UNITED STATES OF AMERICA

NUCLEAR REGULATORY COMMISSION

BEFORE THE ATOMIC SAFETY AND LICENSING BOARD

TESTIMONY OF STEPHAN ALAN GRAHAM

On Behalf Of

INTERVENORS

Regarding

CONTENTION 1

GEOLOGY

In The Matter Of

DIABLO CANYON NUCLEAR POWER PLANT, UNITS 1 & 2

Docket Nos. STN 50-275, 50-323

NOVEMBER 17, 1978

TESTIMONY OF STEPHAN ALAN GRAHAM

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Regarding

<u>CONTENTION 1 - GEOLOGY</u>

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Docket Nos. STN 50-275, 50-323

1. My name is Stephan Alan Graham. I am currently employed as an exploration geologist for Chevron USA Inc. I have been subpoened by the Joint Intervenors to present testimony at this proceeding. My resume is attached to this testimony (Attachment A).

2. This testimony sets forth my conclusions regarding through-going continuity of the San Gregorio-Hosgri fault zone.

3. My conclusions are as follows:

(a) Geologic evidence suggests that the San Gregorio-Hosgri was a continuous fault in the past that was the focus of shear resulting from the stresses generated by the movement of the North American and the Pacific plates. This evidence is discussed in Attachment B.

(b) Although this evidence does not require through-going continuity in the present, it is suggestive of present through-going continuity. Further, I know of no geologic data that preclude such continuity.

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* Intervenors are: Scenic Shorelines Preservation Conference, Inc., San Luis Obispo Mothers for Peace, Ecology Action Club, Sandra A. Silver, and John J. Forster

(c) The focus of shear appears to have moved east to the San Andreas fault zone.

(d) Factors cited in my study which could be considered in evaluating the significance of the San Gregorio-Hosgri fault are:

(i) geologic evidence of former through-going continuity;

(ii) magnitude of the past offset;

(iii) physical tie to the San Andreas; and

(iv) orientation with respect to the San Andreas.

RESUME

Stephan Alan Graham
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General
- Born 4/25/50, Evansville, Indiana
- Married 5/27/72, wife-Pamela, 1 child
- U.S. citizen, military status-1H, foreign language-German

Education

A.B.	Indiana University	1972	Geology, with Honors
M.S.	Stanford University	1974	Geology
Ph.D.	Stanford University	1976	Geology

Specialization: Sedimentary geology, in particular sedimentary tectonics

Thesis: Middle Tertiary paleogeography and structural development of the Salinian block, California; Ph.D. committee: W. R. Dickinson (advisor), J. C. Ingle, Jr., B. M. Page

Professional Experience
1. 1968, 1970: Subsurface mapping, Fritz Operating Co., Ft. Branch, Ind., (summers)
2. 1970: X-ray diffractometer technician, Indiana Univ., Bloomington Ind., (part-time)
3. 1971-1972: Consulting geologist for Peninsula Exploration Co., Corpus Christi, Texas, (part-time)
4. 1972: Associate Instructor, Indiana University Geologic Field Station, Cardwell, Montana, (summer)
5. 1973: Research assistant, Stanford University, Stanford, Ca., (summer)
6. 1973: Instructor, Stanford Geological Survey, Bridgeport, Ca., (summer)
7. 1976: Research Geologist, Exxon Production Research Co., Houston, Texas
8. 1976 - Exploration Geologist, Chevron USA Inc., San Francisco, CA

Awards, Assistantships, and Fellowships
1. Earth Sciences Freshman Scholarship, Indiana University, 1968
2. Arthur R. Metz Distinguished Scholarship, Indiana University, 1968-1972
3. Indiana University Geologic Field Station tuition award, 1969
4. Standard Oil of Texas undergraduate geology award, 1969, 1970
5. Best student paper, Rocky Mtn. Section, Geol. Soc. America, 1971
6. Senior faculty scholarship award, Indiana University, 1972
7. Phi Beta Kappa, 1972
8. National Science Foundation Graduate Fellowship, 1972-1975

Professional Societies

Geological Society of America

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Society of Economic Paleontologists and Mineralogists

Public[illegible]ions

Graham, S.A., 1971, Occurrence of middle Cambrian islands in southwest Montana: Geol. Soc. America Abs. with Programs, Rocky Mtn. Section, 383-384.

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Graham, S.A., 1978, Role of the Salinian block in the evolution of the San Andreas fault system: Amer. Assoc. Petroleum Geologists Bull., v. 62, # 11 (in press).

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APPARENT OFFSETS OF ON-LAND GEOLOGIC FEATURES ACROSS THE SAN GREGORIO-HOSGRI FAULT TREND

By Stephan A. Graham [1] and William R. Dickinson[2]

Abstract

Component faults of the San Gregorio-Hosgri fault trend, roughly coincident with the present central California coastline and part of the San Andreas fault system, may have experienced about 115 km of Neogene right-slip. Evidence for right-slip consists of possible pairs of offset geologic features, including: (1) nearly identical Tertiary sequences at Point Reyes and in the southern Santa Cruz Mountains, (2) similar Cretaceous and Oligocene-Miocene strata of the western Santa Cruz Mountains and the northern Santa Lucia Range, (3) the structural contact between granitic basement and Franciscan complex north of Bodega Head and in the northern Santa Cruz Mountains, (4) tectonic slabs of potassium feldspar-bearing sandstones within the Franciscan complex near Point Sur and Cambria, (5) Franciscan-derived Miocene sandstone near Point Sur and potential source terranes to the south, and (6) Mesozoic ophiolite and overlying Tertiary sections near San Simeon and Point Sal. The suggested right-slip is definitely post-early Miocene and probably post-middle Miocene. Because the San Gregorio-Hosgri fault trend intersects the San Andreas fault offshore south of Bolinas, the total apparent offset of granitic basement along the San Andreas fault is actually the sum of offsets on the San Gregorio-Hosgri and the San Andreas faults. Comparison of time-displacement curves demonstrates that these two faults account for much of the post-Oligocene displacement between the Pacific and North American plates. Recognition of Neogene San Gregorio-Hosgri right-slip thus reduces considerably the apparent magnitude of right-slip along an early Tertiary proto-San Andreas fault.

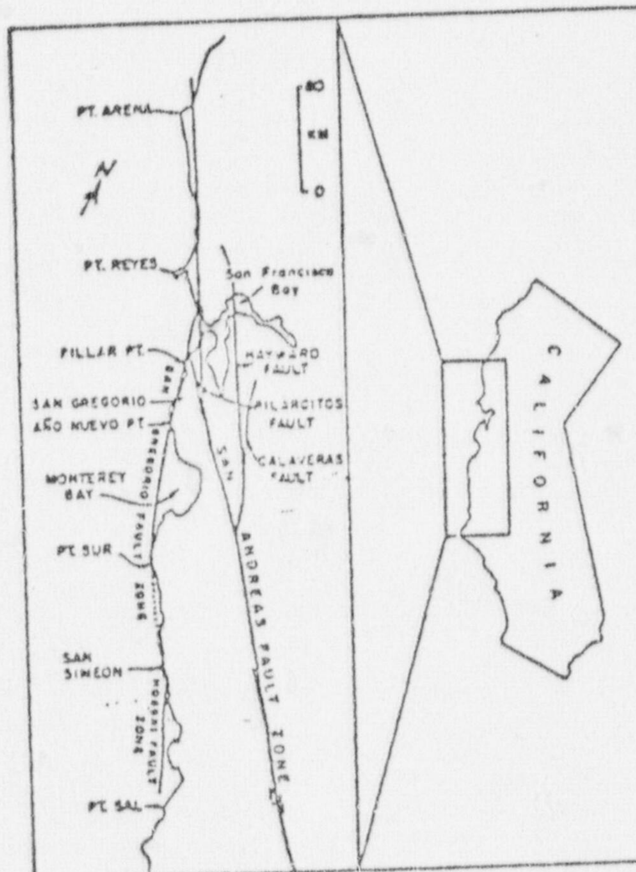

FIGURE 1. Major elements of the San Andreas fault system, central California.

INTRODUCTION

Early geologic mapping of the central California coast demonstrated that striking stratal discontinuities exist across the San Gregorio fault (figure 1) some 50 km south of San Francisco (Branner and others, 1909). Originally mapped only as an on-land fault segment running from near the village of San Gregorio south to Año Nuevo Point, the fault now generally is considered to trend offshore near San Gregorio and to re-emerge at Pillar Point, 20 km to the northwest (figure 1), as the Seal Cove fault (e.g., Glen, 1959; Jennings and Burnett, 1961; Weber, 1974). This connection has not been verified rigorously, but a series of linear shoals extending south from the Seal Cove fault across the mouth of Half Moon Bay toward the San Gregorio fault make the connection a virtual certainty. Seismic profiling data establish that the Seal Cove segment of the San Gregorio fault trends northward offshore from San Francisco to join the San Andreas fault zone underwater south of the town of Bolinas (Cooper, 1973).

South of the on-land type segment, the San Gregorio fault has been traced by seismic profiling across outer Monterey Bay and Monterey submarine canyon, and thence up Carmel submarine canyon (Greene and others, 1973). Greene and others (1973) mapped the San Gregorio fault returning ashore as the Palo Colorado fault in the northern Santa Lucia Range between Carmel and Point Sur (figure 2), and referred to the over-all trend as the Palo Colorado-San Gregorio fault zone. This paper, however, advocates an alternative to the Palo Colorado connection. Evidence is offered here to indicate that the San Gregorio fault instead is continuous, via a portion of the Sur fault zone, with the San Simeon-Hosgri fault zone (Hall, 1975) along the coast to the south (figure 1). Precise relationships between all branching and *en echelon* segments of this complex system remain unresolved, but the term San Gregorio-Hosgri fault trend will be used in this paper to designate the whole array of linked traces.

In its type area, the San Gregorio fault consists of a near vertical strand or multiple strands forming a fault zone hundreds of meters wide (Clark, 1970, Cummings and others, 1962; Web-

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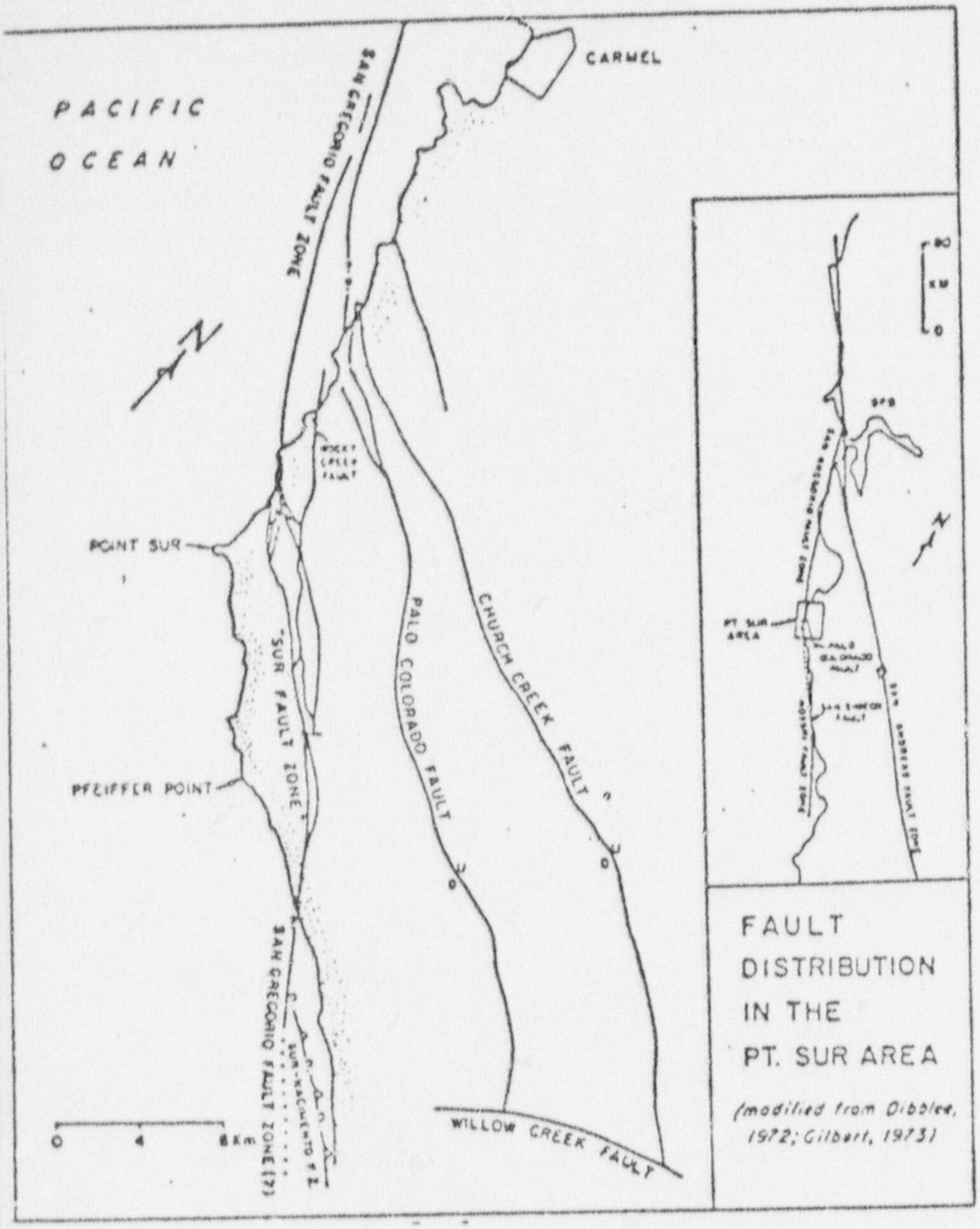

FIGURE 2. Relationship of the San Gregorio, Sur, and Palo Colorado faults in the Point Sur area.

er, 1974). Upper Cretaceous sedimentary rocks crop out extensively west of the fault in the San Gregorio area but are unknown east of the fault in the Santa Cruz Mountains; conversely, a well-developed Paleocene through Oligocene sequence is present in the Santa Cruz Mountains but is absent west of the fault (Cummings and others, 1962). The occurrence of generally similar Pliocene marine rocks on both sides of the fault in its type area led previous investigators to conclude that the San Gregorio fault had experienced no significant strike-slip movement (Cummings and others, 1962). However, the similarities in character and orientation of the San Gregorio fault and the San Andreas fault prompted Hill and Dibblee (1953) to suggest that the former might also be a major right-lateral strike-slip fault. The subsequent discovery of the convergence of the two faults offshore northwest of San Francisco further supports the idea that the San Gregorio and San Andreas faults are structurally related. We thus regard the San Gregorio–Hosgri fault trend as part of the San Andreas fault system. The importance of the San Gregorio–Hosgri fault trend is evidenced by its apparent control of the position of the modern central California coastline (figure 1).

THE SOUTHERN SAN GREGORIO FAULT ZONE AND RELATIONS WITH THE HOSGRI FAULT

From the head of Carmel submarine canyon, Greene and others (1973) projected the San Gregorio fault south into the Palo Colorado fault onshore (figure 2). This connection requires an abrupt bend in a fault trace that is otherwise rather straight. Data are rather poor offshore in the vicinity of the presumed connection (J. Dohrenwend, 1971; personal communication, 1974), however, and the proposed bend is therefore queried on the map of Greene and others (1973).

The Palo Colorado fault was described by Trask (1926) as one of a family of probable high-angle reverse faults that trend northwest–southeast in the northern Santa Lucia Range. Faults of this set locally thrust Salinian granitic basement rocks over lower Tertiary sedimentary rocks with dip-slip displacements of at least several hundred meters (Trask, 1926; Dickinson, 1965; Compton, 1966). Most published geologic maps of the region

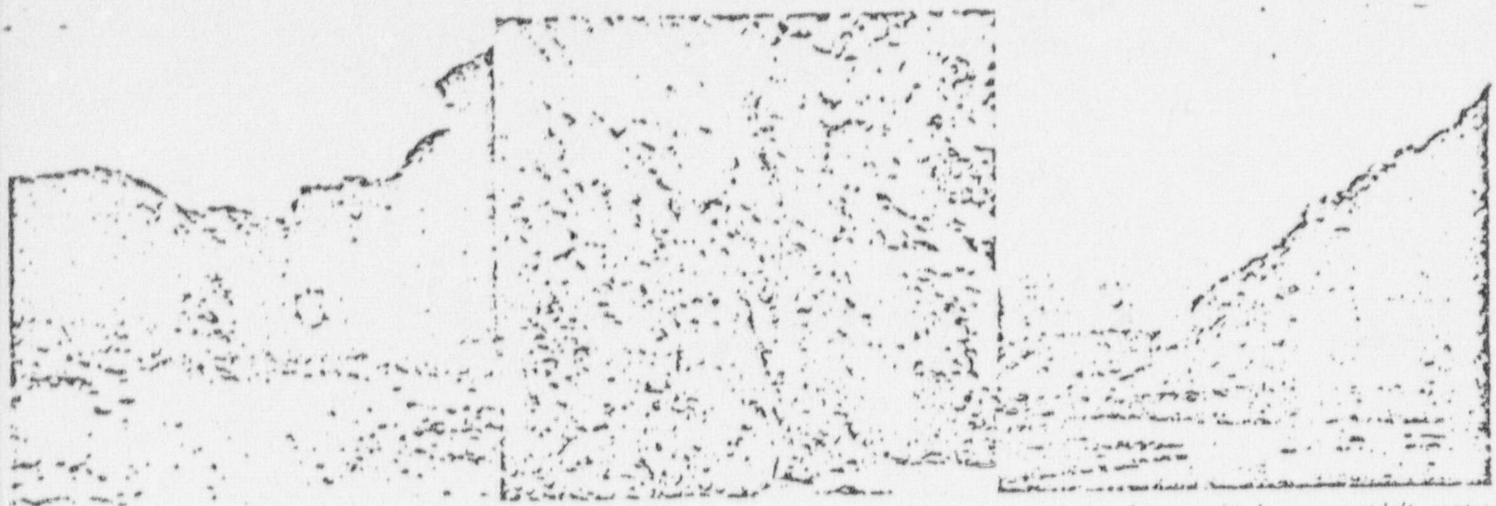

FIGURE 3. *Left,* seacliff exposure of the Palo Colorado fault (in gully) separating Paleocene (?) turbidites at right from granitic basement at left; *center,* highly sheared granitic basement involved in the Rocky Creek fault zone; staff is 1.5 meters; *right,* retaining wall (3 meters high) at base of seacliff exposures of Rocky Creek fault zone.

have shown the Palo Colorado fault terminating to the south against the east–west Willow Creek fault (figure 2) within the granitic basement terrain of the Salinian block (Reiche, 1937; Dickinson, 1965; Dibblee, 1974). A recent basement geology map by Ross (1976) alternatively shows the Palo Colorado fault as veering more southerly to join the Coast Ridge fault zone; however, this connection was inferred solely from the distribution of charnockitic basement rocks and was not field checked by Ross.

The southern course of the Palo Colorado fault is not critical to the present discussion; more important is the presumed continuity of the San Gregorio and Palo Colorado faults. Several observations make the correlation uncertain, if not untenable. The connection between the two faults was inferred in a region where data are poor, providing an unusual resultant geometry. In its type area, the San Gregorio fault has characteristics typical of strike–slip faults, such as a broad, complex, vertical fault zone. In contrast, sea cliff exposures of the Palo Colorado fault north of Point Sur reveal a modest, meter–thick shear zone separating granitic basement and upper Cretaceous or Paleocene sedimentary rocks (figure 3), which occur in normal depositional contact nearby at Carmel. High–angle reverse faults commonly are associated with strike–slip fault zones, particularly as splays or as connecting fault segments (e.g., Dickinson, 1966), but the Palo Colorado fault has been depicted as the primary extension of the San Gregorio fault and not as an auxiliary fault (e.g., Green and others, 1973). However, the Palo Colorado fault resembles neither the San Gregorio fault in its type area nor other well–documented strike–slip faults like the San Andreas fault. Moreover, it is not more than about 50 km long, regardless of which trace is selected as its southern extension.

If the San Gregorio and Palo Colorado faults were continuous, the fault system could have no significant strike–slip component because the Palo Colorado fault, using either interpretation of its southern course, dies out within the Salinian block without disrupting the depositional patterns of sedimentary units (Graham, 1976a). Furthermore, the Church Creek high–angle reverse fault (figure 2), subparallel and nearby to the northeast, converges with the Palo Colorado fault near the coast (Dibblee, 1974) and is constrained to minimal strike–slip movement by the cross–fault occurrence of a unique graphic–pyritic basement unit near its southern end (Wiebe, 1970, Ross, 1976). These data and evidence for an alternative southern extension of the San Gregorio fault, discussed below, seemingly disallow the Palo Colorado fault either as a major strike–slip fault or as the main southern extension of the San Gregorio fault. This conclusion does not imply, however, that the San Gregorio fault and the high–angle reverse faults of the northern Santa Lucia Range are unrelated. As will be seen, the San Gregorio fault is likely post–middle Miocene and is thus approximately synchronous with the permissive Plio–Pleistocene age of the Church Creek, Palo Colorado, and allied faults (Compton, 1966). The whole family of faults is more readily understandable in the larger context of the Salinian block and the San Andreas fault system (Graham, 1976a), which will be considered briefly in the final section of this discussion.

Where the Palo Colorado fault fails as the southern extension of the San Gregorio fault, a seemingly more viable alternative pathway extends the San Gregorio fault south from the head of Carmel submarine canyon into the onshore Sur fault zone north of Point Sur (figure 2). This pathway then diverges from the Sur zone as mapped when it trends offshore again southeast of Pfeiffer Point, and ultimately joins with the San Simeon–Hosgri fault system (Hall, 1975; Wagner, 1974) along the coast farther south (figure 2).

The Sur fault zone long has been recognized as a complex feature forming the boundary between Salinian granitic basement on the northeast and Franciscan complex on the southwest (e.g., Trask, 1926). Although this key contact is primarily a relic of underthrusting at a Mesozoic convergent continental margin (Page, 1970), the Sur zone itself also had a Neogene history of activity that likely included strike–slip movement in the Point Sur area (Gilbert, 1971; Gilbert, 1973). The actual connection of the Sur zone and the San Gregorio fault is not yet defined, but it may in part utilize an unnamed shear zone well displayed in cliffs at the mouth of Rocky Creek (figure 2). Unlike the coastal exposures of the Palo Colorado fault, the Rocky Creek fault is a shear zone several hundred meters wide, including numerous shear surfaces and gouge zones (figure 3). The steep cliffs of sheared material tend toward failure, and a massive concrete retaining wall has been constructed at the strand line at the base of the cliffs (figure 3). The Rocky Creek shear zone separates granitic intrusives on the northeast from a small structural block of Salinian schist basement on the southwest and trends into the Sur zone, 6 km to the southeast (Dibblee, 1974).

Two pieces of evidence provide additional support for the San Gregorio–Sur connection. (1) The Franciscan in the vicinity of

Point Sur (figure 4) is an unmetamorphosed, albeit structurally complex, graywacke–mudstone assemblage in which detrital K-feldspar is present (Gilbert, 1971). In contrast the Franciscan complex in the on-land exposures in the Lopez Point area nearby to the south (figure 4) is a blueschist-facies metamorphic sequence in which K-feldspars are absent (Gilbert, 1971). Strike-slip movement on the San Gregorio fault utilizing the Sur zone in the Point Sur area readily explains the striking local contrasts in Franciscan facies observed in the area. Furthermore, as discussed below, the unmetamorphosed Franciscan of the Point Sur area apparently is offset in a right-lateral sense from similar rocks far to the south, thus supporting the Sur pathway. (2) A small fault-bounded slice of Miocene sandstone within the Sur fault zone (figures 4 and 5) is composed exclusively of Franciscan-derived detritus (Trask, 1926; Brooke, 1957; Gilbert, 1971; Graham, 1976a). This sandstone crops out less then 2 km from Salinian granitic basement known to be subaerially exposed through much of Miocene time (Graham, 1976a), yet contains no Salinian detritus. Although special circumstances could be invoked to explain the presence of the Franciscan-derived sandstone, right-lateral strike-slip on a San Gregorio–Sur fault system offers the most convenient explanation.

Evidence for the course of the San Gregorio fault south of its presumed divergence from the Sur zone offshore southeast of Pfieffer Point is circumstantial. We infer a near-shore fault from Pfieffer Point to the San Simeon area primarily on the basis of the apparent on-strike alignment of the San Gregorio and Hosgri faults (figure 2). Some previous investigators (Hoskins and Griffiths, 1971; Wagner, 1974) have shown the Hosgri fault trending out to sea south of San Simeon (figure 1) rather than emerging onshore as the San Simeon fault (Hall, 1975). Hall's Point Sur–San Simeon ophiolite–Tertiary rock offset (discussed below) depends on the validity of the latter interpretation. The presumed connection lies, as is the case with the San Gregorio–Palo Colorado–Sur problem, near shore in shallow water where acoustic data of good quality are difficult to obtain. The near-perfect alignment of the prominent San Gregorio and Hosgri fault segments through the San Simeon fault segment seems to us unlikely to be a chance phenomenon, even though the details of the San Gregorio–Hosgri connection are uncertain. Furthermore, if our offset criteria are correct, such a connection is required.

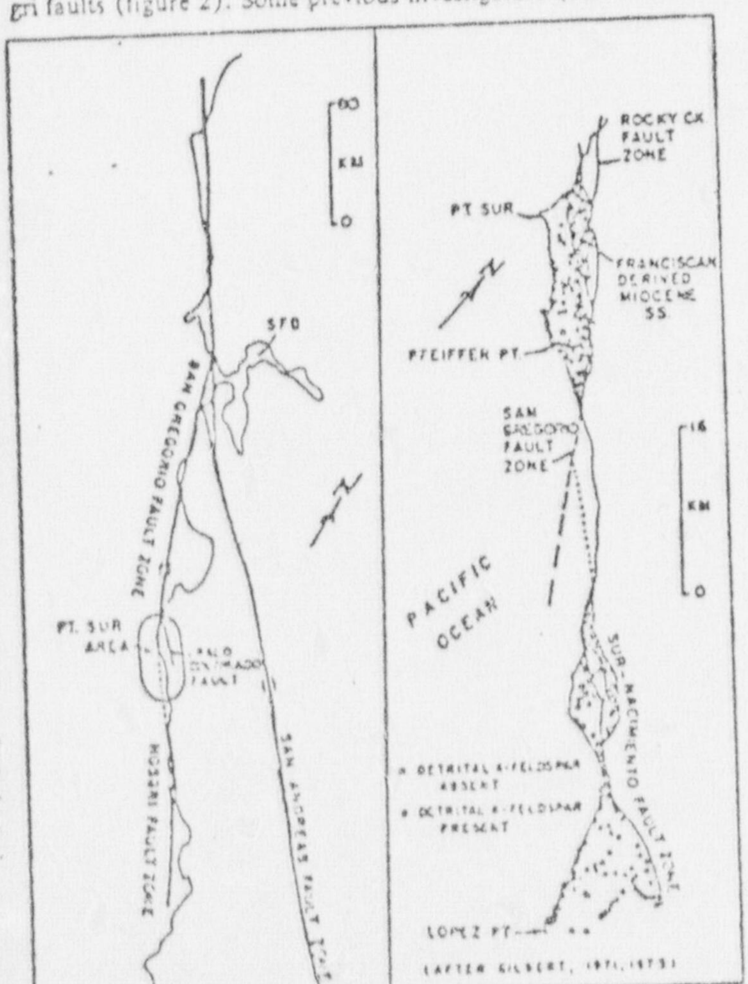

FIGURE 4. Course of the San Gregorio fault in the Point Sur area, and cross-fault contrasts in Franciscan sandstone composition and metamorphic grade.

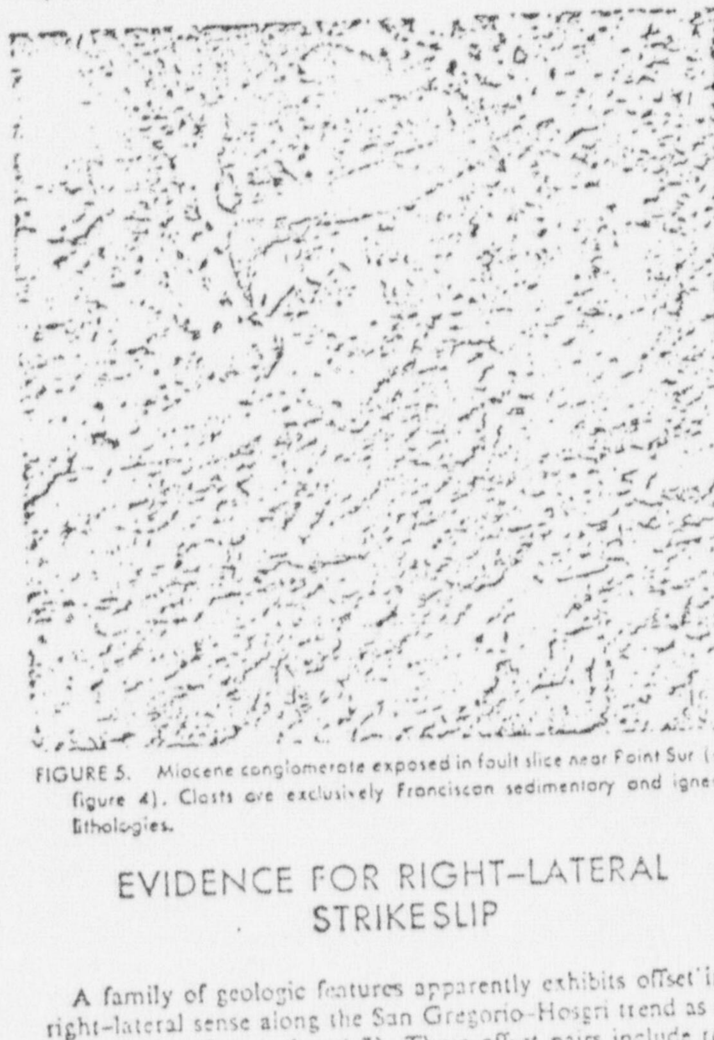

FIGURE 5. Miocene conglomerate exposed in fault slice near Point Sur (see figure 4). Clasts are exclusively Franciscan sedimentary and igneous lithologies.

EVIDENCE FOR RIGHT–LATERAL STRIKESLIP

A family of geologic features apparently exhibits offset in a right-lateral sense along the San Gregorio–Hosgri trend as defined above (figures 6 and 7). These offset pairs include rock bodies, sedimentary units and inferred source terranes, a pre-San Gregorio fault, and a late-Cretaceous basin margin. The latter two are linear features whose intersection with the San Gregorio-Hosgri fault trend produces piercing points from which, ideally, the best estimates of offset are obtained (Crowell, 1962). Nevertheless, because of uncertainties inherent in the estimation of the boundaries or positions of all of these features, offset values are given in terms of ranges. Assuming valid cross-fault correlations, the overlap of offset ranges indicates approximately 115 km of right-lateral strike-slip on component faults of the San Gregorio-Hosgri fault trend (figure 7). Few, if any, of the offset pairs discussed below individually constitute unique evidence. Taken together, however, we feel that they present a compelling argument for major right-lateral strike-slip on faults of the San Gregorio-Hosgri fault trend.

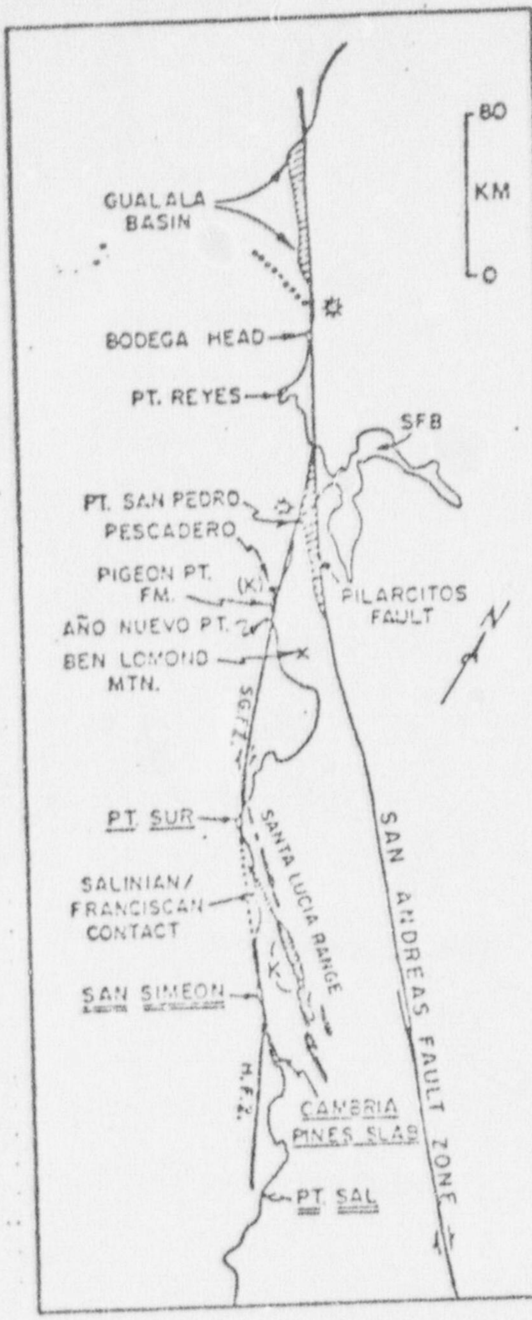

FIGURE 6. Map of geologic features offset in a right-lateral sense along the San Gregorio–Hosgri fault trend. See text for discussion.

Bodega/Gualala Fault – Pilarcitos Fault Offset Pair

The Pilarcitos fault (figures 1 and 6) lies along the spine of the San Francisco Peninsula subparallel to the San Andreas fault, truncated to the south by the San Andreas fault and to the north offshore by the San Gregorio fault (modification of Cooper, 1973, based on later data: K. Lajoie, personal communication, 1976; Graham, 1976a). The Pilarcitos fault, although lying west of the modern San Andreas fault (figure 6) is the local structural boundary between Franciscan complex on the northeast and Salinian granitic basement on the southwest, and, thus, is considered to be an inactive and cut-off trace of the San Andreas fault (e.g., Nilsen and Simoni, 1973). Poorly exposed and poorly studied lower Tertiary rocks unconformably (?) overlie Franciscan complex within the structural block between the Pilarcitos and the San Andreas faults (Brabb, 1970).

Far to the north, the last on-land exposures of granitic basement of the Salinian block occur at Bodega Head immediately west of the San Andreas fault as it heads offshore (figure 6). Where the fault re-emerges 22 km to the north, the terrain west of the fault is underlain by a thick sequence of Cretaceous through Eocene sedimentary rocks comprising the Gualala basin (Wentworth, 1968). The basement of the Gualala basin is not known with certainty, but spilitic basalts, possibly of Franciscan affinity, structurally and perhaps stratigraphically underlie the oldest sediments (Wentworth, 1968). If the Gualala basin is underlain by Franciscan complex, then a structural contact between Franciscan complex and Salinian granitic basement analogous to the Pilarcitos fault must exit between the Gualala basin and Bodega Head and be truncated offshore between those points by the San Andreas fault (figure 6). We conclude that these two Franciscan-granitic basement contacts may be equivalent and offset from each other in a right-lateral sense along a San Gregorio–San Andreas pathway (stars in figure 6).

If perfectly known, offset fault traces would provide piercing points in the San Gregorio–San Andreas fault plane which would yield accurate estimates of the magnitude of offset. Unfortunately, both intersections lie offshore in regions of poor or non-existent data. Consequently, we present an offset range (figure 7) with a minimum based on the position of the Bodega Head exposures (92.5 km) and a maximum based on the southern limit of exposures of the Gualala basin (115 km).

The Gualala-Pilarcitos correlation can be tested. If the two faults are offset equivalents, the Gualala basin sedimentary units are offset lateral equivalents of the lower Tertiary sedimentary rocks at Pt. San Pedro in the Santa Cruz Mountains (figure 6). Both sequences are deep-sea fan facies with northwesterly paleocurrent directions (Wentworth, 1968; Chipping, 1972). A modest amount of petrographic data are presently available for these areas, but more must be obtained to test the correlation adequately.

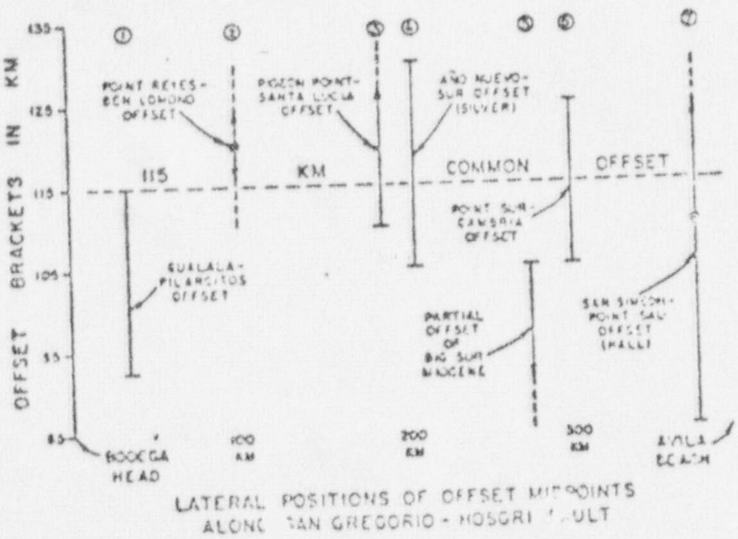

FIGURE 7. Offset range chart for suggested offset pairs.

Point Reyes Section – Ben Lomond Mountain Section Offset Pair

The granitic basement of the Point Reyes Peninsula (figure 6) is blanketed partially by erosional remnants of Paleocene and more extensive Neogene sedimentary rocks (figure 8). The Neogene units comprise two unconformity-bound sedimentary packages (Galloway, 1976; Blake and others, 1974): a Miocene couplet of shallow marine sandstone overlain by basinal siliceous shales (Laird Sandstone and Monterey Formation) and an upper Miocene-Pliocene couplet of shallow marine sandstone and overlying basinal mudstones ("sandstone and mudstone near Drakes Bay"). The Paleocene rocks are primarily conglomerate, with lesser amounts of sandstone and mudstone. Our observations suggest that the Paleocene rocks, preserved only at Point Reyes proper, were deposited in an inner fan or channelized mid-fan environment (terminology of Ricci-Lucchi, 1975) on a Paleocene deep-sea fan. This interpretation is substantiated by a probable lower bathyal (> 2000-meter water depth) foraminiferal fauna obtained from the mudstone (A. J. Galloway, written communication, 1975).

The Santa Cruz Mountains to the south of San Francisco are underlain by a relatively complete Tertiary section of rocks, but the southern flank of the Ben Lomond Mountain (figure 6) basement uplift displays an abbreviated Tertiary section (figure 8). The Ben Lomond Mountain section includes a Paleocene unit (Locatelli Formation) unconformably overlain by unconformity-bound, shallow marine sandstone/basinal mudstone packages (Clark, 1966) of middle Miocene (Lompico Sandstone/Monterey Formation) and late Miocene-Pliocene age (Santa Margarita Sandstone/Santa Cruz Mudstone). The Paleocene Locatelli Formation contains a shallow marine fauna near its base, but a deep marine fauna in its upper part (Clark, 1966; Clark, 1968). We suggest that the Point Reyes-Ben Lomond Mountain sections, with their unusual Paleocene/middle Miocene/upper Miocene-Pliocene sedimentary packaging, are lateral equivalents offset by the San Gregorio fault (x's in figure 6; figure 7). Clark (1968), in his thorough study of the southern Santa Cruz Mountains, noted the virtual identity of the Point Reyes and Ben Lomond Mountain Neogene sections. The spottily preserved Paleocene rocks of both areas are deep-water marine facies, although perhaps deposited in differing submarine fan environments. In addition, a reconnaissance study of Salinian basement rocks by Ross (1972) revealed an abundance of alaskite dikes in only two areas, the Point Reyes and Ben Lomond Mountain areas.

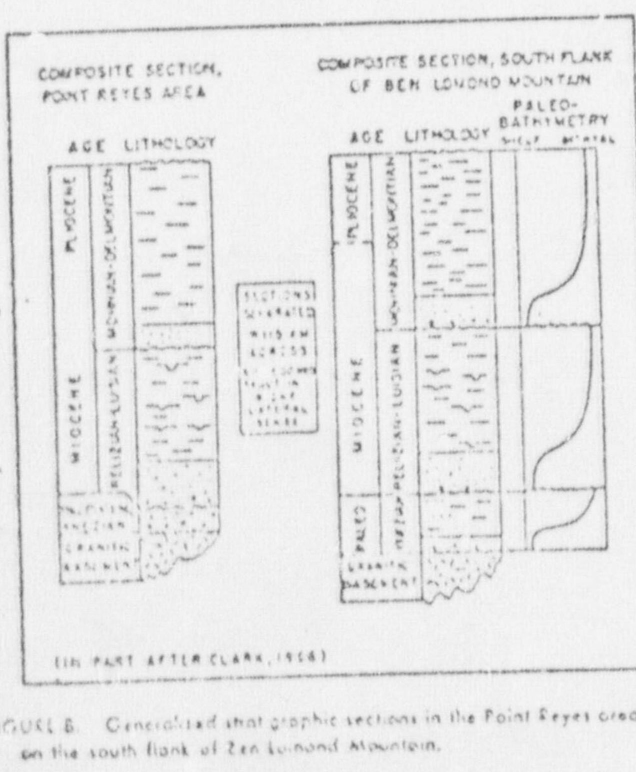

FIGURE 8. Generalized stratigraphic sections in the Point Reyes area and on the south flank of Ben Lomond Mountain.

The offset rock bodies offer no absolute constraints on the amount of right-slip. A minimum of 115 km is based on the southern limit of Eocene rocks cropping out on the northern flank of Ben Lomond Mountain, while the most reasonable apparent value is about 120 km.

Pigeon Point Formation – Santa Lucia Cretaceous Offset Pair

The upper Cretaceous Pigeon Point Formation (Hall and others, 1959) crops out extensively west of the San Gregorio fault from San Gregorio to Año Nuevo Point (figure 6), but is unknown directly across the fault to the east in the Santa Cruz Mountains (Cummings and others, 1962). The conglomerate-mudstone-sandstone succession is best characterized as a regressional/progradational deep-sea fan-to-shelf sequence (Lowe, 1972). Approximately fifty paleocurrent measurements (Wentworth, 1960; Paredes, 1960) obtained from a variety of turbidite-associated paleocurrent indicators suggest dispersal to the south-southwest. Pigeon Point Formation conglomerates, common in the channelized fan facies, contain some Salinian basement-derived clasts, but are composed principally of well-rounded clasts of acidic to intermediate composition, varicolored, porphyritic volcanics (Tyler, 1972). The ultimate source of these volcanic clasts, common in Coast Range Cretaceous and Tertiary sedimentary rocks, remains unknown.

Cretaceous sedimentary rocks are present from San Gregorio to Año Nuevo Point, but occur nowhere else on the Salinian block from San Francisco to Monterey. Rocks very similar to the Cretaceous Pigeon Point Formation in facies and composition rest on basement south of Monterey in the vicinity of Carmel (the Carmelo Formation, Bowen, 1965). However, those rocks are Paleocene, while the Pigeon Point Formation is entirely upper Cretaceous, based on molluscs we have found in the uppermost shallow marine facies of Lowe (1972). Cretaceous sedimentary rocks do crop out a few tens of kilometers farther south of Carmel (figure 6) in the Point Sur (Trask, 1926) and Lucia (Reiche, 1937) quadrangles, and then in a nearly continuous strip down the Santa Lucia Range to the Transverse Ranges (Jennings, 1958; Jennings and Strand, 1958).

The Cretaceous strata of the northern Santa Lucia Range are virtually unstudied, but abundant shallow marine fossils occurring locally near the base of the sequence (Reiche, 1937) may indicate that the rocks are, in part, shallow marine in origin. Twenty kilometers inland along depositional strike to the southeast in the upper Arroyo Seco area, upper Cretaceous sandstones and conglomerates, bearing evidence of southwesterly directed paleocurrents, likely were deposited as a submarine canyon-fill (Ruetz, 1976). Apparently two different clast assemblages characterize the upper Cretaceous conglomerates, a porphyritic volcanic-dominated suite in northern outcrops and a Salinian basement-dominated suite in southern outcrops (Reiche, 1937; Ruetz, 1976).

The Pigeon Point Formation thus may be offset from the porphyritic volcanic-bearing Cretaceous rocks of the northern Santa Lucia Range by right-slip on the San Gregorio fault (black areas in figure 6; figure 7). Limited paleocurrent and paleoenvironmental data are compatible with such a correlation. In the Arroyo Seco area, the overlap of Cretaceous rocks by Paleocene deep-sea fan deposits defines the local northern limit of the Cretaceous basin (Ruetz, 1976). The limit of the Cretaceous basin along depositional strike at the coast can be no farther south than the Carmel area, where Paleocene rocks rest n basement. The basin edge could lie as far south as the Palo Colorado fault (figure [illegible] f the sandstones exposed where the ault intersects the c[illegible] Tertiary (W. R. Dickinson, unpubished data) rath[illegible] etaceous (Trask, 1926; Dibblee, 974). The Cre[illegible] edge constitutes a linear feature which would y[illegible] imate of San Gregorio offset if the basin edge was be[illegible] ined near the coast. No Paleocene strata are associated with the Pigeon Point Formation to define the Cretaceous basin margin west of the San Gregorio fault, but we take the shallow marine facies capping the Pigeon Point Formation to signal immediate proximity to a Cretaceous basin margin. Assuming that the Palo Colorado coastal sandstones are Paleocene as inferred here, the Cretaceous basin margin is offset by a minimum of 110 km (figure 7).

Preliminary comparison of Oligocene-Miocene rocks overlying the Pigeon Point Formation with coeval strata of the northern Santa Lucia Range supports the cross-fault Cretaceous ties. Upper Oligocene-lower Miocene shallow-marine sandstone and interbedded basaltic volcanics at Pescadero and coeval deep-marine mudstone at Año Nuevo Point (figure 6; Clark and Brabb, 1977, and this volume) suggest a south-facing paleoslope. Similarly, a southwest-facing late Oligocene–early Miocene paleoslope (not shown in figure 6) is documented for the northern Santa Lucia Range (Graham, 1976a,b). In addition, restoration of 115 km of right-slip places the Pescadero basalts on projection from a trend of upper Oligocene-lower Miocene bimodal volcanics (e.g., Ernst and Hall, 1974; Graham, 1976a) cropping out south of and parallel to the Cretaceous outcrop band in the Santa Lucia Range at the southwest margin of the Salinian block (figure 6).

Offset of Offshore Gravity Ridge

Silver (1974) proposed that an offshore linear gravity "high" was offset 90 km by right-lateral strike-slip on the San Gregorio fault. The southern flank of the feature comes ashore near Año Nuevo Point west of the fault and was suggested to be offset from the edge of Salinian basement marked by the Sur fault where it trends offshore north of Point Sur. Remeasuring the indicated offset to the edge of Salinian basement south of Point Sur, we suggest a range of 105 to 130 km (figure 7) for Silver's offset.

Point Sur Franciscan – Cambria Pines Slab Offset Pair

A cross-fault contrast in metamorphic facies in the Franciscan complex serves to define the probable course of the San Gregorio fault near Point Sur (figure 4). From the Point Lopez area south, the Franciscan complex contains extensive mélange units, is metamorphosed to varying degrees, and generally is devoid of detrital K-feldspar (Gilbert, 1971; Hsu, 1969). However, an unmetamorphosed K-feldspar-bearing Franciscan graywacke sequence is exposed near Cambria (Hall, 1974), and we suggest that this Cambria Pines slab (Hsu, 1969) is the offset equivalent along the San Gregorio-Hosgri trend of the unmetamorphosed K-feldspar-bearing Franciscan complex at Point Sur (figures 4 and single underlines in figure 6). Matching the north end of the Cambria Pines slab with the north end of the Point Sur block yields a minimum offset of 105 km. The southern end of the Cambria Pines slab must lie under Estero Bay, based on the on-land distribution of Franciscan lithologies (Hsu, 1969; Hall, 1973), thus setting the probable upper limit of offset at 125 km.

Point Sur Miocene Sandstone–Franciscan Source Terrane Offset Pair

As discussed earlier, the position of a Franciscan-derived Miocene sandstone caught within the San Gregorio–Sur fault zone east of Point Sur (figures 4 and 5) is incompatible with its immediate proximity to Salinian basement. At least 60 km of right-slip on the San Gregorio–Hosgri fault trend is required to provide an adequate source terrane for the Miocene sandstone. The offset of the sandstone cannot exceed 105 km, however, because it contains no volcanic clasts derived from the Cambria Felsite as do Miocene sandstones in the Cambria area (Hall, 1974). This maximum is less than the minimum offset indicated for certain of the offset pairs (figure 7), but the lack of overlap poses no problem because the Miocene sandstone is in a fault-bounded slice which likely was incorporated in the fault zone at an intermediate distance.

San Simeon Ophiolite–Point Sal Ophiolite Offset Pair

Hall (1975) reported the probable offset of a Mesozoic ophiolite and overlying distinctive Tertiary sequence from Point Sal to the San Simeon area along the San Simeon–Hosgri segment of the then unrecognized larger San Gregorio–Hosgri fault trend (double underlines in figure 6). Hall claimed a minimum of 80 km of offset, but in reexamining local relations we suggest a minimum of 85 km from the north end of San Simeon outcrops to the limit of outcrops at Point San Luis. An offset value of 110 km is gained from the center of the outcrop pattern west of the fault to the center of the outcrops east of the fault (figure 7).

TIMING OF MOVEMENT

Geologic relations indicate that the offset of the Point Sal–San Simeon ophiolite–Tertiary sequence by the Hosgri fault segment was accomplished 5–13 million years ago (Hall, 1975). Most of the indicators on the San Gregorio segment merely indicate a post–Cretaceous age, but two offset pairs are more specific. The fault slice of Miocene sandstone near Point Sur contains *Crossostrea titan subtitan* (Trask, 1926; Graham, 1976a). Although ranging throughout the Miocene, this mollusc is most typical of lower Miocene strata in the Cambria area (Hall, 1974). We thus infer that major right-slip involving the sandstone is probably post-lower Miocene. The Point Reyes–Ben Lomond Mountain offset pair relies on similar middle Miocene and upper Miocene–Pliocene sections. If valid, this correlation implies that right-slip may have commenced by at least late Miocene time, and the sub-upper Miocene unconformity could reflect this event. A late Miocene or conservative post-middle Miocene age for the initiation of strike-slip is compatible with the timing suggested for the Hosgri segment.

At 6 cm/yr, the rate of movement on the modern San Andreas fault (e.g., Dickinson and others, 1972), the entire 115 km of indicated right-slip could be accomplished in less than 2 million years. At least modest Holocene movement on elements of the San Gregorio-Hosgri fault trend is indicated by the local thrusting of Miocene rocks over terrace deposits at Año Nuevo Point (Clark, 1970, Weber and LaJoie, 1977), by probable offsets of the sea floor locally (Greene and others, 1973; Wagner, 1974), and by seismicity (Gawthrup, 1977). However, the major period of movement may well have been earlier.

THE ROLE OF THE SAN GREGORIO–HOSGRI FAULT TREND IN THE SAN ANDREAS FAULT SYSTEM

The assumption of approximately 115 km of post-middle Miocene right-lateral strike-slip on faults of a San Gregorio–Hosgri fault trend connecting with the San Andreas fault implies that the total offset of Salinian basement by the San Andreas fault is only an apparent number integrating the offsets of both the San Gregorio and the San Andreas faults. The minimum total offset (510 km) is based on the northernmost on-land exposures of Salinian basement at Bodega Head (figure 9), while a maximum estimate (600 km) assumes granitic basement offshore to near Point Arena (Silver and others, 1971). Deducting 115 km of San Gregorio–Hosgri right-slip from the 600/510 km maximum/minimum on the San Andreas total leaves 485/395 km maximum/minimum of right-slip on the San Andreas fault zone *sensu strictu* (figure 9). Post-Oligocene ("modern") San Andreas right-slip, all based on cross-fault ties south of the San Gregorio-San Andreas juncture and thus unaffected by it, amounts to approximately 310 km (Dickinson and others, 1972; Matthews, 1976). Consequently, since no major right-slip faults other than the San Gregorio-Hosgri trend are known to intersect the San Andreas fault zone, the difference between the true San Andreas basement offset (having removed the San Gregorio–Hosgri component) and the post–Oligocene San Andreas right-slip must be a measure of right-slip on a pre–Oligocene proto-San Andreas fault roughly coincident in central California with the trace of the "modern" San Andreas fault zone (figure 9). Proto–San Andreas right-slip thus amounts to 175/85 km maximum/minimum.

The timing of movement on such a proto-San Andreas fault has been discussed elsewhere (e.g., Dickinson and others, 1972; Nilsen and Link, 1975), but it must certainly be pre-Eocene to honor the Butano-Point of Rocks cross-fault tie (Clark and Nilsen, 1973). An intra-Paleocene age is suggested by unconformable relations in nearby areas (Graham, 1976a, b). Significantly, however, consideration of right-slip on the San Gregorio-Hosgri fault trend reduced by at least a third and perhaps by two-thirds the apparent right-slip on the proto-San Andreas fault were the San Gregorio-Hosgri trend not considered. Furthermore, if Sierran basement east of the San Andreas fault underlies Tertiary basin fill (queried, dotted line in figure 9) northwest of its outcrop limit, and if Bodega Head west of the fault is close to the northern limit of Salinian basement, restoration of Neogene San Gregorio-Hosgri and San Andreas right-slip accounts for all basement separation. In those extreme conditions, a proto-San Andreas fault coincident with the modern San Andreas fault in central California is without support.

The right-slip history of the San Andreas fault is conveniently displayed in a time-versus-displacement graph (figure 10). Curve A, Figure 10, is the San Andreas fault time-displacement curve of Dickinson and others (1972) and Nilsen and Link (1975), modified in accordance with a Miocene–Pliocene boundary near 5 M.Y.B.P. (see Graham, 1976a, for further discussion). The curve clearly shows the two-stage nature of the history of the San Andreas fault. The dotted modification of the San Andreas curve prior to 60 M.Y.B.P. represents the effect of disregarding San Gregorio-Hosgri right-slip, while the solid curve considers San Gregorio-Hosgri right-slip and hence is the "true" San Andreas time-displacement curve.

Curve B, Figure 10, represents the history of relative movement between the Pacific and North American plates (Atwater and Molnar, 1973). Within the limits of uncertainty inherent in both curves, it is apparent that most movement between the two plates has been accomplished solely by the San Andreas fault for at least the past six million years. Between that time and the early Miocene, the two curves diverge, but most of the plate motion can be distributed between the San Andreas and San Gregorio–Hosgri faults. The latter is probably best regarded as an offshore strand of the former, and as such, probably absorbed a large proportion of the relative motion between the Pacific and North American plates prior to Pliocene time.

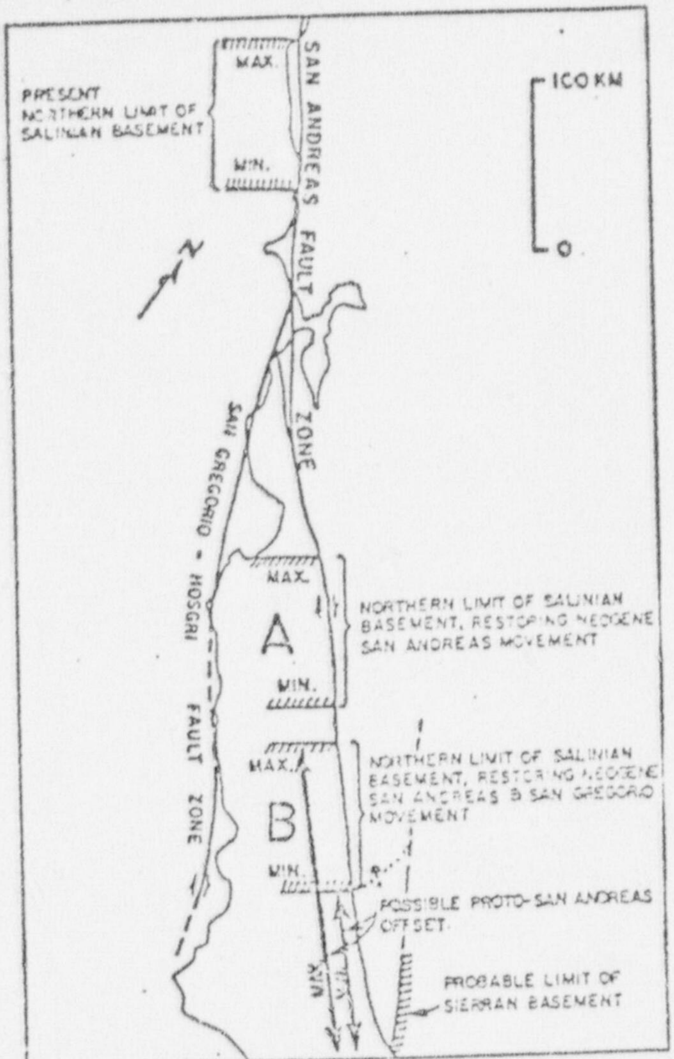

FIGURE 9. (A) Restoration of Neogene right-slip on the San Andreas fault alone, and (B) on the San Andreas fault plus San Gregorio–Hosgri fault trend. Remaining offset of granitic basement not accounted for by Neogene San Andreas and San Gregorio–Hosgri right-slip may be a measure of right-slip on a proto–San Andreas fault.

These data thus constitute a compromise between two extreme views of the evolution of the San Andreas fault: a two-stage proto–San Andreas history (e.g., Suppe, 1970), and a single-stage history involving Neogene slicing and extension of Salinian basement via the San Andreas fault and a system of allied faults (Johnson and Normark, 1974). Our consideration of the San Gregorio-Hosgri fault trend indicates that there was an episode of proto-San Andreas right-slip, albeit considerably more modest than previously supposed. In addition, however, the San Andreas fault clearly is the major component in a larger Neogene to recent San Andreas fault system of which the San Gregorio Hosgri fault trend is a part. The proto-San Andreas right-slip episode may have entailed an extensive fault system analogous to the Neogene San Andreas system, as suggested by

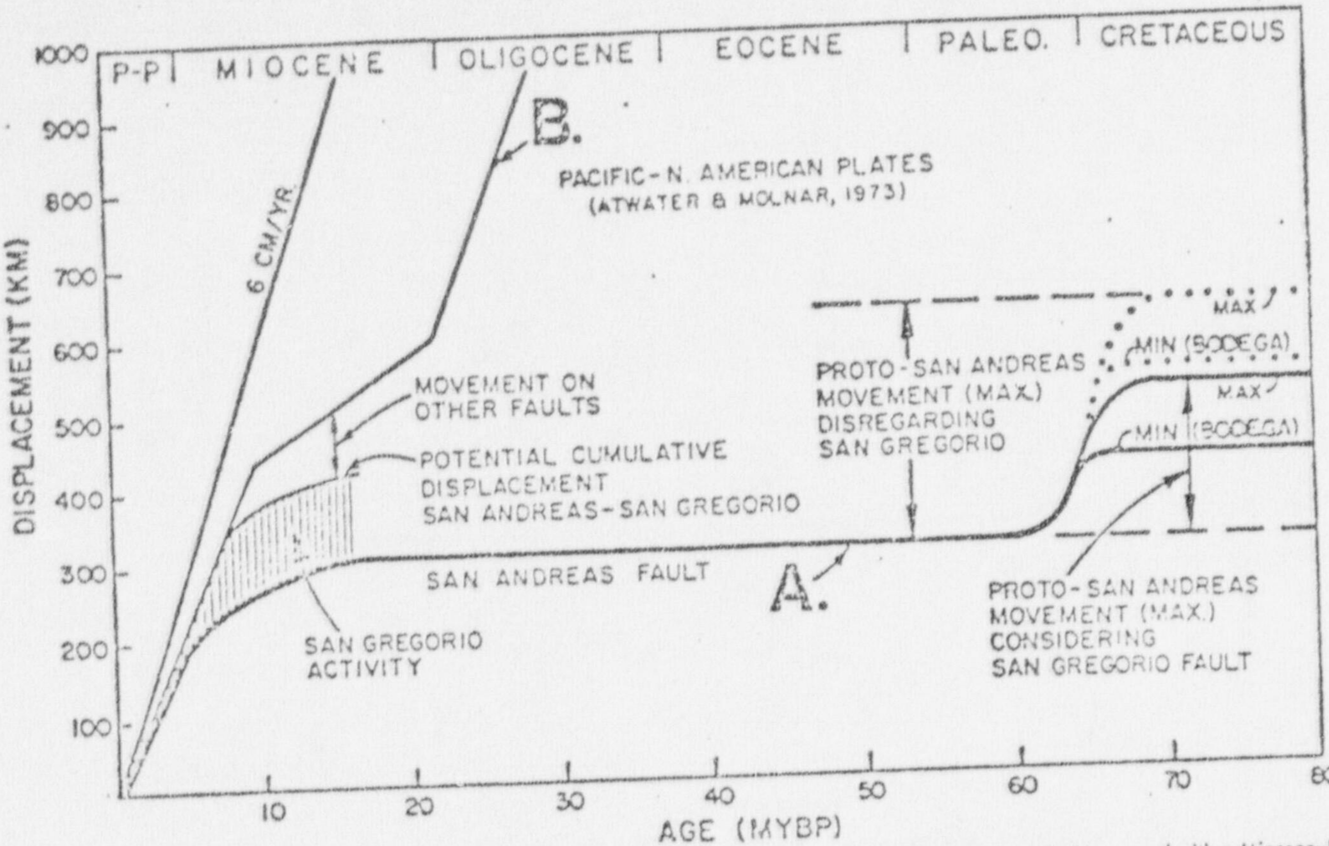

FIGURE 10. Time–offset curves. (A) San Andreas fault curve (Dickinson and others, 1972; Nilsen and Link, 1975) modified in accord with a Miocene–Pliocene boundary at about 5MYBP and to display the effect of San Gregorio–Hosgri fault zone right-slip; (B) Relative motion of the Pacific and North American plates. See text for discussion.

the early Tertiary continental borderland configuration (Nilsen and Clarke, 1975), but the details of such a system remain uncertain. The proto-San Andreas fault system possibly was the structural resolution of early Tertiary oblique subduction, rather than a transform fault system like the modern San Andreas fault system. This inference is compatible with reconstructions showing late Cretaceous–early Tertiary oblique convergence between the Farallon and North American plates (Coney, in press).

Acknowledgments

Our research was supported in part by the Earth Science Section, National Science Foundation, NSF Grant DES 7201728. Megafossil identifications were provided by W. O. Addicott. Chevron U.S.A. assisted in preparation of the manuscript.

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UNITED STATES OF AMERICA
NUCLEAR REGULATORY COMMISSION

Before The Atomic Safety & Licensing Board

In The Matter Of:)
)
PACIFIC GAS & ELEC[T]RIC COMPANY) Docket Nos. 50-275 OL
(Diablo Canyon Nuclear Power) 50-323 OL
Plant, Units 1 & 2))

CERTIFICATE OF SERVICE

I hereby certify that I have this 21st day of November, 1978 served copies of the foregoing TESTIMONY OF THE JOINT INTERVENORS - STEPHAN ALAN GRAHAM upon all of the parties listed below by depositing copies thereof in the U.S. Mails, first-class, postage prepaid.

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