto

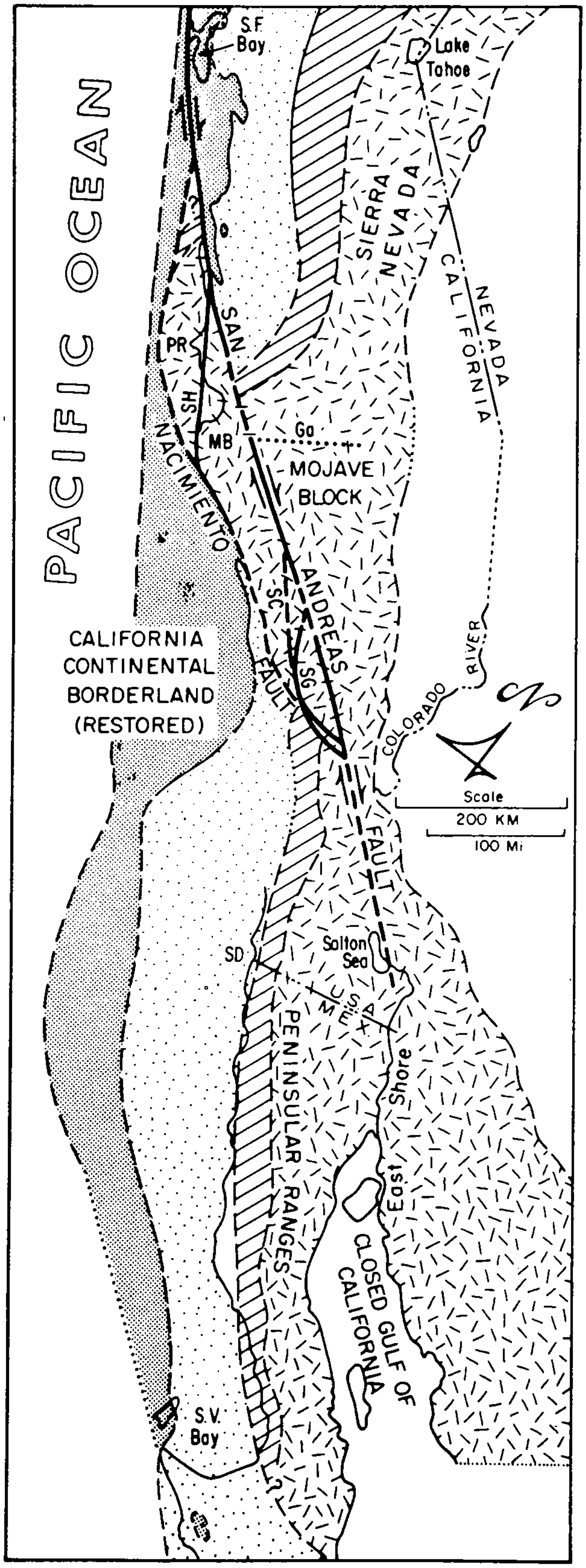

FIG. 8—Early Tertiary regional distribution of principal Mesozoic lithotectonic belts in California and Baja California. Neogene slip on fault strands of San Andreas system and on Garlock fault restored as discussed in text. See Figure 2 for symbols and abbreviations.

Mountain fault (Fig. 2). However, lesser suggested displacements of 5 and 10 km (3 and 6 mi) on the Blue Cut and Chiriaco faults farther south (Crowell and Ramirez, 1979) were not required to straighten the San Andreas fault, but perhaps only because of the scale adopted for plotting.

West of the San Andreas fault, the San Gregorio–Hosgri fault was reversed to restore 110 km (68 mi) of dextral offset of the northwest end of the Salinian block. Simultaneously, a block including the Santa Ynez Mountains, Santa Monica Mountains, and Channel Islands of the western Transverse Ranges was rotated about a pivot at its eastern end from its present east-west position to a north-south position. The bulge in the contact between the Franciscan and Great Valley belts in the continental borderland as thus restored here would be further reduced if the rotation of those terranes were somewhat greater (Hornafius et al, 1981). The rotation applied swings the Santa Monica Mountains back against the flank of the Peninsular Ranges. This result was anticipated by Jones and Irwin (1975), and allows the Los Angeles Basin (Fig. 7) to be viewed as a Neogene basin of pull-apart origin (Campbell and Yerkes, 1976; Turcotte and McAddo, 1979).

To make room offshore for the rotation of the Transverse Ranges terranes, major dextral slip of about 225 km (140 mi) was restored on the fault in the central part of the California continental borderland (Fig. 2) to close the oceanic southern part of the borderland in the general manner suggested by Crouch (1979, 1981). This restoration accounts for the displacement of Paleogene strata containing so-called Poway clasts (Abbott and Smith, 1978) from the San Diego area to the Channel Islands (Howell and Link, 1979). The existence of such a fault was postulated by Howell et al (1974).

In the reconstruction (Fig. 8), Franciscan rocks now exposed in the vicinity of Santa Catalina Island (Fig. 2) are not shown. This omission was made on the premise that this part of the Franciscan terrane was concealed beneath the overthrust Great Valley belt until exposed by Neogene uplift and erosion. A local Franciscan source for detrital sediment first became prominent in medial Miocene time during deposition of the San Onofre Breccia and related deposits adjacent to the Newport-Inglewood fault trend (Fig. 2) and other Neogene faults in the borderland (Stuart, 1979a, b).

Also west of the San Andreas fault in southern California, the following amounts of Neogene dextral slip were reversed on faults subparallel to the San Andreas in the Peninsular Ranges (Fig. 2): San Jacinto fault, 24 km (15 mi) (Sharp, 1967, 1975) and Elsinore fault, 40 km (25 mi) (Sage, 1973). Farther north, Neogene dextral displacements of 14 km (9 mi) on the San Juan–Chimeneas fault (Bartow, 1978) and 65 km (40 mi) on the San Gabriel fault (Bohannon, 1975; Crowell, 1975) can be regarded as branching components of the net slip on the San Andreas fault (Figs. 2, 8).

San Andreas Fault

In central California, about 310 km (192 mi) of total Neogene displacement on the San Andreas fault is given by the offset of the Pinacles Volcanics on the east edge of the Salinian block from the correlative Neenach Volcanics on the west edge of the Mojave block (Matthews, 1976). The volcanics are part of the same disrupted local volcanic field erupted near the Oligocene-Miocene time boundary. Reversal of 310 km (192 mi) of Neogene slip on the San Andreas fault (Fig. 8) also brings the correlative Butano and Point of Rocks Formations of Paleogene age and an earliest Miocene shoreline assemblage into approximate juxtaposition (Clarke and Nilsen, 1973).

In southern California, total Neogene displacement of 310 km (192 mi) was partitioned into about 65 km (40 mi) on the San Gabriel fault and 245 km (152 mi) on the San Andreas fault proper (Crowell, 1975; Ehlig et al, 1975). Restoration of these amounts of combined slip (Fig. 8) brings three presently isolated belts of Pelona–Orocopia Schist into alignment. The three occurrences now lie in the San Emigdio Mountains at the south end of the Salinian block (Fig. 7), in the central San Gabriel Mountains between the San Gabriel and San Andreas faults, and in the Orocopia Mountains east of the Salton Sea. The restoration also places marine Paleogene strata of the Maniobra Formation (Crowell and Suzuki, 1959), now exposed east of the Salton Sea, into a position adjacent to the truncated edge of the Paleogene basin in the western Transverse Ranges (Chipping, 1972).

Movement on the modern San Andreas fault is coupled to plate separation in the Gulf of California. As the width of young oceanic crust in the mouth of the gulf is roughly 245 km (152 mi), that amount of net San Andreas slip evidently occurred in Pliocene and Quaternary times. Hence, the slip on the San Gabriel fault probably occurred earlier, during the Miocene. A comparable amount of intra-Miocene slip occurred along the San Andreas fault farther north in central California (Huffman, 1972), where wrench faulting within the Salinian block began in middle Miocene time (Graham, 1978). This early phase of San Andreas movement may have accompanied or immediately followed the rotation of fault-bounded crustal panels in the western Transverse Ranges.

PROTO–SAN ANDREAS FAULT

Reversal of known Neogene displacement within the San Andreas system leaves a residual mismatch of about 195 km (121 mi) between the northwestern end of the Salinian block and comparable terranes at the southern end of the Sierra Nevada block just north of the Garlock fault (Fig. 8). The short segment of the foothills lithotectonic belt shown beneath the offshore end of the Salinian block (Figs. 2, 8) is inferred from the occurrence of pre-Cretaceous metasedimentary rocks in the subsurface (Hoskins and Griffiths, 1971). The amount of the mismatch shown is probably a maximum value, for no shortening of the Salinian block was made in the reconstruction except for reversal of slip on the San Gregorio–Hosgri and San Juan–Chimeneas faults. However, the mismatch was unlikely to have been less than about 150 km (93 mi) (Dickinson et al, 1979). This minimum value is controlled by a residual apparent offset of 150 to 160 km (93 to 99 mi) between (a) outcrops of uppermost Cretaceous (Campanian-Maestrichtian) gabbro-bearing conglomerates exposed at Gualala near the northwestern end of the Salinian block (Wentworth, 1968), and (b) suitable gabbroic source rocks exposed at Eagle Rest Peak across the San Andreas fault near the southern end of the Sierra Nevada block (Ross, 1970).

The additional pre-Neogene slip implied by the mismatch is attributed here to dextral displacements along a proto–San Andreas fault after the terminology of Suppe (1970). Proto–San Andreas movement must have preceded the deposition of Eocene strata in the Butano and Point of Rocks formations which are offset along the San Andreas fault by the same amount as Neogene rocks (Nilsen, 1978). However, Paleogene strata in central California were deposited in local basins having complex bathymetry within a continental borderland (Nilsen and Clark, 1975). The configuration of this Paleogene borderland in central California may have been formed by deformation associated with the proto–San Andreas fault, just as the configuration of the modern continental borderland off southern California is related to deformation within the Neogene San Andreas system.

The most likely time window for proto–San Andreas motion is latest Cretaceous and/or earliest Tertiary time. The proto–San Andreas fault was probably an arc-parallel transform induced by oblique subduction during the shallow plate descent that triggered classic Laramide deformation at about the same time farther inland (Dickinson et al, 1979). The latest Cretaceous conglomerates and associated strata near Gualala may have been deposited in a linear trough that developed along the proto–San Andreas zone. Unconformities within the Paleocene section of the Salinian block may reflect the end of proto–San Andreas dislocations.

The course of the proto–San Andreas fault southward into southern California is unclear. Where the San Andreas and San Gabriel faults diverge near the present juncture with the Garlock fault (Fig. 2), the proto–San Andreas fault could not have followed either modern fault line. Reversal of Neogene displacements along the subparallel San Gabriel and San Andreas faults fully achieves alignment of key bodies of Pelona-Orocopia Schist and associated rock masses, hence precludes additional movements. Smith (1977) noted that the San Juan–Chimeneas fault farther west (Figs. 2, 8) has probably been the locus of significant dextral slip perhaps amounting to more than 175 km (109 mi). Ross (1972) reported that the greatest contrast in basement type observed within the Salinian block occurs across the San Juan–Chimeneas fault. In effect, that fault marks the present contact between basement types characteristic of the Salinian block and the Transverse Ranges, respectively.

Accordingly, restoration of proto–San Andreas displacement (Fig. 9) is achieved here by reversal of 195 km (121 mi) of dextral slip on the San Juan–Chimeneas fault, which merges to the north and south with the San Andreas fault (Figs. 8, 9). The inferred course of the proto–San Andreas fault southward into Sonora is speculative (Fig. 9).

NACIMIENTO SINISTRAL SLIP

Reversal of combined San Andreas and proto–San Andreas dextral slip thus reveals about 550 to 575 km (340

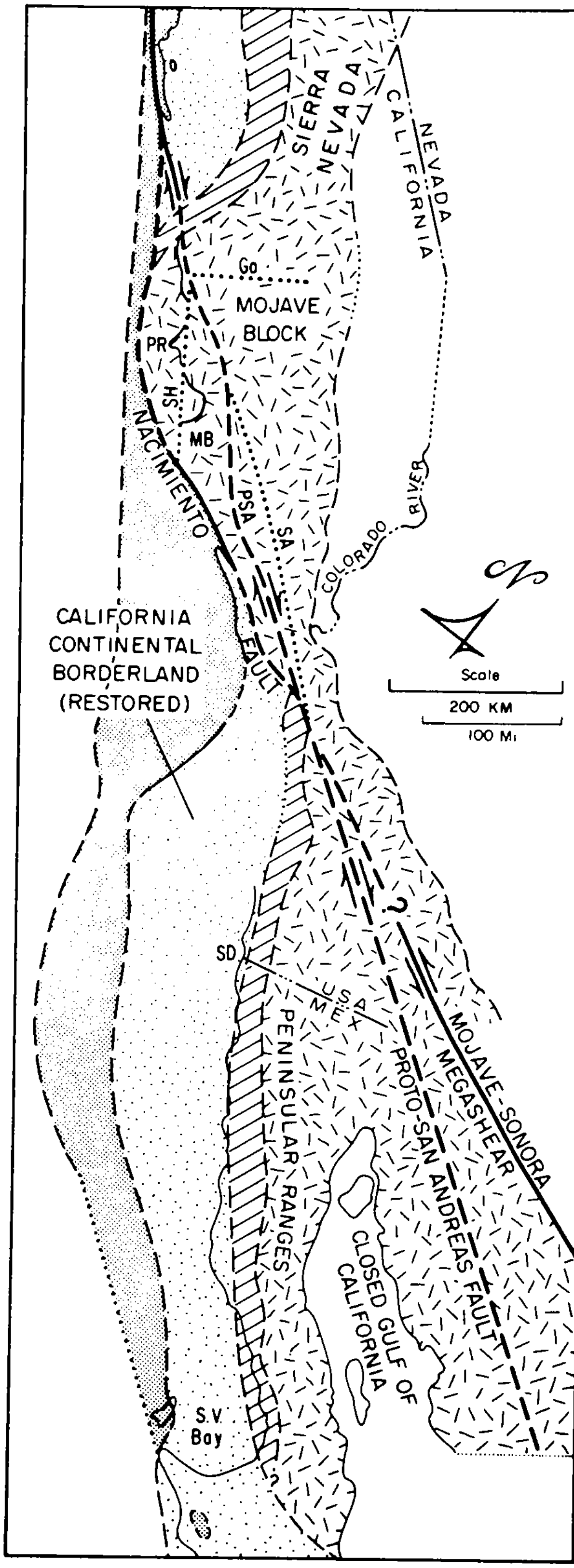

FIG. 9—Late Cretaceous regional distribution of principal Mesozoic lithotectonic belts in California and Baja California. Latest Cretaceous and/or Paleocene dextral strike slip on inferred proto-San Andreas fault restored as discussed in text. See Figure 2 for symbols and abbreviations, and Figure 8 for Paleogene configuration after proto-San Andreas displacement. Position of Mojave-Sonora megashear after Dickinson (1981b).

to 355 mi) of apparent sinistral offset of the four key Mesozoic lithotectonic belts in California and Baja California (Fig. 9). Reversal of 560 km (350 mi) of intra-Cretaceous sinistral slip along the Nacimiento fault brings the four lithotectonic belts into alignment to form a simple geometric pattern of tectonic elements (Fig. 10). This restoration can be tested by comparison of terranes presently exposed in central and southern California.

Strontium Isotopic Ratios

Figure 11 shows the Sierra Nevada, Mojave, Salinian, and Peninsular Ranges blocks juxtaposed in the configuration implied by the Cretaceous reconstruction (Fig. 10). Dextral slip was reversed on the following faults as discussed earlier: Elsinore, 40 km (25 mi); San Jacinto, 24 km (15 mi); San Gregorio-Hosgri, 110 km (68 mi); San Juan-Chimeneas, 195 km (121 mi); San Gabriel, 65 km (40 mi); San Andreas (and proto-San Andreas), 505 km (314 mi) north of the San Juan-Chimeneas junction, 245 km (152 mi) south of the San Gabriel junction, and 310 km (192 mi) between those two junctions. To preserve the present geometry of the Mojave block, internal deformation and dextral slip of 60 km (37 mi) on the adjacent Garlock fault were not restored. To do so would change slightly the orientation of the terranes west of the San Andreas fault, but would not affect their mutual relationships. About 560 km (c. 350 mi) of sinistral slip on the Nacimiento fault were also reversed to make the reconstruction.

The points plotted on Figure 11 represent initial ratios of radiogenic strontium for Mesozoic granitic rocks within the blocks involved. Such strontium isotopic ratios are widely held to reflect the fundamental nature of the underlying crust (Kistler and Peterman, 1978). In general, higher ratios reflect more continentality and lower ratios reflect more oceanic affinities. In their restored positions, the plotted points form a coherent array through which isoratio lines of simple geometry can be drawn. Values of the ratio increase monotonically from west to east with few reversals. The plot thus constitutes a satisfactory solution for the initial configuration of the complex mosaic of crustal blocks that are now dispersed widely along the continental margin. The cluster of anomalously low ratios near the Garlock fault lies within or near the region where allochthonous eugeosynclinal Paleozoic rocks are exposed in the El Paso Mountains (Dibblee, 1967). The reason for the anomalously high ratios in one area within the Sierra Nevada batholith is unknown, but does not affect analysis of the transported terranes.

Salinian Correlation Problems

Ross (1977, 1978) has discussed the difficulty of correlating specific terranes within the Salinian block with possible offset counterparts in the Mojave region despite the gross similarities that exist (Wiebe, 1970). One problem is the dissimilarity of granitic and metamorphic rocks just north of the Garlock fault at the southwestern extremity of the Sierra Nevada block to any part of the observed Salinian basement. In Cretaceous restorations (Figs. 9 to 11), however, these rocks lie adjacent to the presently sub-

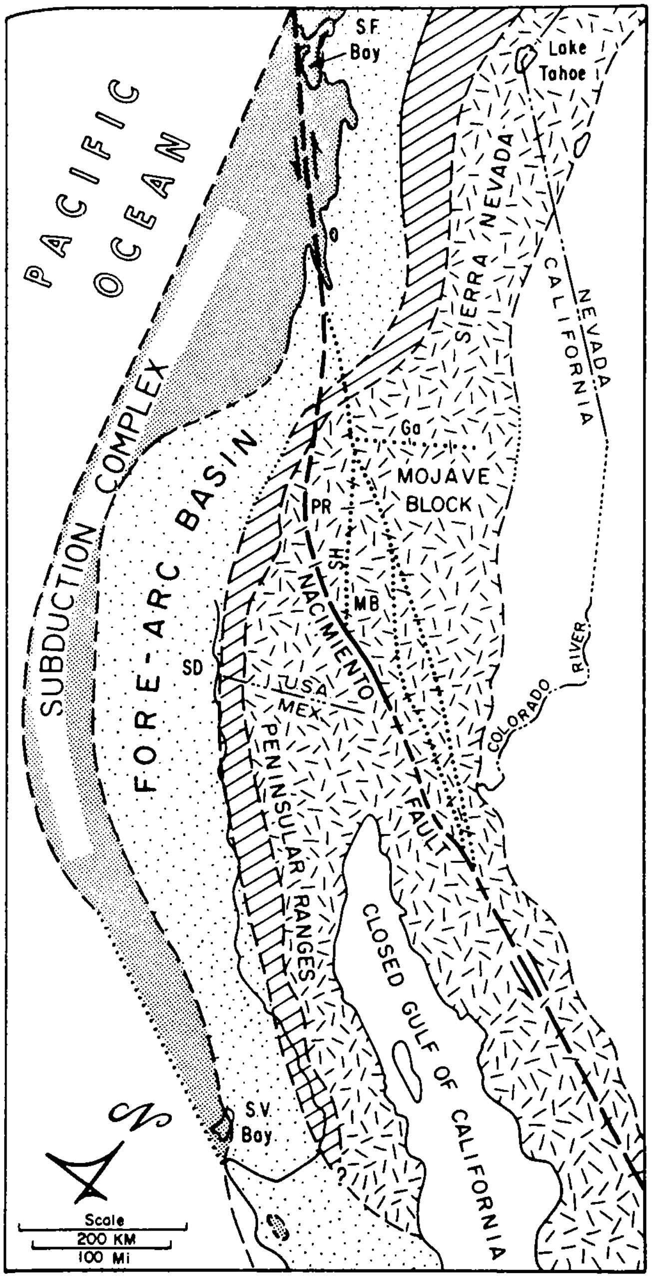

FIG. 10—Early Cretaceous regional distribution of principal Mesozoic lithotectonic belts in California and Baja California. Mid-Cretaceous to early Late Cretaceous, or medial Late Cretaceous, sinistral strike slip on Nacimiento fault restored as discussed in text. See Figure 2 for symbols and abbreviations, and Figure 9 for Late Cretaceous configuration after Nacimiento displacement.

merged northwestern tip of the Salinian block where the nature of the basement offshore is poorly known.

A second problem is the lack of clear-cut evidence for equivalents of the Cordilleran miogeoclinal belt within the Salinian block, even though metamorphosed representatives of those strata locally extend as far as the San Andreas fault in the southernmost Mojave block (Stewart and Poole, 1975). These rocks are exposed in the San Bernardino Mountains, which lie along the San Andreas fault just west of its junction with the Pinto Mountain fault (Fig. 11). However, the metamorphic rocks of the northwestern Mojave block, which lies adjacent to part of the Salinian block in the Cretaceous reconstructions (Figs. 9 to 11), are composed of little studied assemblages that are distinctly different from the rocks of the miogeoclinal belt (Miller, 1981). Moreover, Precambrian strata that form the lower part of the miogeoclinal succession in the San Bernardino Mountains are unlike familiar facies equivalents farther east, and may have offset counterparts in the Transverse Ranges and the Salinian block (Cameron, 1980). These stratigraphic complexities within the Mojave block suggest that failure to find typical miogeoclinal rocks within the Salinian block does not preclude the restorations of Figures 9 to 11.

Possible correlations between the southwest side of the Salinian block and the northeast flank of the Peninsular Ranges have not been considered previously. The metamorphic rocks appear generally comparable (Sharp, 1967), but no detailed correlations have been established. Most of the granitic rocks of the Peninsular Ranges were emplaced 90 to 120 m.y.B.P. (Silver et al, 1979), a time span that includes the most likely time of emplacement for many of the plutons now part of the Salinian block.

Mesozoic Plate Motions

Prior to episodes of dextral slip on the San Andreas and proto-San Andreas faults, the trend of the Nacimiento fault was roughly on line with the trend of the Mojave-Sonora megashear (Fig. 9), a Mesozoic sinistral fault in Mexico (Silver and Anderson, 1974). It is tempting to suppose that the Nacimiento fault was the northwestern end of the Mojave-Sonora megashear. However, the megashear was a transform related to the Jurassic opening of the Gulf of Mexico (Dickinson and Coney, 1980), which had formed before the end of Late Jurassic time (Dickinson, 1981b). By contrast, Nacimiento fault displacement presumably occurred in mid-Cretaceous or Late Cretaceous time, not earlier than latest Early Cretaceous (Aptian-Albian) or early Late Cretaceous time and not later than medial Late Cretaceous time (see previous discussion). Thus, the Nacimiento fault and the Mojave-Sonora megashear apparently could not have formed the same continuous slip surface.

Nevertheless, displacements on the Nacimiento fault and the Mojave-Sonora megashear were related in a kinematic sense (Fig. 12). It is conceivable that Nacimiento sinistral slip occurred because a transform plate boundary in Mesoamerica stepped westward after Yucatan rifted away from Texas to form the Gulf of Mexico. The tectonic history of central and southern Mexico is not yet known well enough to test such an hypothesis.

Current concepts of mid-Cretaceous plate motions in the Cordilleran region are tentatively compatible with the notion of mid-Cretaceous sinistral slip on the Nacimiento fault (Fig. 12). The absolute motion of the interior of the North American plate toward the Cordilleran arc-trench system was roughly parallel with the trend of the Nacimiento fault. The fault thus had a suitable orientation to be viewed as a tear along the flank of the overriding North American plate as that plate advanced against the sub-

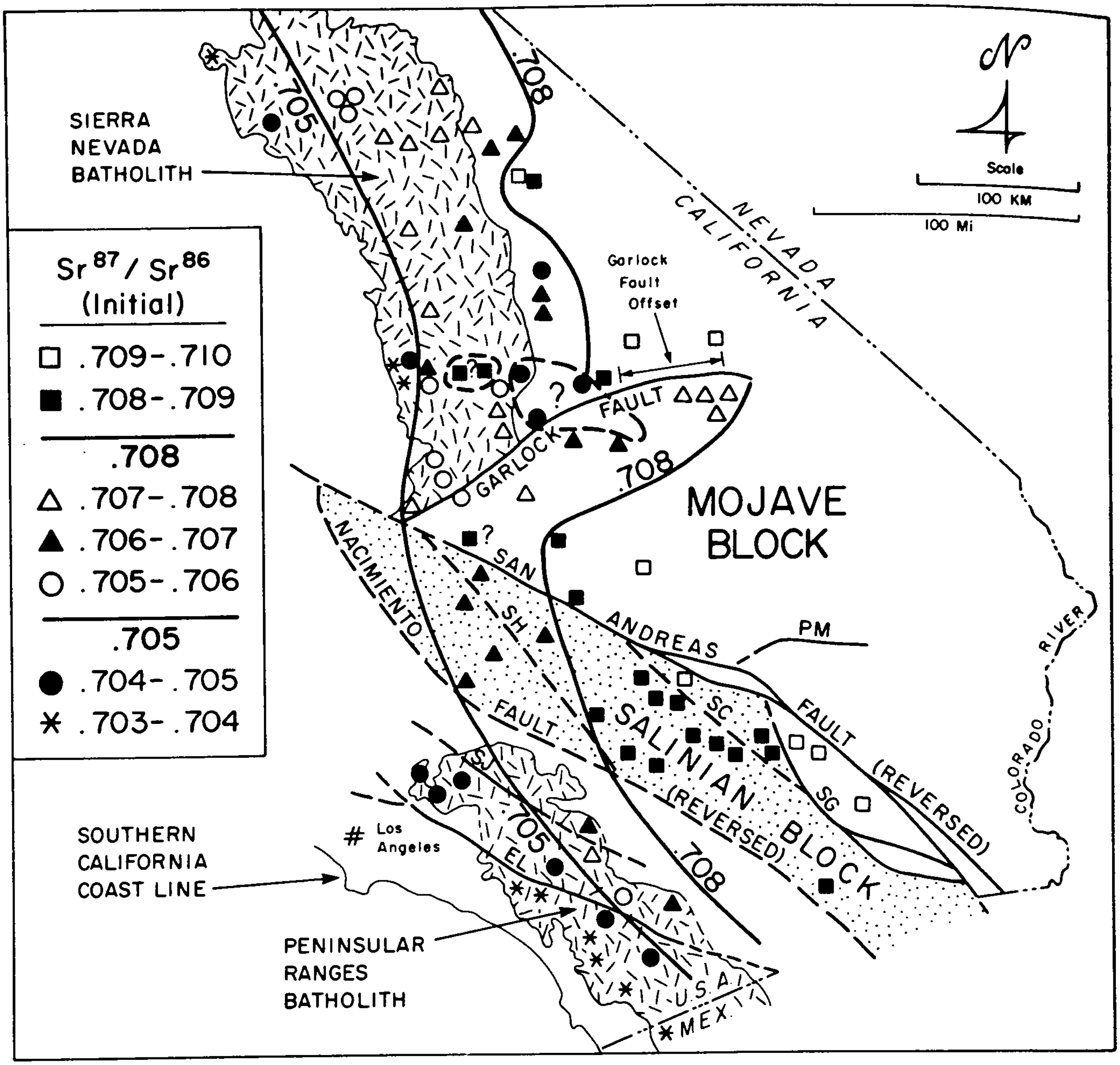

FIG. 11—Areal pattern of initial strontium isotopic ratios in Mesozoic granitic rocks of central and southern California with Sierra Nevada, Mojave, Salinian, and Peninsular Ranges blocks restored to inferred mid-Cretaceous relative positions (see Fig. 10). Displacement on Garlock fault and internal distortion within Mojave block not restored; other reconstructions described in text. Data from Kistler and Peterman (1973, 1978), Kistler et al (1973), and Silver et al (1979). Restoration of inferred east-west extension within Mojave block, and of pre-Miocene clockwise rotation of southernmost end of Sierra Nevada block (Kanter and McWilliams, 1982) would tend further to straighten the curvilinear isoratio line (for initial $Sr^{87}/Sr^{86} = 0.705$) as plotted here.

ducted slab of the arc-trench system.

Alternatively, the relative motion of the offshore Farallon plate with respect to the North American plate was for a time in the mid-Cretaceous oriented in the correct sense to produce sinistral transform motion along the Nacimiento fault (Engebretson et al, 1981). The inferred rate of movement was sufficient to achieve the requisite 550 to 575 km (340 to 355 mi) of net displacement along the fault within 10 m.y. or less. Relative motion of this style would predict temporary cessation of subduction along the Cordilleran arc-trench system while the Nacimiento fault was active.

Available Paleomagnetic Data

Paleomagnetic data have been cited recently as evidence that the Salinian block and the adjoining Obispo belt were transported northward together for about 2,500 km (1,550 mi) since the Cretaceous (Champion et al, 1980; Howell et al, 1980). If this inference is correct, the reconstructions proposed in this paper are invalid. The most critical paleomagnetic data were obtained on uppermost Cretaceous (Campanian-Maestrichtian) sedimentary rocks at Pigeon Point west of the San Gregorio fault (Fig. 6). The inference of dramatic northward transport is based upon the

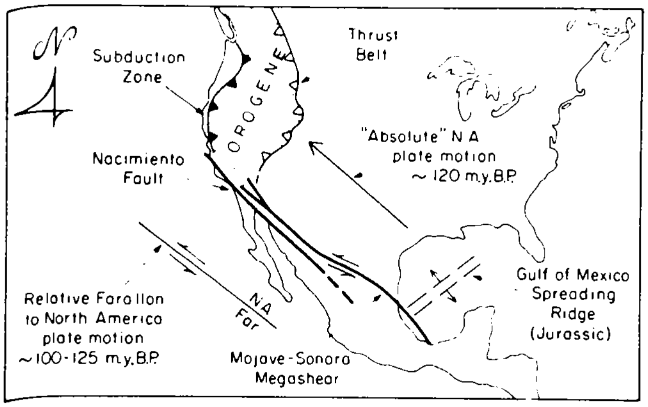

FIG. 12—Sketch map showing tectonic setting of Nacimiento fault in relation to mid-Cretaceous plate motions. Absolute North American motion after Coney (1978) and North America/ Farallon relative plate motion after Engebretson (personal commun., 1981); see text for discussion.

interpretation that the inclination between observed paleomagnetic vectors and present bedding attitudes is a faithful record of the paleolatitude at the point of origin. However, the strata are strongly deformed and have undergone diagenetic alteration. The magnetic remanence is clearly postdepositional, for its orientation is continuous through slump folds (Champion et al, 1981). Anomalously low inclinations that would be interpreted erroneously as indicative of low paleolatitudes might arise from (a) sediment compaction that could reorient remanent vectors, or (b) acquisition of diagenetic remanence after regional tilting, but before local folding. Preliminary paleomagnetic data on less deformed and less compacted sedimentary strata of the same age near San Diego appear to show no evidence of dramatic northward transport (Marshall and McNaboe, 1979). On the other hand, recent paleomagnetic measurements on basalts and turbidite sediments of the Coast Range ophiolite and the Great Valley sequence in the Obispo belt (McWilliams and Howell, 1982) reveal low apparent paleolatitudes far from the inferred paleolatitude of California during the Mesozoic.

Available paleomagnetic data are thus partly contradictory and inadequate to test the proposed tectonic reconstructions. Additional work will doubtless clarify the picture in coming years. Evidence presented here indicates that terrane restorations which incorporate the hypothesis of Cretaceous sinistral slip on the Nacimiento fault are the most appropriate ones to be tested against additional data.

CONCLUSIONS

1. The juxtaposition of Franciscan rocks and granitic rocks across the Nacimiento fault in coastal California required major lateral tectonic transport.
2. Sinistral strike slip of about 560 km (350 mi) along the Nacimiento fault during the Cretaceous is a viable alternative to existing hypotheses for tectonic erosion during subduction or dextral strike slip of arbitrarily large magnitude.
3. The hypothesis of sinistral strike slip accounts well for both the close similarities and the minor differences in the Mesozoic terranes of the Diablo Range and the Obispo belt to the east and west of the Salinian block.
4. The Luyendyk et al (1980) model for Miocene tectonic rotations within the Transverse Ranges provides a satisfactory explanation for observed structural features locally, and apparently describes well the style of tectonics that developed along the continental margin during an early phase in the evolution of the San Andreas transform boundary between the Pacific and American plates.
5. Reversal of inferred (a) Cenozoic dextral displacements and rotations within the San Andreas system, (b) proto-San Andreas movements, and (c) Cretaceous sinistral slip on the Nacimiento fault restores the subparallel Mesozoic lithotectonic belts of California and Baja California to a mid-Cretaceous configuration of simple geometry.
6. The resulting mid-Cretaceous reconstruction of crustal blocks in southern California produces an internally consistent and theoretically satisfying array of points representing measurements of initial strontium isotopic ratios in Mesozoic granitic rocks.
7. Current knowledge of relative and absolute plate motions in the Mesoamerican region during the Mesozoic is compatible with a Cretaceous episode of sinistral strike slip along the Nacimiento fault.
8. Available paleomagnetic data are inadequate to test the restorations of crustal blocks involved in the reconstructions presented here, hence additional work is needed.
9. The reconstructions imply specific correlations between basement terranes whose possible initial juxtapositions have not been suspected previously, but can be verified or denied by appropriate field and laboratory investigations.

REFERENCES CITED

Abbott, P. L., and T. E. Smith, 1978, Trace-element comparison of clasts in Eocene conglomerates, southwestern California and northwestern Mexico: Jour. Geology, v. 86, p. 753-762.

Anderson, D. S., 1980, Provenance and tectonic implications of mid-Tertiary nonmarine deposits, Santa Maria basin and vicinity, California: Master's thesis, Univ. California at Los Angeles, 218 p.

Armstrong, R. L., and J. Suppe, 1973, Potassium-argon geochronometry of Mesozoic igneous rocks in Nevada, Utah, and southern California: Geol. Soc. America Bull., v. 84, p. 1375-1392.

Atwater, T., 1970, Implications of plate tectonics for Cenozoic evolution of western North America: Geol. Soc. America Bull., v. 81, p. 3513-3536.

Bachman, S. B., 1978, A Cretaceous and early Tertiary subduction complex, Mendocino coast, northern California, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 419-430.

Bailey, E. H., M. C. Blake, Jr., and D. L. Jones, 1970, On-land Mesozoic oceanic crust in California Coast Ranges: U.S. Geol. Survey Prof. Paper 700-C, p. C70-C81.

——— W. P. Irwin, and D. L. Jones, 1964, Franciscan and related rocks, and their significance in the geology of western California: California Division Mines and Geology Bull. 183, 177 p.

Bartow, J. A., 1978, Oligocene continental sedimentation in the Caliente Range area, California: Jour. Sed. Petrology, v. 48, p. 75-98.

Beutner, E. C., R. J. McLaughlin, H. N. Ohlin, and D. H. Sorg, 1980, Geologic map of the King Range and Chemise Mountain instant study areas, northern California: U.S. Geol. Survey Misc. Field Studies Map MF-1196-A, scale 1:62,500.

Blake, M. C., Jr., R. H. Campbell, T. W. Dibblee, Jr., D. G. Howell, T.

H. Nilsen, W. R. Normark, J. G. Vedder, and E. A. Silver, 1978, Neogene basin formation in relation to plate-tectonic evolution of San Andreas fault system, California: AAPG Bull., v. 62, p. 344-373.

Bohannon, R. G., 1975, Mid-Tertiary conglomerates and their bearing on Transverse Range tectonics, southern California, *in* San Andreas fault in southern California: California Division Mines and Geology Special Rept. 118, p. 75-82.

——— and D. G. Howell, 1982, Kinematic evolution of the junction of the San Andreas, Big Pine and Garlock faults, California: Geology, v. 10, p. 358-363.

Boles, J. R., 1978, Basin analysis of the Eugenia Formation (Late Jurassic), Punta Eugenia area, Baja California, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 493-498.

Burchfiel, B. C., and G. A. Davis, 1981, Mojave Desert and environs, *in* W. G. Ernst, ed., The geotectonic development of California: Englewood Cliffs, N.J., Prentice-Hall, p. 217-252.

Cameron, C. S., 1980, Late Precambrian strata of the San Bernardino Mountains, California: their relation to the Cordilleran miogeocline: Geol. Soc. America Abs. with Programs, v. 12, p. 100.

Campbell, R. H., and R. F. Yerkes, 1976, Cenozoic evolution of the Los Angeles basin area; relation to plate tectonics, *in* Aspects of the geologic history of the California Continental Borderland: AAPG Pacific Sec. Misc. Pub. 24, p. 541-558.

Champion, D., S. Gromme, and D. G. Howell, 1980, Paleomagnetism of the Cretaceous Pigeon Point Formation and the inferred northward displacement of 2,500 km for the Salinian block, California: EOS (Transactions, American Geophysical Union), v. 61, p. 948.

——— ——— ——— 1981, Paleomagnetic study of the Upper Cretaceous Pigeon Point Formation, *in* V. Frizzell, ed., Upper Cretaceous and Paleocene turbidites, central California coast: SEPM Pacific Sec., p. 53-55.

Chipping, D. H., 1972, Early Tertiary paleogeography of central California: AAPG Bull., v. 56, p. 480-493.

Clarke, S. H., Jr., and T. H. Nilsen, 1973, Displacement of Eocene strata and implications for the history of offset along the San Andreas fault, central and southern California, *in* Proceedings of the conference on tectonic problems of the San Andreas fault system: Stanford Univ. Pubs. Geol. Sci., v. 13, p. 358-367.

Coney, P. J., 1978, Mesozoic-Cenozoic Cordilleran plate tectonics: Geol. Soc. America Mem. 152, p. 33-50.

——— D. L. Jones, and J. W. H. Monger, 1980, Cordilleran suspect terranes: Nature, v. 288, p. 329-333.

Coppersmith, K. J., and G. B. Griggs, 1978, Morphology, recent activity, and seismicity of the San Gregorio fault zone: California Division Mines and Geology Special Rept. 137, p. 33-43.

Cowan, D. S., and B. M. Page, 1975, Recycled Franciscan material in Franciscan melange west of Paso Robles, California: Geol. Soc. America Bull., v. 86, p. 1089-1095.

Criscione, J. J., T. E. Davis, and P. Ehlig, 1978, The age of sedimentation/diagenesis for the Bedford Canyon Formation and the Santa Monica Formation in Southern California: a Rb/Sr evaluation, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 385-396.

Crouch, J. K., 1979, Neogene tectonic evolution of the California Continental Borderland and western Transverse Ranges: Geol. Soc. America Bull., v. 90, p. 338-345.

——— 1981, Northwest margin of California Continental Borderland—marine geology and tectonic evolution: AAPG Bull., v. 65, p. 191-218.

Crowell, J. C., 1962, Displacement along the San Andreas fault, California: Geol. Soc. America Special Paper 71, 61 p.

——— 1975, The San Andreas fault in southern California, *in* San Andreas fault in southern California: California Division Mines and Geology Special Rept. 118, p. 7-27.

——— and V. R. Ramirez, 1979, Late Cenozoic faults in southeastern California, *in* J. C. Crowell and A. G. Sylvester, eds., Tectonics of the juncture between the San Andreas fault system and the Salton Trough, southeastern California: Univ. California at Santa Barbara, Dept. Geol. Sci., p. 27-40.

——— and T. Suzuki, 1959, Eocene stratigraphy and paleontology, Orocopia Mountains, southeastern California: Geol. Soc. America Bull., v. 70, p. 581-592.

Curtis, G. H., J. F. Evernden, and J. Lipson, 1958, Age determination of some granitic rocks in California by the potassium-argon method: California Division Mines Special Rept. 54, 16 p.

Davis, G. A., and B. C. Burchfiel, 1973, Garlock fault: an intracontinental transform structure, southern California: Geol. Soc. America Bull., v. 84, p. 1407-1422.

Dibblee, T. W., Jr., 1950, Geology of southwestern Santa Barbara County, California: California Division Mines Bull. 150, 95 p.

——— 1966, Geology of the central Santa Ynez Mountains, Santa Barbara County, California: California Division Mines and Geology Bull. 186, 99 p.

——— 1967, Areal geology of the western Mojave Desert, California: U.S. Geol. Survey Prof. Paper 522, 153 p.

——— 1976, The Rinconada and related faults in the Southern Coast Ranges, California, and their tectonic significance: U.S. Geol. Survey Prof. Paper 981, 55 p.

Dickinson, W. R., 1966, Table Mountain serpentinite extrusion in California Coast Ranges: Geol. Soc. America Bull., v. 77, p. 451-472.

——— 1979, Dislocation of Paleogene depositional systems by Neogene strike slip in western Transverse Ranges of southern California: Geol. Soc. America Abs. with Programs, v. 11, p. 413.

——— 1981a, Hypothesis of Cretaceous sinistral strike slip along Nacimiento fault of coastal California: Geol. Soc. America Abs. with Programs, v. 13, p. 439-440.

——— 1981b, Plate tectonic evolution of the southern Cordillera: Arizona Geol. Soc. Digest, v. 14, p. 113-135.

——— and P. J. Coney, 1980, Plate tectonic constraints on the origin of the Gulf of Mexico, *in* R. H. Pilger, Jr., ed., The origin of the Gulf of Mexico and the early opening of the central North Atlantic Ocean, a symposium: Louisiana State Univ. School of Geosciences, p. 27-36.

——— and E. I. Rich, 1973, Petrologic intervals and petrofacies in the Great Valley sequence, Sacramento Valley, California: Geol. Soc. America Bull., v. 83, p. 3007-3024.

——— R. V. Ingersoll, and S. A. Graham, 1979, Paleogene sediment dispersal and paleotectonics in northern California: Geol. Soc. America Bull., v. 90, pt. I, p. 897-898; pt. II, p. 1458-1528.

——— ——— D. S. Cowan, K. P. Helmold, and C. A. Suczek, 1982, Provenance of Franciscan graywackes in coastal California: Geol. Soc. America Bull., v. 93, p. 95-107.

Duffield, W. A., and R. V. Sharp, 1975, Geology of the Sierra foothills melange and adjacent areas, Amador County, California: U.S. Geol. Survey Prof. Paper 827, 30 p.

Ehlig, P. L., K. W. Ehlert, and B. M. Crowe, 1975, Offset of the upper Miocene Caliente and Mint Canyon Formations along the San Gabriel and San Andreas faults, *in* San Andreas fault in southern California: California Division Mines and Geology Special Rept. 118, p. 83-92.

Engebretson, D., R. Gordon, and A. Cox, 1981, Relative motions between the North America, Pacific, Kula, and Farallon plates from 130 m.y. to the present: EOS (Transactions, American Geophysical Union), v. 61, p. 947.

Ernst, W. G., 1965, Mineral parageneses in Franciscan metamorphic rocks, Panoche Pass, California: Geol. Soc. America Bull., v. 76, p. 879-914.

——— 1970, Tectonic contact between the Franciscan melange and the Great Valley sequence—crustal expression of a late Mesozoic Benioff zone: Jour. Geophysical Research, v. 75, p. 886-901.

——— 1975, Systematics of large-scale tectonics and age progressions in Alpine and Circum-Pacific blueschist belts: Tectonophysics, v. 26, p. 229-246.

——— 1980, Mineral paragenesis in Franciscan metagraywackes of the Nacimiento block, a subduction complex of the southern California Coast Ranges: Jour. Geophysical Research, v. 85, p. 7045-7055.

Evernden, J. F., and R. W. Kistler, 1970, Chronology of emplacement of Mesozoic batholithic complexes in California and western Nevada: U.S. Geol. Survey Prof. Paper 623, 42 p.

Evitt, W. R., and S. T. Pierce, 1975, Early Tertiary ages from the coastal belt of the Franciscan complex, northern California: Geology, v. 3, p. 433-436.

Garfunkel, Z., 1974, Model for the late Cenozoic tectonic history of the Mojave Desert, California, and for its relation to adjacent regions: Geol. Soc. America Bull., v. 85, p. 1931-1944.

Gastil, R. G., 1968, How good is the evidence for 450 miles of offset on the San Andreas fault, *in* Conference on geologic problems of San Andreas fault system, 1967 Proceedings: Stanford Univ. Publications, Geological Science, v. 11, p. 208-211.

——— 1975, Comment: Geology, v. 3, p. 84.
——— G. J. Morgan, and D. Krummenacher, 1978, Mesozoic history of peninsular California and related areas east of the Gulf of California, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 107-115.
——— R. P. Phillips, and E. C. Allison, 1975, Reconnaissance geology of the State of Baja California: Geol. Soc. America Mem. 140, 170 p.
Gilbert, W. G., and W. R. Dickinson, 1970, Stratigraphic variations in sandstone petrology, Great Valley sequence, central California coast: Geol. Soc. America Bull., v. 81, p. 949-954.
Givens, C. R., 1974, Eocene molluscan biostratigraphy of the Pine Mountain area, Ventura County, California: Univ. California Pubs. Geol. Sci., v. 109, 107 p.
Graham, S. A., 1978, Role of Salinian block in evolution of San Andreas fault system, California: AAPG Bull., v. 62, p. 2214-2231.
——— and W. R. Dickinson, 1978a, Apparent offset of on-land geologic features across the San Gregorio–Hosgri fault trend: Science, v. 199, p. 179-181.
——— ——— 1978b, Apparent offsets of on-land geologic features across the San Gregorio–Hosgri fault trend: California Division Mines and Geology Special Rept. 137, p. 13-23.
Greene, H. A., W. H. K. Lee, D. S. McCulloch, and E. E. Brabb, 1973, Faults and earthquakes in the Monterey Bay region, California: U.S. Geol. Survey Misc. Field Studies Map MF-518, 14 p.
Greenhaus, M. R., and A. Cox, 1979, Paleomagnetism of the Morro Rock-Islay Hill complex as evidence for crustal block rotations in central coastal California: Jour. Geophysical Research, v. 84, p. 2393-2400.
Hall, C. A., Jr., 1975, San Simeon–Hosgri fault system, coastal California; economic and environmental implications: Science, v. 190, p. 1291-1294.
——— 1981, San Luis Obispo transform fault and middle Miocene rotation of the western Transverse Ranges, California: Jour. Geophysical Research, v. 86, p. 1015-1031.
——— and C. E. Corbato, 1967, Stratigraphy and structure of Mesozoic and Cenozoic rocks, Nipomo quadrangle, southern Coast Ranges, California: Geol. Soc. America Bull., v. 78, p. 559-582.
Hamilton, W., 1969, Mesozoic California and the underflow of Pacific mantle: Geol. Soc. America Bull., v. 80, p. 2409-2430.
Harding, T. P., 1976, Tectonic significance and hydrocarbon trapping consequences of sequential folding synchronous with San Andreas faulting, San Joaquin Valley, California: AAPG Bull., v. 60, p. 356-378.
Hart, E. W., 1976, Basic geology of the Santa Margarita area, San Luis Obispo County, California: California Division Mines and Geology Bull. 199, 45 p.
Hietanen, A., 1981, Petrologic and structural studies in the northwestern Sierra Nevada, California: U.S. Geol. Survey Prof. Paper 1226, 59 p.
Hill, M. L., and T. W. Dibblee, Jr., 1953, San Andreas, Garlock, and Big Pine faults, California—a study of the character, history, and tectonic significance of their displacements: Geol. Soc. America Bull., v. 64, p. 443-458.
Hopson, C. A., J. M. Mattinson, and E. A. Pessagno, Jr., 1981, Coast Range ophiolite, western California, *in* W. G. Ernst, ed., The geotectonic development of California: Englewood Cliffs, N. J., Prentice-Hall, p. 418-510.
Hornafius, J. S., B. P. Luyendyk, D. W. Weaver, and W. W. Wornardt, 1981, Paleomagnetic results from the Monterey Formation in the western Transverse Ranges: EOS (Transactions, American Geophysical Union), v. 62, p. 855.
Hoskins, E. G., and J. R. Griffiths, 1971, Hydrocarbon potential of northern and central California offshore, *in* Future petroleum provinces of the United States—their geology and potential: AAPG Mem. 15, p. 212-228.
Howell, D. G., 1975, Hypothesis suggesting 700 km of right slip in California along northwest-oriented faults: Geology, v. 3, p. 81-83.
——— and M. H. Link, 1979, Eocene conglomerate sedimentology and basin analysis, San Diego and the southern California borderland: Jour. Sed. Petrology, v. 49, p. 517-540.
——— and J. G. Vedder, 1978, Late Cretaceous paleogeography of the Salinian block, California, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 523-534.
——— H. McLean, and J. G. Vedder, 1980, Late Cretaceous suturing and translation of the Salinian and Nacimiento blocks, California: EOS (Transactions, American Geophysical Union), v. 61, p. 948.
——— C. J. Stuart, J. P. Platt, and D. J. Hill, 1974, Possible strike-slip faulting in the southern California borderland: Geology, v. 2, p. 93-98.
——— J. G. Vedder, H. McLean, J. M. Joyce, S. H. Clarke, Jr., and G. Smith, 1977, Review of Cretaceous geology, Salinian and Nacimiento blocks, Coast Ranges of central California, *in* Cretaceous geology of the California Coast Ranges west of the San Andreas fault: SEPM Pacific Sec., Pacific Coast Paleogeography Field Guide 2, p. 1-46.
Hsu, K. J., 1968, Principles of melanges and their bearing on the Franciscan-Knoxville paradox: Geol. Soc. America Bull., v. 79, p. 1063-1074.
Huffman, O. F., 1972, Lateral displacement of upper Miocene rocks and the Neogene history of offset along the San Andreas fault in central California: Geol. Soc. America Bull., v. 83, p. 2913-2946.
Ingersoll, R. V., 1978a, Paleogeography and paleotectonics of the late Mesozoic forearc basin of northern and central California, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 471-482.
——— 1978b, Petrofacies and petrologic evolution of the Late Cretaceous fore-arc basin, northern and central California: Journal of Geology, v. 86, p. 335-352.
——— 1978c, Submarine fan facies of the Upper Cretaceous Great Valley sequence, northern and central California: Sedimentary Geology, v. 21, p. 205-230.
——— 1979, Evolution of the Late Cretaceous forearc basin, northern and central California: Geol. Soc. America Bull., v. 90, p. 813-826.
——— 1983, Petrofacies and provenance of the Great Valley Group, northern and central California: AAPG Bull., v. 67, in press.
Jacobson, M. I., 1978, Petrologic variations in Franciscan sandstone from the Diablo Range, California, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 401-417.
Jones, D. L., and W. P. Irwin, 1975, Rotated Jurassic blocks in the Transverse Ranges, California: Geol. Soc. America Abs. with Programs, v. 7, p. 330.
——— M. C. Blake, Jr., and C. Rangin, 1976, The four Jurassic belts of northern California and their significance to the geology of the southern California borderland, *in* Aspects of the geologic history of the California Continental Borderland: AAPG Pacific Sec. Misc. Pub. 24, p. 343-362.
Kamerling, M. J., and B. P. Luyendyk, 1979, Tectonic rotations of the Santa Monica Mountains region, western Transverse Ranges, California, suggested by paleomagnetic vectors: Geol. Soc. America Bull., v. 90, p. 331-337.
Kanter, L. R., and M. O. McWilliams, 1982, Rotation of southernmost Sierra Nevada, California: Jour. Geophysical Research, v. 87, p. 3819-3830.
Kistler, R. W., and Z. E. Peterman, 1973, Variations in Sr, Rb, K, Na, and initial Sr^{87}/Sr^{86} in Mesozoic granitic rocks and intruded wallrocks in central California: Geol. Soc. America Bull., v. 84, p. 3489-3512.
——— ——— 1978, Reconstruction of crustal blocks of California on the basis of initial strontium isotopic compositions of Mesozoic granitic rocks: U.S. Geol. Survey Prof. Paper 1071, 17 p.
——— ——— D. C. Ross, and D. Gottfried, 1973, Strontium isotopes and the San Andreas fault, *in* Proceedings of the conference on tectonic problems of the San Andreas fault system: Stanford Univ. Pubs. Geol. Sci., v. 13, p. 339-347.
Krummenacher, D., R. G. Gastil, J. Bushee, and J. Doupont, 1975, K-Ar apparent ages, Peninsular Ranges batholith, southern California and Baja California: Geol. Soc. America Bull., v. 86, p. 760-768.
Lee-Wong, F., and D. G. Howell, 1977, Petrography of Upper Cretaceous sandstone in the Coast Ranges of central California, *in* Cretaceous geology of the California Coast Ranges west of the San Andreas fault: SEPM Pacific Sec., Pacific Coast Paleogeography Field Guide 2, p. 47-55.
Leslie, R. B., 1981, Continuity and tectonic implications of the San Simeon–Hosgri fault zone, central California: U.S. Geol. Survey Open-File Rept. 81-430, 59 p.
Link, M. H., 1975, Matilija Sandstone: a transition from deep-water turbidite to shallow-marine deposition in the Eocene of California: Jour. Sed. Petrology, v. 45, p. 63-78.
Luyendyk, B. P., M. J. Kamerling, and R. Terres, 1980, Geometric model for Neogene crustal rotations in southern California: Geol. Soc.

America Bull., v. 91, p. 211-217.

MacKinnon, T. C., 1978, The Great Valley sequence near Santa Barbara, California, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 483-491.

Mansfield, C. F., 1979, Upper Mesozoic subsea fan deposits in the southern Diablo Range, California: record of the Sierra Nevada magmatic arc: Geol. Soc. America Bull., v. 90, p. 1025-1046.

Marshall, M., and G. J. McNaboe, 1979, Preliminary paleomagnetic results from the Cretaceous Point Loma Formation, *in* P. L. Abbott, ed., Geological excursions in the southern California area: San Diego State Univ. Dept. Geol. Sci., p. 183.

Matthews, V., III, 1976, Correlation of Pinnacles and Neenach volcanic formations and their bearing on San Andreas fault problem: AAPG Bull., v. 60, p. 2128-2141.

Mattinson, J. M., 1978, Age, origin, and thermal histories of some plutonic rocks from the Salinian block of California: Contr. Mineralogy and Petrology, v. 67, p. 233-245.

——— 1982, Granitic rocks of the Gabilan Range, California: U-Pb systematics and implications for age and origin: Geol. Soc. America Abs. with Programs, v. 14, p. 184.

McCracken, W. A., 1972, Paleocurrents and petrology of Sespe sandstones and conglomerates, Ventura basin, California: PhD thesis, Stanford Univ., 192 p.

McLaughlin, R. J., S. A. Kling, R. Z. Poore, K. A. McDougall, and E. C. Beutner, 1982, Post-middle Miocene accretion of Franciscan rocks, northwestern California: Geol. Soc. America Bull., v. 93, p. 595-605.

McWilliams, M. O., and D. G. Howell, 1982, Exotic terranes of western California: Nature, v. 297, p. 215-217.

Miller, E. A., 1981, Geology of the Victorville region, California: Geol. Soc. America Bull., v. 92, pt. I, p. 160-163; pt. II, p. 515-608.

Miller, F. K., and D. M. Morton, 1980, Potassium-argon geochronology of the eastern Transverse Ranges and southern Mojave Desert, southern California: U.S. Geol. Survey Prof. Paper 1152, 30 p.

Mullins, H. T., and D. K. Nagel, 1981, Franciscan-type rocks off Monterey Bay, California: implications for western boundary of Salinian block: Geo-Marine Letters, v. 1, p. 135-139.

Nagel, D. K., and H. T. Mullins, 1983, Late Cenozoic offset and uplift along the San Gregorio fault zone, central California continental margin, *in* D. W. Andersen and M. J. Rymer, eds., Late Cenozoic tectonics and sedimentation along faults of the San Andreas system: SEPM Pacific Sec., in press.

Nilsen, T. J., 1978, Late Cretaceous geology of California and the problem of the proto-San Andreas fault, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 559-573.

——— and P. L. Abbott, 1981, Paleogeography and sedimentology of Upper Cretaceous turbidites, San Diego, California: AAPG Bull., v. 65, p. 1256-1284.

——— and S. H. Clarke, Jr., 1975, Sedimentation and tectonics in the early Tertiary continental borderland of central California: U.S. Geol. Survey Prof. Paper 925, 64 p.

Page, B. M., 1970a, Sur-Nacimiento fault zone of California: Continental margin tectonics: Geol. Soc. America Bull., v. 81, p. 667-690.

——— 1970b, Time of completion of underthrusting of Franciscan beneath Great Valley rocks west of Salinian block, California: Geol. Soc. America Bull., v. 81, p. 2825-2834.

——— 1972, Oceanic crust and mantle fragment in subduction complex near San Luis Obispo, California: Geol. Soc. America Bull., v. 83, p. 957-972.

——— 1981, The southern Coast Ranges, *in* W. G. Ernst, ed., The geotectonic development of California: Englewood Cliffs, N. J., Prentice-Hall, p. 329-417.

——— 1982, Migration of Salinian composite block, California, and disappearance of fragments: Am. Jour. Sci., v. 282, p. 1694-1734.

——— J. G. Marks, and G. W. Walker, 1951, Stratigraphy and structure of mountains northeast of Santa Barbara, California: AAPG Bull., v. 35, p. 1727-1780.

——— H. C. Wagner, D. S. McCulloch, E. A. Silver, and J. H. Spotts, 1978, Geologic cross section of the continental margin off San Luis Obispo, the southern Coast Ranges, and the San Joaquin Valley, California: Geol. Soc. America Map and Chart Ser. MC-28G, 12 p.

Payne, C. M., O. E. Swanson, and B. A. Schell, 1978, Investigation of the Hosgri fault offshore southern California: U.S. Geol. Survey Open-File Rept. 79-1199, 22 p.

Rangin, C., 1978, Speculative model of Mesozoic geodynamics, central Baja California to northeastern Sonora, Mexico, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 85-106.

Redwine, L. E., 1963, Morphology, sediments, and geological history of basins of Santa Maria area, California (abs.): AAPG Bull., v. 47, p. 1775.

Rose, R. L., and I. P. Colburn, 1963, Geology of the east-central part of Priest Valley quadrangle, California, *in* Geology of Salinas Valley and the San Andreas fault: AAPG-SEPM Pacific Sec. Ann. Field Trip Guidebook, p. 38-45.

Ross, D. C., 1970, Quartz gabbro and anorthositic gabbro, markers of offset along the San Andreas fault in the California Coast Ranges: Geol. Soc. America Bull., v. 81, p. 3647-3662.

——— 1972, Petrographic and chemical reconnaissance study of some granitic and gneissic rocks near the San Andreas fault from Bodega Head to Cajon Pass, California: U.S. Geol. Survey Prof. Paper 698, 92 p.

——— 1977, Pre-intrusive metasedimentary rocks of the Salinian block, California—a paleotectonic dilemma, *in* Paleozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 1, p. 371-380.

——— 1978, The Salinian block—a Mesozoic granitic orphan in the California Coast Ranges, *in* Mesozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 2, p. 509-522.

——— and D. S. McCulloch, 1979, Cross section of the southern Coast Ranges and San Joaquin Valley from offshore Point Sur to Madera, California: Geol. Soc. America Map and Chart Ser. MC-28H, 4 p.

Sage, O., Jr., 1973, Paleocene geography of the Los Angeles region, *in* Proceedings of the conference on tectonic problems of the San Andreas fault system: Stanford Univ. Pubs. Geol. Sci., v. 13, p. 348-357.

Schweickert, R. A., and D. S. Cowan, 1975, Early Mesozoic tectonic evolution of the western Sierra Nevada, California: Geol. Soc. America Bull., v. 86, p. 1329-1336.

Sharp, R. V., 1967, San Jacinto fault zone in the Peninsular Ranges of southern California: Geol. Soc. America Bull., v. 78, p. 705-730.

——— 1975, En echelon fault patterns of the San Jacinto fault zone, *in* San Andreas fault in southern California: California Division Mines and Geology Special Rept. 118, p. 147-152.

Silver, E. A., 1978, The San Gregorio–Hosgri fault zone: an overview: California Division Mines and Geology Special Rept. 137, p. 1-2.

——— J. R. Curray, and A. K. Cooper, 1971, Tectonic development of the continental margin off central California, *in* Geologic guide to the northern Coast Ranges: Sacramento Geol. Soc. Ann. Field Trip Guidebook, p. 1-10.

Silver, L. T., and T. H. Anderson, 1974, Possible left-lateral early to middle Mesozoic disruption of the southwestern North American craton margin: Geol. Soc. America Abs. with Programs, v. 6, p. 955-956.

——— H. P. Taylor, Jr., and B. Chappell, 1979, Some petrological, geochemical, and geochronological observations of the Peninsular Ranges batholith near the international border of the U.S.A. and Mexico, *in* P. L. Abbott and V. R. Todd, eds., Mesozoic crystalline rocks: San Diego State Univ. Dept. Geol. Sci., p. 83-110.

Smith, D. P., 1977, San Juan–St. Francis fault—hypothesized major middle Tertiary right-lateral fault in central and southern California: California Division Mines and Geology Special Rept., 129, p. 41-50.

Smith, G. W., D. G. Howell, and R. V. Ingersoll, 1979, Late Cretaceous trench-slope basins of central California: Geology, v. 7, p. 303-306.

Spencer, J. E., and W. R. Normark, 1979, Tosco-Abreojos fault zone: a Neogene transform plate boundary within the Pacific margin of southern Baja California, Mexico: Geology, v. 7, p. 554-557.

Stauffer, P. H., 1967, Grain-flow deposits and their implications, Santa Ynez Mountains, California: Jour. Sed. Petrology, v. 37, p. 487-508.

Stewart, J. H., and F. G. Poole, 1975, Extension of the Cordilleran miogeoclinal belt to the San Andreas fault, California: Geol. Soc. America Bull., v. 86, p. 205-212.

Stuart, C. J., 1979a, Lithofacies and origin of the San Onofre Breccia, coastal southern California, *in* C. J. Stuart, ed., Miocene lithofacies and depositional environments, coastal southern California and northwestern Baja California: SEPM Pacific Sec. Guidebook, p. 25-42.

——— 1979b, Middle Miocene paleogeography of coastal southern California borderland—evidence from schist-bearing sedimentary rocks, *in* Cenozoic paleogeography of the western United States: SEPM Pacific Sec., Pacific Coast Paleogeography Symposium 3, p. 29-44.

Suppe, J., 1970, Offset of late Mesozoic basement terrains by the San Andreas fault system: Geol. Soc. America Bull., v. 81, p. 3253-3258.

Sylvester, A. G., and A. C. Darrow, 1979, Structure and neotectonics of the western Santa Ynez fault system in southern California: Tectonophysics, v. 52, p. 389-405.

Terres, R. H., and A. G. Sylvester, 1981, Kinematic analysis of rotated fractures and blocks in simple shear: Bull. Seismological Soc. America, v. 71, p. 1593-1605.

Travers, W. B., 1972, A trench off central California in late Eocene-early Oligocene time: Geol. Soc. America Mem. 132, p. 173-182.

Truex, J. N., 1976, Santa Monica and Santa Ana Mountains—relation to Oligocene Santa Barbara basin: AAPG Bull., v. 60, p. 65-86.

Turcotte, D. L., and D. C. McAddo, 1979, Thermal subsidence and petroleum generation in the southwestern block of the Los Angeles basin, California: Jour. Geophysical Research, v. 84, p. 3460-3464.

Underwood, M. B., 1977, The Pfeiffer Beach slab deposits, Monterey County, California: possible trench-slope basin, *in* Cretaceous geology of the California Coast Ranges west of the San Andreas fault: SEPM Pacific Sec., Pacific Coast Paleogeography Field Guide 2, p. 57-69.

Van de Kamp, P. C., J. D. Harper, J. J. Conniff, and D. A. Morris, 1974, Facies relations in the Eocene-Oligocene in the Santa Ynez Mountains, California: Jour. Geol. Soc. London, v. 130, p. 545-565.

Vedder, J. G., 1972, Revision of stratigraphic names for some Eocene formations in Santa Barbara and Ventura Counties, California: U.S. Geol. Survey Bull. 1374-D, p. D1-D12.

——— and R. D. Brown, Jr., 1968, Structural and stratigraphic relations along the Nacimiento fault in the southern Santa Lucia Range and San Rafael Mountains, California, *in* Conference on geologic problems of San Andreas fault system, 1967 Proceedings: Stanford Univ. Pubs. Geol. Sci., v. 11, p. 242-259.

——— T. W. Dibblee, Jr., and R. D. Brown, Jr., 1973, Geologic map of the upper Mono Creek-Pine Mountain area, California: U.S. Geol. Survey Misc. Geol. Inv. Map I-752, scale 1:48,000.

——— D. G. Howell, and H. McLean, 1977, Upper Cretaceous redbeds in the Sierra Madre-San Rafael Mountains, California, *in* Cretaceous geology of the California Coast Ranges west of the San Andreas fault: SEPM Pacific Sec., Pacific Coast Paleogeography Field Guide 2, p. 71-78.

Wentworth, C. M., 1968, Upper Cretaceous and lower Tertiary strata near Gualala, California, and inferred large right slip on the San Andreas fault, *in* Conference on geologic problems of San Andreas fault system, 1967 Proceedings: Stanford Univ. Pubs. Geol. Sci., v. 11, p. 130-143.

Wiebe, R. A., 1970, Pre-Cenozoic tectonic history of the Salinian block, California: Geol. Soc. America Bull., v. 81, p. 1837-1842.

Wright, L., 1976, Late Cenozoic fault patterns and stress fields in the Great Basin and westward displacement of the Sierra Nevada block: Geology, v. 4, p. 489-494.

Yeats, R. S., M. R. Cole, W. R. Merschat, and R. M. Parsley, 1974, Poway fan and submarine cone and rifting of inner southern California borderland: Geol. Soc. America Bull., v. 85, p. 293-302.

Yerkes, R. F., H. G. Greene, J. C. Tinsley, and K. R. Lajoie, 1981, Seismotectonic setting of the Santa Barbara Channel area, southern California: U.S. Geol. Survey Misc. Field Studies Map MF-1169, 25 p.