Possible Correlations of Basement Rocks Across the San Andreas, San Gregorio-Hosgri, and Rinconada-Reliz-King City Faults, California

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By DONALD C. ROSS

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A summary of basement-rock relations and problems that relate to possible reconstruction of the Salinian block before movement on the San Andreas fault

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By DONALD C. ROSS

ABSTRACT

A reconstruction that treats the Salinian block as a southward extension of the Sierra Nevada is supported by (1) the possible correlation of several basement-rock features of the central Salinian block and the south end of the Sierra Nevada, and (2) reversal of right-lateral movement on the San Gregorio-Hosgri fault zone that significantly telescopes and shortens the north end of the Salinian block. However, currently accepted and documented movements on the San Gregorio-Hosgri and San Andreas fault zones are not great enough to allow either the Barrett Ridge slice or the K-feldspar-rich Cretaceous and lower Tertiary sedimentary rocks of the Gualala area to be derived from the southern Sierra Nevada. Additional fault displacement or transportation of exotic blocks from considerable distances would seem to be required. A model that treats the Salinian block solely as a fault-derived fragment of the southern Sierra Nevada does not appear to completely resolve the reconstruction problem. Yet the similarities between the basement rocks of the Salinian block and the southern Sierra Nevada are great enough that strong data would be required to support alternative models of Salinian-block origin.

INTRODUCTION

During the past several years, I have gathered considerable information on the distribution, petrography, and chemical composition of the granitic and metamorphic rocks of the California Coast and Transverse Ranges, particularly in the Salinian block. On the basis of that information, I previously noted (Ross, 1978) that a parent terrane for the Salinian block is not evident and that the southernmost Sierra Nevada is not a likely source terrane from which the Salinian block could have been derived. Three strong objections were made (Ross, 1977a, 1978) to a reconstruction that would place the Salinian block adjacent to the southern Sierra Nevada. First, hornblende-rich high-grade metamorphic rocks, which are widespread in the southernmost Sierra Nevada, appear to be absent from the Salinian block. Second, the Salinian block is practically barren of metallic mineralization, whereas metallic-mineral deposits are common in the southern Sierra Nevada. Third, there is no evidence in the Salinian block of metasedimentary rocks that could be correlative with the thick quartzite and marble units of the Cordilleran miogeocline—units that almost certainly reach the San Andreas fault southeast of the Sierra Nevada.

Two recent developments, however, lend support to a reconstruction model that would derive the Salinian block from the southern Sierra Nevada region. First, my mapping in the east-west-trending tail of the Sierra Nevada (San Emigdio Mountains) has revealed a major structural break that juxtaposes oceanic basement[1] on the north against continental basement on the south. The Vergeles-Zayante fault zone in the central Salinian block may be a continuation of that fault zone in the Sierra Nevada.

Second, Graham and Dickinson (1978a) and, more recently, Clark and others (1984) have suggested that significant right-lateral offset may have taken place along the San Gregorio-Hosgri fault zone. A reconstruction that took account of such offset could significantly telescope the northern part of the Salinian block (Bodega Head to Ben Lomond) and help resolve the longstanding contrast between suspected offsets on the San Andreas fault in southern and northern California. About 300 km of right-lateral offset on the San Andreas fault is documented by the offset of several Tertiary and basement-rock units across the fault in central and southern California. More than 500 km of right-lateral offset has been suggested in northern California on the assumption that the northernmost granitic outcrops in the Salinian block were once adjacent to granitic terrane on the northeast side of the San Andreas fault. The telescoping effect of the San Gregorio-Hosgri fault zone, inferrable from the the data of Graham and Dickinson (1978a, p. 17) and Clark and others (1984), removes more than half of the offset discrepancy.

In this report, I review data from selected basement-rock units in the Salinian block, the south-

[1]As used in this report, "oceanic basement" includes not only greenstone, basalt, and gabbro derived from oceanic crust, but also the Franciscan assemblage and associated rocks, most of which were deposited on, and are closely associated with, oceanic crustal material.

ernmost Sierra Nevada, and nearby areas in relation to the problem of offset on the San Gregorio-Hosgri, San Andreas, and Rinconada-Reliz-King City fault zones. I also discuss problems concerning the Barrett Ridge slice and the Gualala granitic clasts—problems that are difficult, if not impossible, to resolve on the basis of 300 to 350 km of basement movement between the central Salinian block and the southern Sierra Nevada.

By their very nature, basement-rock correlations are equivocal; for this reason, I place little faith in "one-to-one" basement-rock correlations. The comparison of several basement-rock units to several similar basement-rock units is much more convincing, and such a comparison is more apt to provide a genuine contribution to a correlation model; however, the correlations of Cordilleran granitic suites and their surrounding metamorphic rocks are particularly difficult because in this region similar rocks are widespread and recurrent. The work then becomes a search for unusual rock types that may be, if not unique, at least rare enough to be regionally significant. The younger, fossiliferous rocks, whose correlation parameters (such as shorelines and lithofacies pinchouts) are more definitive, give us a better chance for unequivocal correlations, but these younger rocks cannot be used to resolve fundamental offset problems concerning events that predate their existence. Thus, I have for the most part consciously ignored the younger sedimentary, volcanic, and alluvial units that are inherently part of any reconstruction

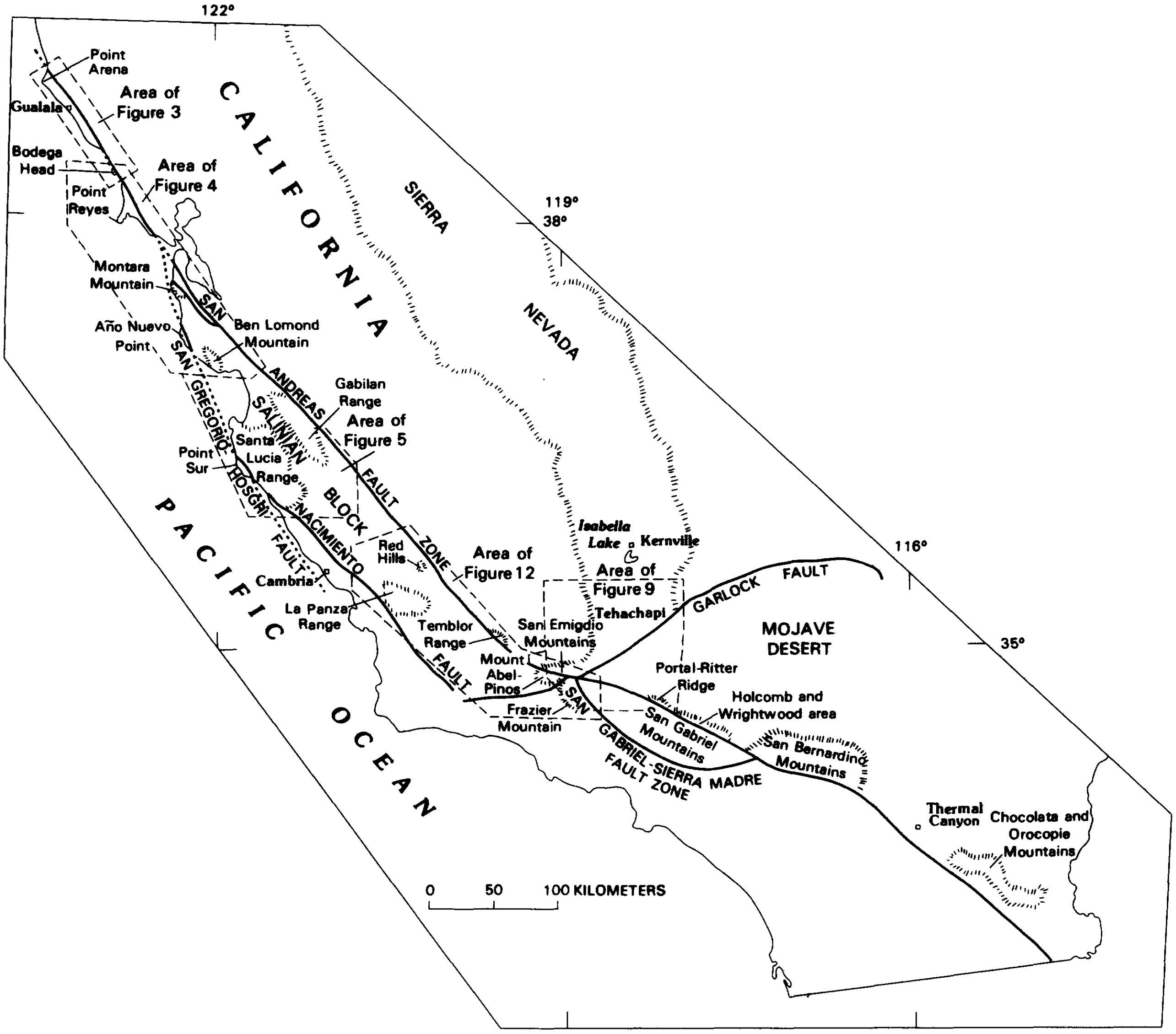

FIGURE 1.—Index map of central and southern California, showing selected geologic and geographic features and locations for figures 3, 4, 5, 9, and 12.

model; my studies have been concerned solely with the basement rocks and with the maximum movements of fault blocks, as recorded by these rocks.

A series of generalized geologic maps of parts of the Salinian block, the southern Sierra Nevada, and nearby related areas is included in this report to show the distribution of those basement-rock units that are pertinent to the discussion. Figure 1 shows the areas covered by these geologic maps.

SAN GREGORIO-HOSGRI FAULT ZONE

Graham and Dickinson (1978a, b) suggested as much as 115 km of right-lateral slip along the northern part of the San Gregorio-Hosgri fault zone, on the basis of correlation of several features across the fault zone, including: similar Cretaceous and Tertiary sedimentary sections, two similar anomalous K-feldspar-bearing tectonic slabs of the Franciscan assemblage, a matching pair of Mesozoic ophiolite patches, an offset gravity feature, and a tectonic contact of the Franciscan terrane against Salinian-block basement between Bodega Head and the Gualala Basin (see fig. 4) that has been observed to match certain relations along the Pilarcitos fault. If these Cretaceous, Tertiary, and ophiolite correlations are valid, then the northern Salinian-block basement rocks must also have been dismembered and moved a comparable distance. Graham and Dickinson (1978a) noted that their pairs of offset geologic features are not "tightly constrained" and that they "show probable offset ranges." More recent work by Clark and others (1984) indicates that a larger right-lateral offset on the San Gregorio fault of about 150 km is called for by the present distribution of Tertiary sedimentary rocks of the Point Reyes, Santa Cruz Mountains, and Monterey areas. The granitic basement of this same region is also compatible with such an offset (see supplementary section below entitled "Comparison of the Porphyritic Granodiorites of Point Reyes and Monterey").

A basement reconstruction using either the 115-km offset of Graham and Dickinson (1978b) or the 150-km offset of Clark and others (1984), is permissible, considering the vagaries of shapes of granitic bodies. The larger offset, however, in my opinion, permits a better "onstrike" alignment of a number of possibly related tonalitic bodies, as well as an alignment of the porphyritic granodiorites of Point Reyes and Monterey (fig. 2). Either reconstruction would place the granitic rocks of Bodega Head opposite Montara Mountain—a permissible correlation because both masses are dominantly hornblende-biotite tonalite. This adjustment would also place all known onshore and offshore outcrops of the northern Salinian block (Bodega Head, Point Reyes area, Cordell Bank, and the Farallon Islands) to the south of the Pilarcitos fault (see fig. 4). Furthermore, it follows that if, as Silver and others (1971) suggested, the Gualala Basin is underlain by Franciscan basement, then a blunt-ended Salinian block rests against Franciscan basement on the north. The presence of Franciscan basement is suggested by a small fault-bounded outcrop of spilite (fig. 3) near Black Point (Wentworth, 1968). Such spilitic basement rocks are unknown in the Salinian block but are found in the Franciscan basement.

Even if the Gualala area is underlain by Franciscan basement, granitic basement rocks must be relatively close by to have supplied a source terrane for a thick section of Cretaceous and lower Tertiary K-feldspar-bearing arkose and conglomerate that is rich in clasts of granitic rock. If the Gualala Basin is floored by the Franciscan assemblage, then this basin cannot be too wide because granitic basement must be present to the west or south; that is, the Salinian block probably extends northward from its exposures at Bodega Head and Cordell Bank, possibly as far as Point Arena (fig. 3).

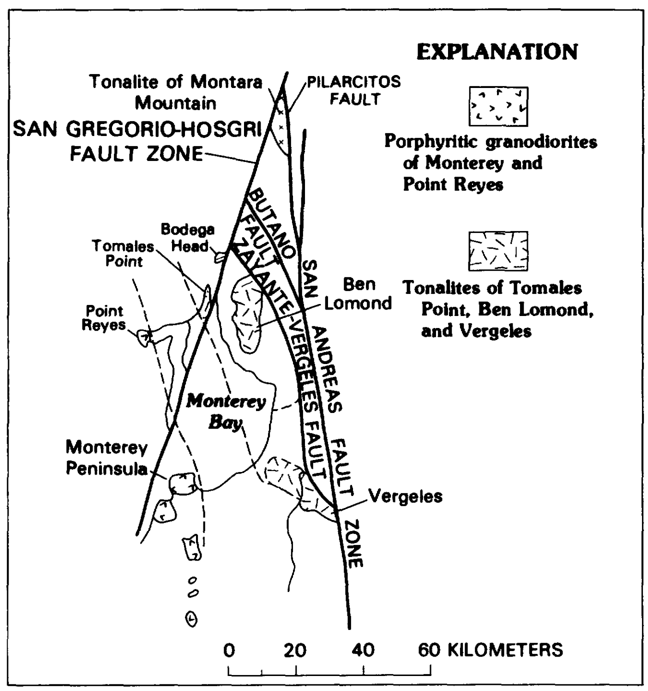

FIGURE 2.—Postulated realignment of some basement-rock units along the San Gregorio-Hosgri fault zone.

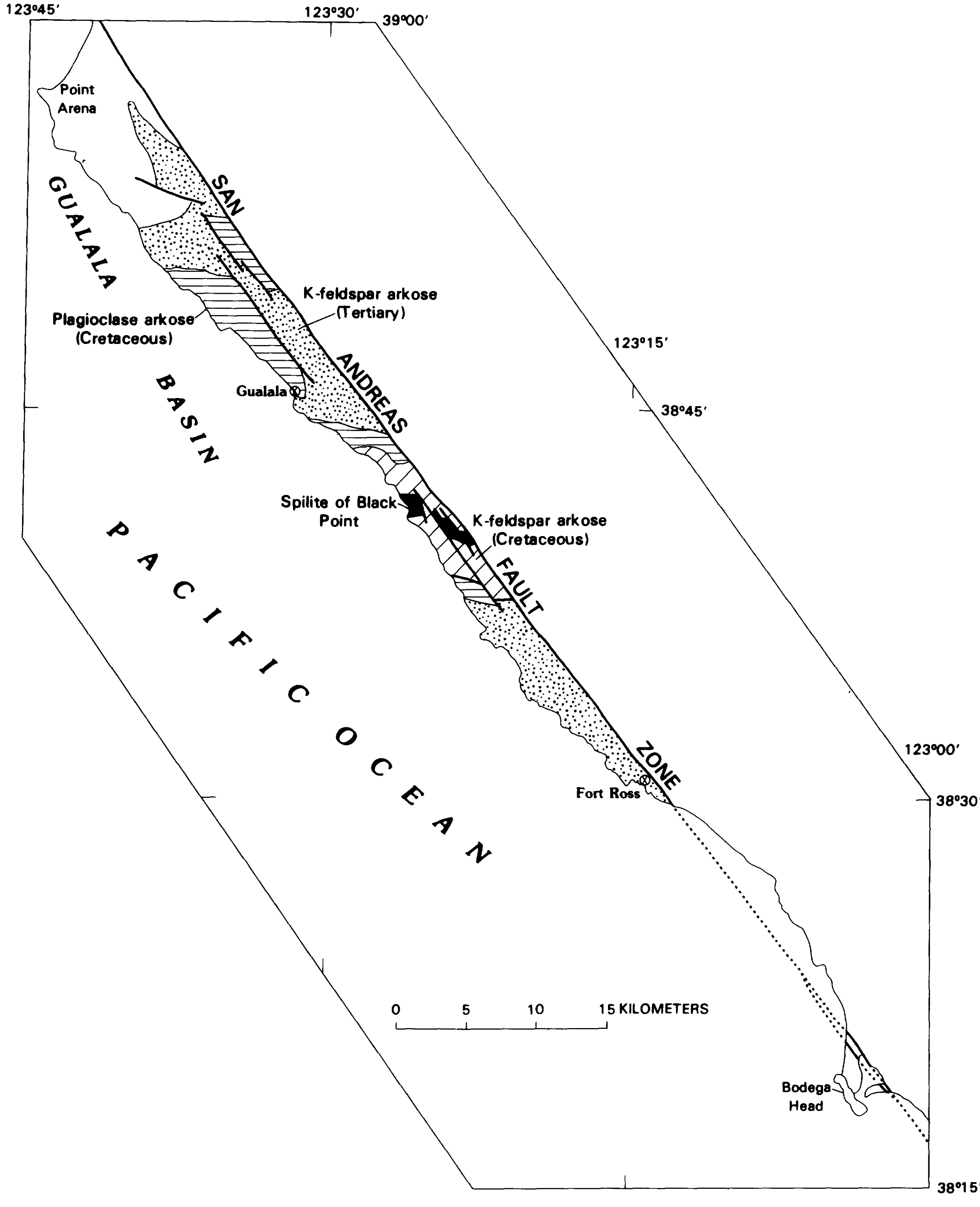

FIGURE 3.—Generalized geologic map of the Gualala area (modified from Wentworth, 1968).

Instead of the large block (sphenochasm) that Silver and others (1971) suggested for the Gualala Basin, there may be only a thin sliver of the Franciscan that is bounded by a fault on the west—just offshore, as Wentworth (1968) suggested. This fault could well be an extension of the Pilarcitos fault—that is, a San Andreas fault strand. If the Pilarcitos fault correlates with a structural contact north of Bodega Head and south of Fort Ross, as suggested by Graham and Dickinson (1978a), then granitic basement rocks may extend as much as 70 km northward of Bodega Head and offshore of Gualala (fig. 3). It would be interesting to know whether any of the Eocene rocks east of Montara Mountain between the Pilarcitos and San Andreas faults resemble the K-feldspar arkoses of the same age in the Gualala area; such a resemblance would be expected if the offset suggested by Graham and Dickinson (1978a) is valid.

Placing Bodega Head opposite Montara Mountain would leave granitic rocks north of probable oceanic basement. Both geologic and geophysical evidence suggest that oceanic basement may be present between the Vergeles-Zayante fault and the Butano fault (figs. 4, 5). The only basement outcrop between these two faults is the hornblende quartz gabbro and anorthositic gabbro near Logan (fig. 5). These basement-rock types are unlike any granitic basement in the Salinian block, and their chemistry and petrography suggest that they are probably oceanic (Ross, 1970).

West of the Logan outcrops (fig. 5), the occurrence of a gravity high (Clark and Rietman, 1973) suggests that gabbroic rocks extend westward of the present outcrop, possibly to the Vergeles fault. Also, Hanna and others (1972) and Brabb and Hanna (1981) noted that the Boulder Creek aeromagnetic anomaly north of Ben Lomond Mountain between the Zayante and Butano faults is one of the largest magnetic features in the vicinity of the San Andreas fault. The Boulder Creek high and the somewhat less impressive Corralitos aeromagnetic high (fig. 4) are most likely caused by gabbroic rocks similar to those exposed near Logan, where there is also an impressive aeromagnetic anomaly (Hanna and others, 1972). Seismic-refraction velocities of about 5.5 km/s have recently been obtained from the basement between the Zayante and Butano faults. These velocities are compatible with those obtained elsewhere in the region from Franciscan graywacke (A. G. Lindh, written commun., 1982). Graywacke in this block would be as compatible as gabbro with an oceanic basement. Seismic-refraction profiles obtained recently north of the Vergeles-Zayante fault zone suggest that the Logan-type gabbroic rocks may be less extensive than had previously been believed. The only other basement-rock data for the area between these two fault zones are from the Union Hihn #2 oil well (fig. 4). This well is east of Ben Lomond, and its plotted position is just east of the Zayante fault (Ross and Brabb, 1973). The core material from the well is much like that from the basement outcrop just west of the Zayante fault. The Union Hihn #2 may actually bottom west of the Zayante fault—if the fault dips steeply east, or if the well is somewhat deflected or either the well or the fault are slightly mislocated. Union Hihn #1, a few hundred feet northeast of Union Hihn #2, bottomed at 7,747 ft in Miocene beds, whereas the basement samples from Union Hihn #2 are from depths of 3,400 to 3,500 ft (Ross and Brabb, 1973). These data suggest some discordance (the Zayante fault?) between the two holes. Nevertheless, Salinian basement in the block between the Vergeles-Zayante and Butano faults cannot be ruled out on the basis of the present data. I first suggested (Ross, 1970) that the gabbroic rocks at Logan composed a thin fault sliver along the San Andreas fault, but later gravity and aeromagnetic data (Clark and Rietman, 1973; Hanna and others, 1972) have suggested that the gabbroic rocks are much more extensive; nonetheless, the seismic-refraction velocity of 5.5 km/s seems to contradict all these older data. Clearly, more data are needed to delineate the basement of this block.

If the block between the Butano and Vergeles-Zayante faults is oceanic, the Vergeles-Zayante fault zone may be an old strand of the San Andreas system, as Dibblee (1980) suggested. Alternatively, the terrane between the Butano and Vergeles-Zayante faults could be an exotic sliver that was caught up in the Salinian block. The problem with considering the Vergeles-Zayante fault zone to be a major oceanic-continental break is that the Montara Mountain granitic massif would then be marooned east of the westernmost fault of the San Andreas fault system. On the basis of the presence of the Montara mass (fig. 4), the basement between the Butano and Pilarcitos faults is generally thought to be granitic.

A northward continuation of the Ben Lomond fault that would tie into the La Honda fault (fig. 6) was suggested by C. M. Wentworth (oral communication, 1982) on the basis of an abrupt change in the geologic grain and attitude of bedding in Tertiary sedimentary-rock units across this zone. The occurrence of such a fault would suggest that granitic basement underlies the block of country between the proposed La Honda-Ben Lomond fault and the San Gregorio fault from Montara Mountain south to Ben Lomond (fig. 6). Such a north-south-trending fault and the accompanying block of granitic basement would contradict my current suggestion that a suture of oceanic basement between the Zayante-Vergeles and Butano faults extends westward to the San Gregorio fault.

Granitic rocks and metasedimentary rocks exposed east of the Ben Lomond fault are grossly similar to the basement rocks of the Ben Lomond Mountain area; that similarity suggests that the Ben Lomond fault is not a significant basement break and that displacement of the basement is modest. However, an impressive aeromagnetic

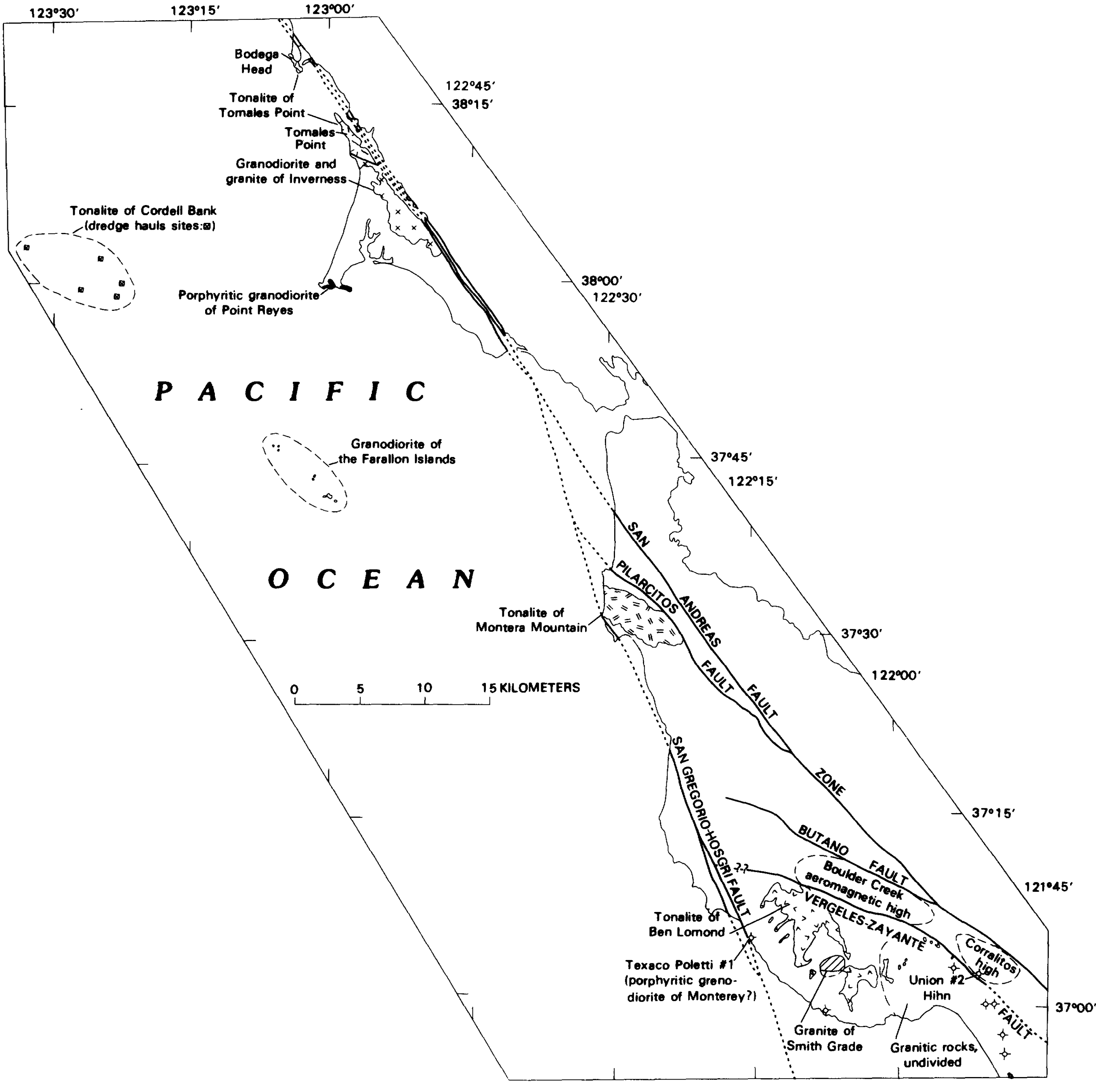

FIGURE 4.—Generalized geologic map of the northern Salinian block. Well symbol (✧) shows location of undivided granitic rocks in the subsurface.

high between the Zayante and Butano faults (fig. 6), which suggests the presence of gabbroic rocks there similar to exposed rocks near Logan (Brabb and Hanna, 1981), appears to terminate near the line of the proposed fault. The aeromagnetic-anomaly gradient drops off rapidly west of the proposed fault, but it is questionable whether the gradient change is enough to allow the interpretation that granitic basement is faulted there against gabbroic basement.

Information provided by present exposures and geophysical data do not appear to be sufficient for a unique solution to the problem of a possible north-south-trending fault and an accompanying strip of granitic basement. Closer examination of the area near the junction of the Ben Lomond and Zayante faults might resolve whether the Ben Lomond fault is truncated by the Zayante fault or vice versa, but probably nothing short of additional subsurface basement data can resolve this dilemma.

Because of similar gravity patterns near Año Nuevo Point (west of Ben Lomond) (fig. 1) and offshore from Point Sur (fig. 5), Silver and others (1971) suggested an offset of only some 90 km on the San Gregorio fault. They interpreted these data to indicate offset on the west margin of the Salinian block (the Nacimiento fault zone). More recent data, however, suggest that the Franciscan assemblage of the Point Sur area has been displaced from similar rocks near Cambria (fig. 1) along the San Gregorio-Hosgri fault zone (Graham and Dickinson, 1978a). Thus, the Sur fault is most probably a segment of the San Gregorio-Hosgri fault zone and not part of the Nacimiento fault

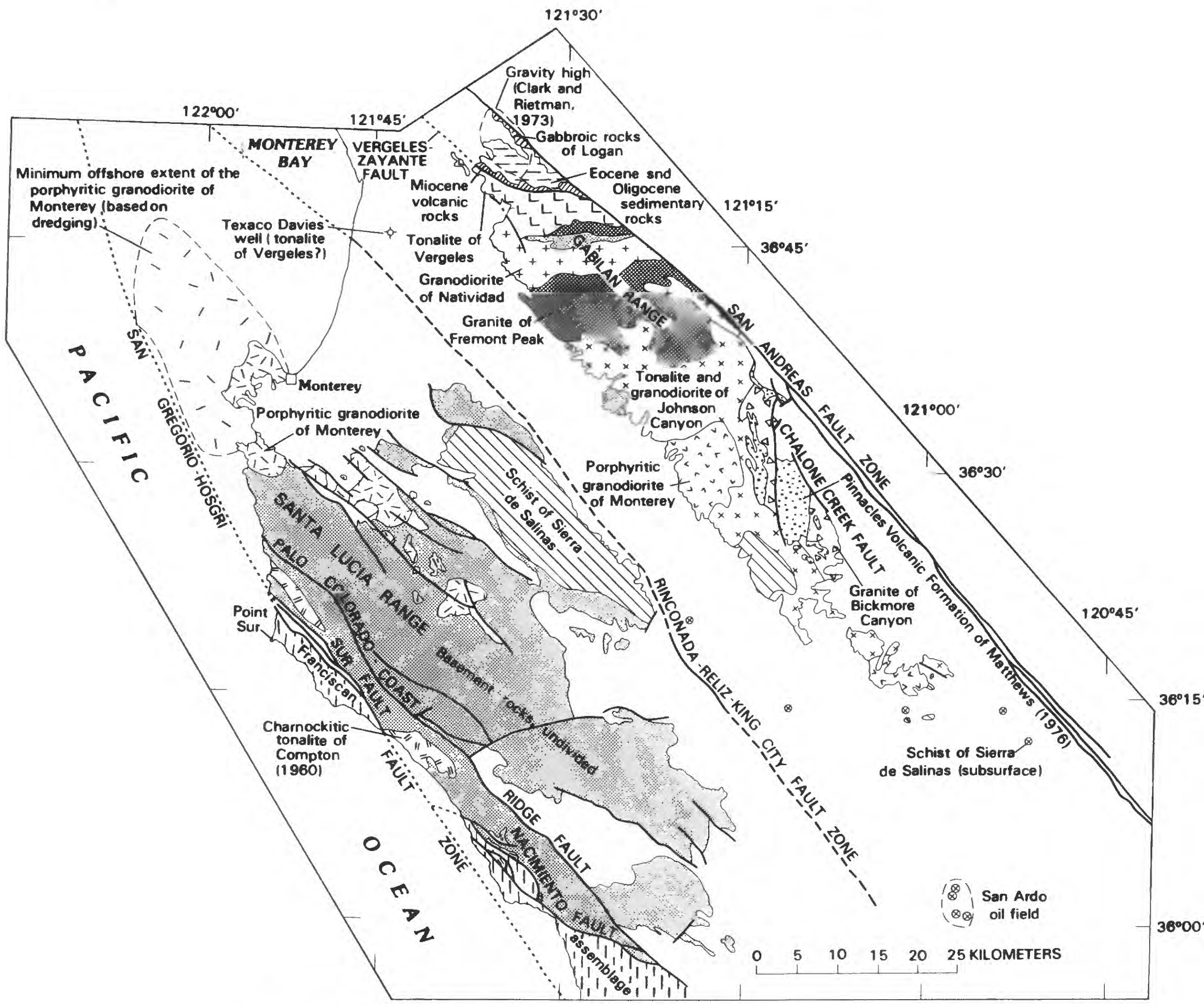

FIGURE 5.—Generalized geologic map of the central Salinian block.

zone. If so, the offset on the Nacimiento fault zone is about 130 to 135 km (fig. 7). The question then arises whether the gravity pattern off Point Sur (Silver and others, 1971) is related to the gravity expression of the Farallon Ridge to the north. Note that this offset on the Nacimiento fault zone is somewhat less than the 150-km offset indicated by data of Clark and others (1984) for the San Gregorio fault. The structure is complex where the Nacimiento fault intersects the shoreline south of Monterey, and more San Gregorio-Hosgri slivers may exist there that are analogous to the one at Point Sur. Thus, the seeming discrepancy may be less than the present figures suggest.

Recent dredging in Ascension Canyon (off the coast west of the Ben Lomond area) (fig. 7) has brought up specimens of spilitic basalt and serpentinite that are considered to be inplace Franciscan (Mullins and Nagel, 1981). This dredged material provides a definite tie point to limit the westward extent of the Salinian block at that latitude.

SAN ANDREAS FAULT ZONE

Matthews (1976) presented compelling evidence that his Pinnacles Volcanic Formation in the southern Gabilan Range and his Neenach Volcanic Formation on the opposite side of the San Andreas fault (see fig. 20) are correlative and were contiguous 23 m.y. ago, in Miocene time. To directly juxtapose the Neenach and Pinnacles volcanic areas, Matthews suggested that the Chalone Creek fault (fig. 8) is an early Miocene trace of the San Andreas fault. He based this suggestion on the alignment of the Chalone Creek fault with Peach Tree Valley and on the absence of granitic outcrops in the sliver between the Chalone Creek and San Andreas faults. Oil wells have penetrated granitic basement at 2,000 to 4,300 ft within this sliver, however, and the core material suggests ties with the central Salinian block (Ross, 1974).

Core samples 34 and 45 (fig. 8) are probably of the schist of Sierra de Salinas. These cores are located very near the extension of the Chalone Creek fault proposed by Matthews, but the fact that the samples were recovered at depths of 5,300 and 5,800 ft suggests that they are east of the Chalone Creek fault, because surface outcrops are present no more than 5 km to the west. If samples 34 and 45 are of the schist of Sierra de Salinas and if sample 27 is of the tonalite and granodiorite of Johnson Canyon, as its lithology suggests, it is unlikely that

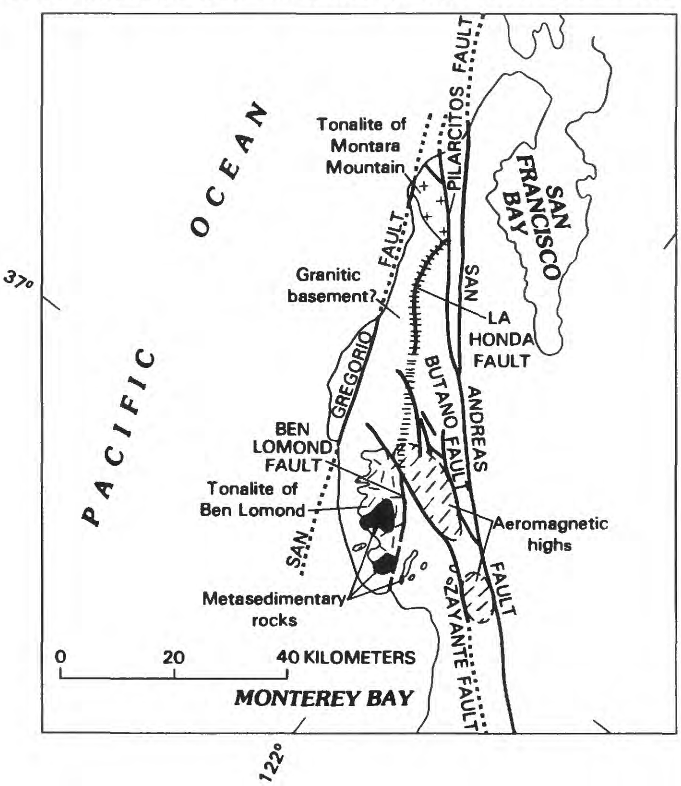

FIGURE 6.—Generalized geologic map showing location of possible north-south-trending fault (hachured line) connecting the Ben Lomond and La Honda faults.

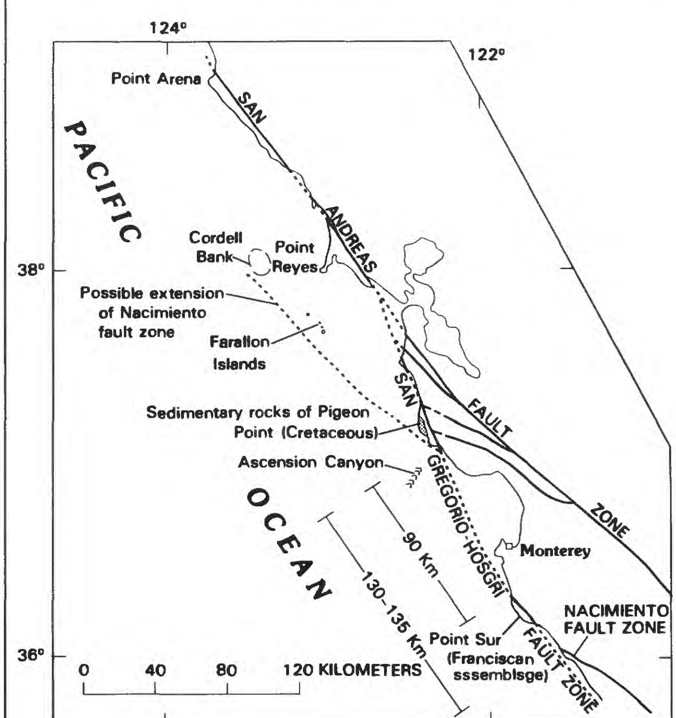

FIGURE 7.—Probable offset of west margin of the Salinian block (Nacimiento fault) by the San Gregorio-Hosgri fault zone.

the Chalone Creek fault has had significant strike-slip displacement, and it may be dominantly dip slip, as Andrews (1936) suggested. The general configuration of the slice between the Chalone Creek and San Andreas faults more closely resembles a sliver along the San Andreas fault, and the well-core data are admittedly sparse. Even if the Chalone Creek fault is not a strike-slip fault, Matthews' (1976) correlation is still valid. The present separation of these two volcanic-rock units compares well with earlier estimates of San Andreas basement offsets by Crowell and Walker (1962) and with various Tertiary offset features described by Addicott (1968) and Grantz and Dickinson (1968). These offsets would bring the Gabilan Range (fig, 5) up against the Sierra Nevada tail (San Emigdio Mountains) (fig. 1). I am skeptical of this correlation for several reasons, mainly because there is no evidence in the Salinian block of counterparts to the hornblende-rich high-grade metamorphic rocks of probable oceanic affinity that underlie large areas of the Sierran tail. However, the recent realization that the Pastoria fault zone (fig. 9) of Crowell (1952) may extend westward to intercept the San Andreas fault has caused me to speculate that the Pastoria fault zone may have a counterpart fault in the Salinian block—the Vergeles-Zayante fault zone. The Pastoria fault zone and, by much inference, the Vergeles-Zayante fault zone may indicate a major structural discordance (strike-slip or reverse fault movement, or both) that juxtaposes oceanic and continental terranes. Certainly, the gabbroic rocks at Logan (see figs. 5, 14) and Eagle Rest Peak (see fig. 9, 14) near these two fault zones are petrographically and chemically compatible with each other (Ross, 1970; Ross and others, 1973). The absence north of the Vergeles-Zayante fault zone of representatives of the horn-

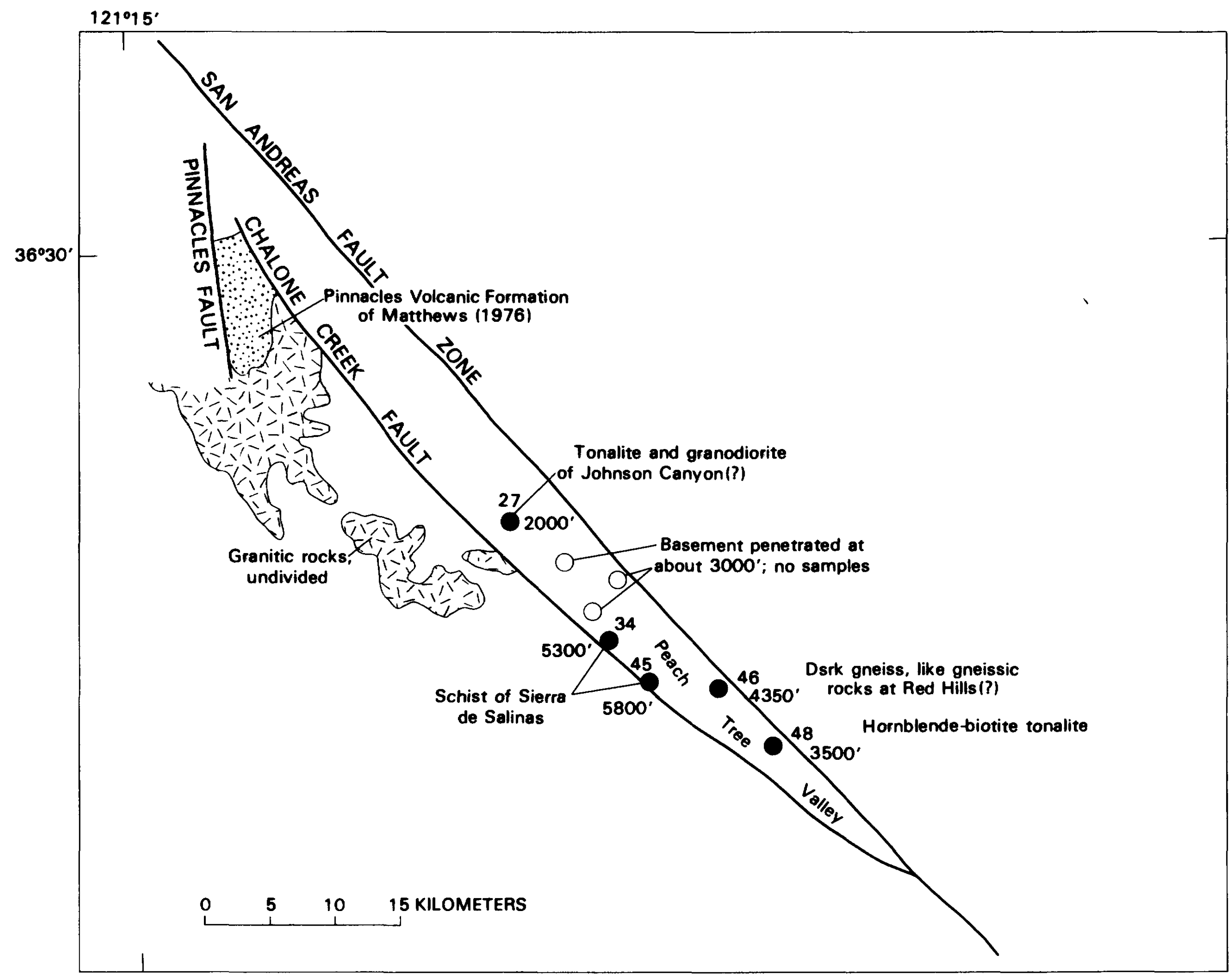

FIGURE 8.—Locations of wells to basement between the Chalone Creek and San Andreas faults, showing rock types penetrated, sample numbers, and depths to basement. Modified from Matthews (1976, fig. 18); basement core data from Ross (1974).

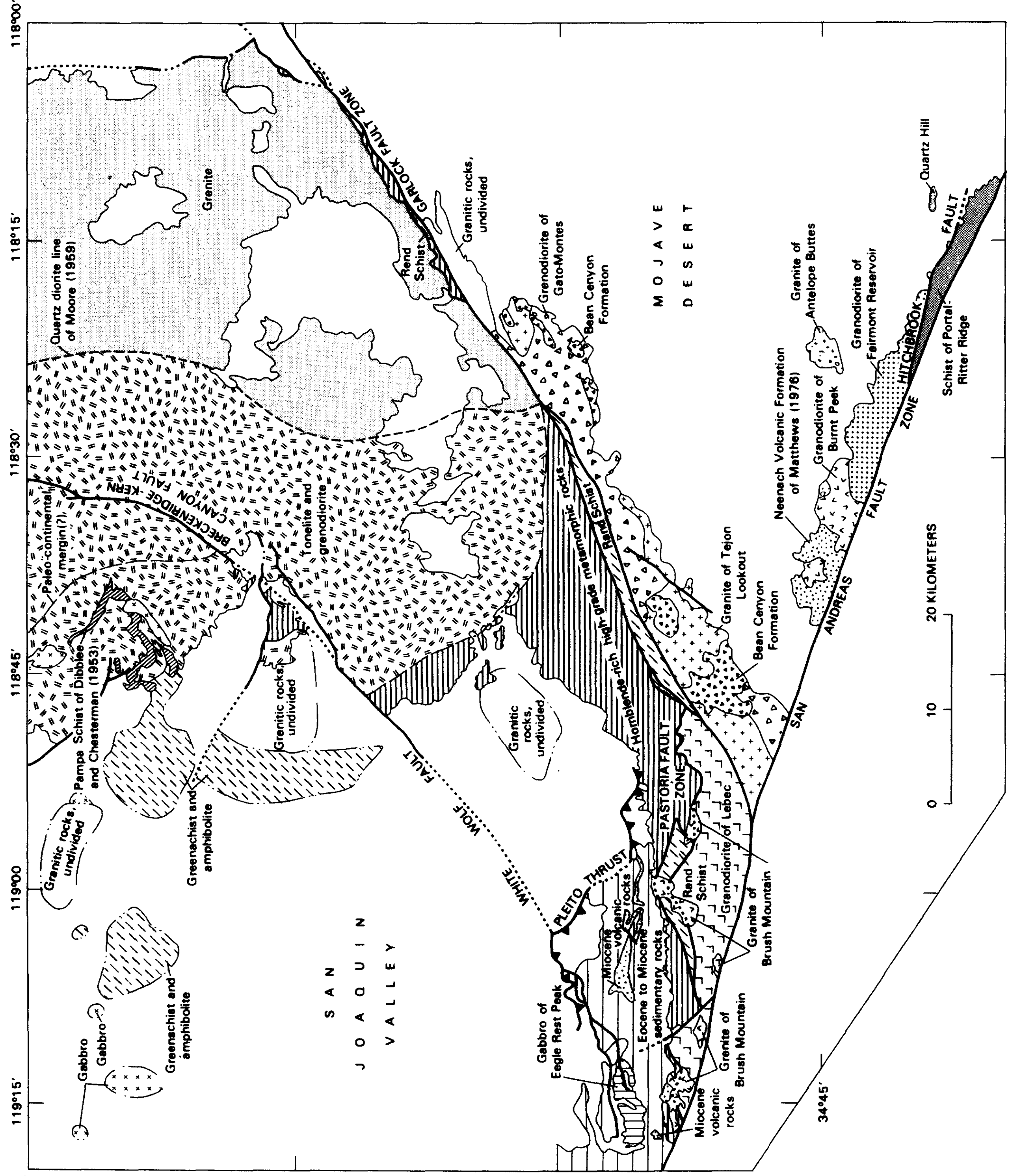

FIGURE 9.—Generalized geologic map of the southernmost Sierra Nevada and the westernmost Mojave Desert.

blende-rich high-grade metamorphic rocks may simply indicate more overlap by Eocene and Oligocene sedimentary rocks and Miocene volcanic rocks there than to the north of the Pastoria fault zone. The outcrop belt of the hornblende-rich metamorphic rocks thins markedly north of the Pastoria fault zone near the San Andreas fault, and so the absence of such rocks along the north side of the Vergeles-Zayante fault is not surprising.

On an earlier map of the Vergeles fault area, Allen (1946) showed a sliver of granitic rocks north of the Vergeles fault about 5 km south of San Juan Bautista (fig. 10). My examination of this area revealed marble, mica schist, the tonalite of Vergeles, and medium- to coarse-grained granite, all sparsely exposed along a ridge that extends from the Vergeles fault northward to the Old Stage Road, where tonalite and granite are exposed in a roadcut. These granitic rocks might have been emplaced across the Vergeles fault zone, and they may have a relation analogous to that of the granite of Brush Mountain to the Pastoria fault zone (fig. 9). However, the granitic rocks that appear to be on the north side of the Vergeles fault zone are more likely a sliver along the fault.

Cursory examination of the rocks at several localities along the Vergeles fault zone has revealed only a modest amount of shearing that can be related to the fault (fig. 10). Several thin slickensided shear zones were observed in Tertiary sandstone immediately northeast of the Vergeles fault zone at its west limit of exposure east of U.S. Highway 101. There, the fault takes a more northerly trend, and shears that strike about N. 20° W. are aligned with the mapped fault trend. The slickensided zones dip 60°–70° S. and flake off in flattened ovoid plates that have the appearance of paper shale. Sparsely exposed granitic rocks just southwest of

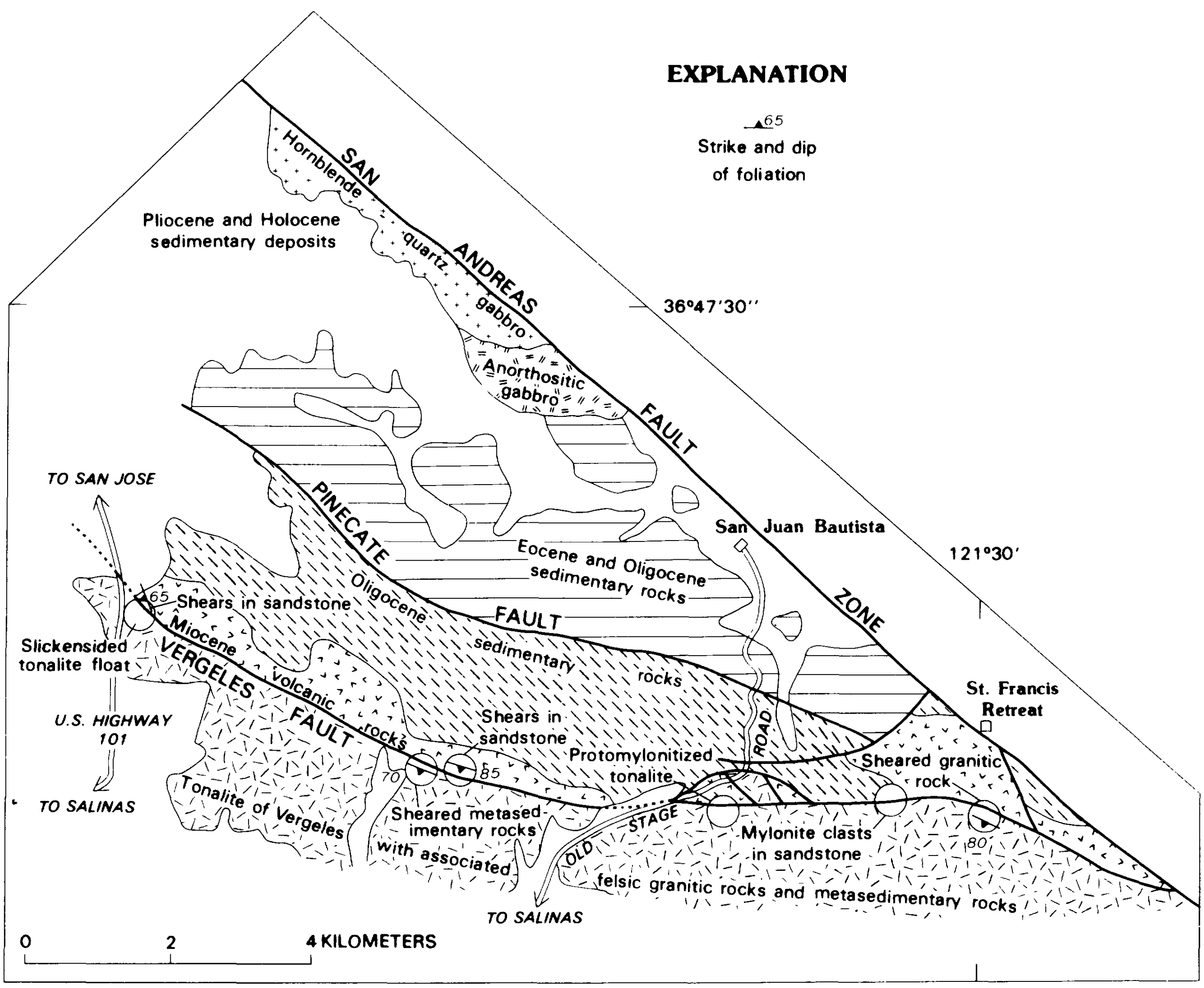

FIGURE 10.—Generalized geologic map showing locations of sheared rocks (circles) along the Vergeles fault. Geology simplified from Clark and Rietman (1973) and Dibblee (1980).

the faultline are deeply weathered and show no obvious evidence of shearing. Slickensides were observed, however, in some granitic float.

Shearing also occurs in Tertiary sandstone and in micaceous schist on both sides of the Vergeles fault along the San Juan Grade Road between Salinas and San Juan Bautista (about 8 km east along the fault from the U.S. Highway 101 locality). Slickensided shear zones, as much as 0.3 m wide, cut Tertiary sandstone beds that are in, or just north of, the Vergeles fault zone. The shear zones trend N. 70° W. and dip about 85° S. About 0.2 km south of the fault zone, shearing and granulated lenses are evident in micaceous schist in a roadcut. These shear zones also strike N. 70° W., but they dip somewhat less steeply at 70° S. Some of this so-called shearing, parallel to the schistose foliation, may merely be weathered metamorphic foliation. The granulated zones, however, observed in thin section, definitely postdate the metamorphic foliation and reflect later deformation.

Shear zones were also seen in granitic rocks about 0.2 km south of the Vergeles fault zone, directly south of the St. Francis Retreat (fig. 10). A few thin red shear zones cut the granitic rocks and trend N. 65° W. and dip about 80° S. Very near the mapped trace of the Vergeles fault in San Juan Canyon (about 2 km to the west of the previous locality), a roadcut on the south side of the canyon exposes Tertiary sandstone. This sandstone contains many angular quartz grains, as much as 4 mm across, that are strongly undulatory, granulated, and (or) slivered; some of these grains may be fragments of mylonite. Other clasts are polycrystalline and consist of plagioclase and deformed quartz. The general clast lithologies suggest that the source rocks were cataclastically deformed, probably felsic granitic rocks. Most of the sandstone that I sampled near the Vergeles fault in the Tertiary section probably is locally derived. By analogy, the sandstone containing the clasts of cataclastic(?) quartz and granitic fragments was apparently derived from deformed granitic rocks along the Vergeles fault.

Just south of the Old Stage Road, biotite granodiorite is exposed on a ridge on the north line of sec. 16, T. 13 S., R. 4 E., just south of the trace of the Vergeles fault (about 4 km west of the mylonite clast locality, fig. 10). These granitic rocks have a protomylonitic texture in thin section; they include strung-out, mosaicked, and slivered quartz as well as streaked-out biotite that gives an anastamosing fabric to the rocks. These rocks seem to be deformed more pervasively than are the outcrops previously described, in which deformation is localized along discrete shear zones. Because of poor exposures, relations are unclear there, but I suspect that the deformed granitic rocks are in or very near the Vergeles fault zone. These protomylonitized granitic rocks are a likely source for the Tertiary sandstone in San Juan Canyon that contains mylonitized grains of granitic composition.

The clues of mylonitization at these latter two localities suggest that strong compression is part of the deformational pattern of the Vergeles fault. Mylonite would also seem to be more compatible with a strongly compressional strike-slip fault zone than with a largely extensional dip-slip fault zone, which the Vergeles fault had previously been considered to be. However, the basement is certainly downdropped north of the Vergeles fault; seismic-refraction lines across the fault suggest a downdrop of several thousand feet (W. D. Mooney, written commun., 1982).

Coppersmith (1979), in a detailed study of the Vergeles-Zayante fault zone, noted slickensides in trenches across the fault zone whose orientations indicated a significant horizontal component in most recent movements. He also noted that several streams crossing the fault trace had clearly been diverted in a right-lateral sense. Coppersmith further noted that fault-plane solutions of several seismic events that most probably were associated with the Vergeles-Zayante fault zone show strike-slip focal mechanisms with little or no vertical component of movement. Dupré (1975) observed that the Sangamon-age Watsonville terrace complex (100,000 years old) is deformed by faulting and that Holocene activity is evident in the fault-controlled geomorphology. He cited these observations as evidence that the Vergeles-Zayante fault zone is active and has undergone late Pleistocene and Holocene movements. Dupré (1975) also cited current seismic activity in the Vergeles-Zayante region as indicative of ongoing fault movement. These two fairly recent studies support the view that the Vergeles-Zayante fault zone is an active strike-slip fault zone.

Coppersmith (1979) also noted that along much of the more than 80-km trace of the Vergeles-Zayante fault zone, a main fault is difficult or impossible to identify and that there are many relatively short fault segments without much lateral continuity. It is difficult to reconcile this statement with my contention that the Vergeles-Zayante fault zone is a major throughgoing strike-slip fault zone. Poor exposures may explain the apparent absence of a mappable main fault; nevertheless, if Coppersmith's interpretation is correct, it creates difficulties for my suggestion that the Vergeles-Zayante fault zone is a major strike-slip fault zone.

Miocene volcanic rocks directly north of the Vergeles fault have a radiometric age of 22 m.y., which is the same as the age of similar volcanic rocks just north of the Pastoria fault zone in the San Emigdio Mountains (fig. 9) (Huffman and others, 1973). The suggestion that these two volcanic areas were once part of one volcanic field is strengthened by lithologic and petrologic similarities (Bazeley, 1961), and by similarities of both bulk chemical analyses of the volcanic rocks and trace-element concentrations in garnet and biotite from the two areas (Turner, 1968).

Numerous workers, the earliest of whom were Hill and Dibblee (1953), have noted stratigraphic similarities between the Eocene to Miocene sedimentary section in the western San Emigdio Mountains (fig. 9) and the interconnected depositional area that received sediment of the same age in the northern Santa Lucia Range and the northern Gabilan Range north of the Vergeles fault (fig. 5; see sources cited by Clarke and Nilsen, 1973, and Nilsen and Link, 1975).

In all, there is abundant evidence from such diverse groups of rocks as oceanic gabbroic rocks, Miocene volcanic rocks, and Eocene to Miocene sedimentary rocks for a firm tie between the northernmost Gabilan Range and the westernmost San Emigdio Mountains (Sierra Nevada tail). In view of this tie, as well as the compelling similarity between the Pinnacles Volcanic Formation in the southern Gabilan Range and the Neenach Volcanic Formation southeast of the San Emigdio Mountains, the question should be asked: Can the Salinian block basement units of the Gabilan Range be fitted to the basement units in the San Emigdio Mountains on the east of the San Andreas fault?

I have long been intrigued by the close resemblance of the granodiorite of Natividad in the Gabilan Range to the granodiorites of Lebec and Gato-Montes in the Sierran tail (figs. 5, 9); in fact, I commonly referred to the granodiorites of Lebec and Gato-Montes early in my Sierran work as "Natividad type." All three granodiorites are medium-fine grained and contain distinctive scattered coarse biotite flakes. All three masses are distinguished by scattered hornblende crystals with red cores that indicate the presence of skeletal clinopyroxene remnants. Modally and chemically, the three masses are also virtually identical. Coarse-grained biotite granite, of the typical and common "low melting trough" granitic rock type, is associated with all three granodiorites—the granites of Fremont Peak (Gabilan Range), Tejon Lookout, and Brush Mountain (Sierran tail).

Neither the tonalite of Vergeles nor the tonalite and granodiorite of Johnson Canyon of the Gabilan Range (fig. 5) appear to have counterparts in the Sierra Nevada tail (fig. 1) (San Emigdio Mountains). The granodiorite of the Fairmont Reservoir, however, which crops out near the Neenach Volcanic Formation, is similar lithologically, modally, and chemically to the Johnson Canyon body, which crops out near the Pinnacles Volcanic Formation. Both the Fairmont Reservoir and Johnson Canyon granitic bodies contain much sphene with inclusions of opaque material in shapes resembling arabic- to runic-written characters. I have observed this feature in other plutonic masses in the California Coast and Transverse Ranges, but it is uncommon there, and so its abundance in both the Fairmont Reservoir and Johnson Canyon masses may be significant. More detail on the similarity of those two granitic masses is presented in the supplementary section below entitled "Comparison of the Granitic Rocks near the Pinnacles and Neenach Volcanic Formations of Matthews (1976)." The presence in the Sierra Nevada tail of equivalents to the Johnson Canyon and Vergeles bodies would greatly strengthen correlation of the tail with the central Salinian block, but considering the common shape and distribution vagaries of granitic bodies, the absence of such equivalents is not devastating to the proposed correlation.

Strontium-isotopic data available for the central Salinian block and the Sierra Nevada tail enable a general comparison between these two areas. Relatively high initial strontium-isotopic ratios (approx 0.7082) have been determined for several granitic samples from the Gabilan and Santa Lucia Ranges (Kistler and Peterman, 1973). More detailed work by J. M. Mattinson (written commun., 1982) indicates that not all the Gabilan Range plutons are cogenetic and that there is some variance in initial strontium-isotopic ratios; nevertheless, all are relatively high. Similar high initial strontium-isotopic ratios (0.7079-0.7085) have been determined in one sample of the granodiorite of Lebec and in several samples of the granodiorite of Gato-Montes in the Sierra Nevada tail (R. W. Kistler, written commun., 1981). One granitic sample from the La Panza Range has an initial strontium-isotopic ratio of 0.7080 (Kistler and others, 1973). These data, though admittedly sparse, point to strontium-isotopic compatibility between the central Salinian block and the Sierra Nevada tail.

Doe and Delevaux (1973) determined the lead-isotopic compositions in seven granitic samples from the length of the Sierra Nevada for the Late Cretaceous part of the Sierra Nevada batholith. Of particular interest in their studies is the $^{206}Pb/^{204}Pb$ ratio, which is a measure of the uranogenic or "radiogenic (J-type)" lead. The two southernmost samples analyzed from the batholith (lat approx 35°45′ N., near Isabella Lake, fig. 1) are two of the three Sierran samples with the highest $^{206}Pb/^{204}Pb$ ratios (19.37 and 19.15). Doe and Delevaux (1973) reported similar relatively high $^{206}Pb/^{204}Pb$ ratios from the Santa Lucia Range (19.53 and 19.11) and Point Reyes (19.44) in the Salinian block. They suggested that these data support the contention that the Salinian block is a faulted-off part of the Sierra Nevada batholith. This conclusion, though permissible, is admittedly based on very limited data.

Another feature that seems to relate the two areas is their anomalous structural grain. The granitic contacts, and the trend and strike of much of the metamorphic pendant material in the northern part of the Gabilan Range, are generally east-west, markedly different from the north-southward to northwestward trend of most California basement. If the Gabilan Range is placed alongside the Sierra Nevada tail and if the Vergeles and Pastoria faults and the Neenach and Pinnacles Volcanic Formations are lined up, the combined block will have a generally east-west-trending grain.

Another correlation between these two areas has already been suggested, on the basis of the similarity of the schist (metagraywacke) of Sierra de Salinas (figs. 5, 11) to the schist of Portal-Ritter Ridge (Pelona Schist?) (fig. 9); (Ross, 1976). The exposed schist of Sierra de Salinas, together with similar schist in well cores, composes a rather impressive belt that appears to be cut off by the San Andreas fault. If the Gabilan Range is placed next to the Sierra Nevada tail, this belt aligns with outcrops of the schist of Portal-Ritter Ridge.

The strong physical and chemical similarity of the schists in these two areas has already been established (Ross, 1976); similarity of their structural settings remains to be shown. The schist of Sierra de Salinas in the Gabilan Range is intruded by granitic rocks and has some migmatitic marginal zones. In addition, dikes and sills of volcanic rocks (probably related to the Pinnacles Volcanic Formation) are conspicuous near the south end of the large outcrop area of schist in the Gabilan Range. By contrast, the only known intrusions into the schist of Portal-Ritter Ridge (fig. 9) are dark diabasic dikes composed of labradorite, hornblende, clinopyroxene, and minor quartz. The source of these dikes is unknown.

The contact along the north margin of the schist of Portal-Ritter Ridge has been mapped as a fault—the Hitchbrook fault of Dibblee (1960, 1961). However, this fault does not cleanly separate granitic rock on the north from schist on the south. For example, the large mass of schist at Quartz Hill is north of the fault, and the Hitchbrook fault, as mapped, passes through a spur of schist in the main Portal-Ritter Ridge body (Dibblee, 1961). Furthermore, Evans (1978) showed a small outcrop of granitic rock south of, and adjacent to, the Hitchbrook fault. This outcrop, immediately south of a distinctive hill of lithic lapilli tuff, is not shown as fault-bounded against schist; however, no mention of this outcrop is made in Evans' text. The contact between the schist and the granitic rocks is covered with alluvium along much of its length. In my brief examination of the rocks along the Hitchbrook fault in a few localities, I saw sheared granitic rock and no granitic apophyses into the schist. Nevertheless, I am not convinced that the Hitchbrook fault is a tectonic break between the schist of Portal-Ritter Ridge and the granitic terrane to the north. I suggest that a thorough search along this contact be made for intrusive relations whose occurrence would support the thesis that the schist terranes of the Sierra de Salinas and Portal-Ritter Ridge are correlative and were once contiguous.

Together with the Tertiary correlations, the possibility of basement-rock correlations suggests that the Gabilan Range (figs. 5, 11) may have originated opposite the area of the present Sierra Nevada tail (fig. 9). Important to this correlation is my interpretation that the Pastoria and Vergeles-Zayante fault zones represent a tectonic contact between oceanic and continental terranes. If it can be determined that the basement between the Vergeles-Zayante and Butano faults is largely oceanic, and if similar rocks underlie the block north of the Butano fault, these facts would suggest a major break between continental and oceanic terranes that would greatly strengthen the correlation between the Gabilan Range and the Sierran tail.

A reconstruction that attaches the Gabilan Range to the Sierran tail would probably carry the Santa Lucia Range along with the Gabilan Range. The gneissic and tonalitic rocks (with associated migmatite of the Santa Lucia Range) might have their onstrike equivalents in the gneisses and tonalites of the Holcomb and Wrightwood area (fig. 1); (Ross, 1972a). Correlation of these two gneissic terranes was suggested to me several years ago by P.

L. Ehlig, and the idea still seems to have merit. At present, such a correlation must remain speculative because much of the basement between the Santa Lucia Range and the San Andreas fault is covered by younger rocks, but it is worth noting that the correlation would fit with the Gabilan-Sierran correlations. One possible reason to reject this correlation is the fact that the route from the Santa Lucia Range to the San Andreas fault seems to be blocked by granitic rocks and schist similar

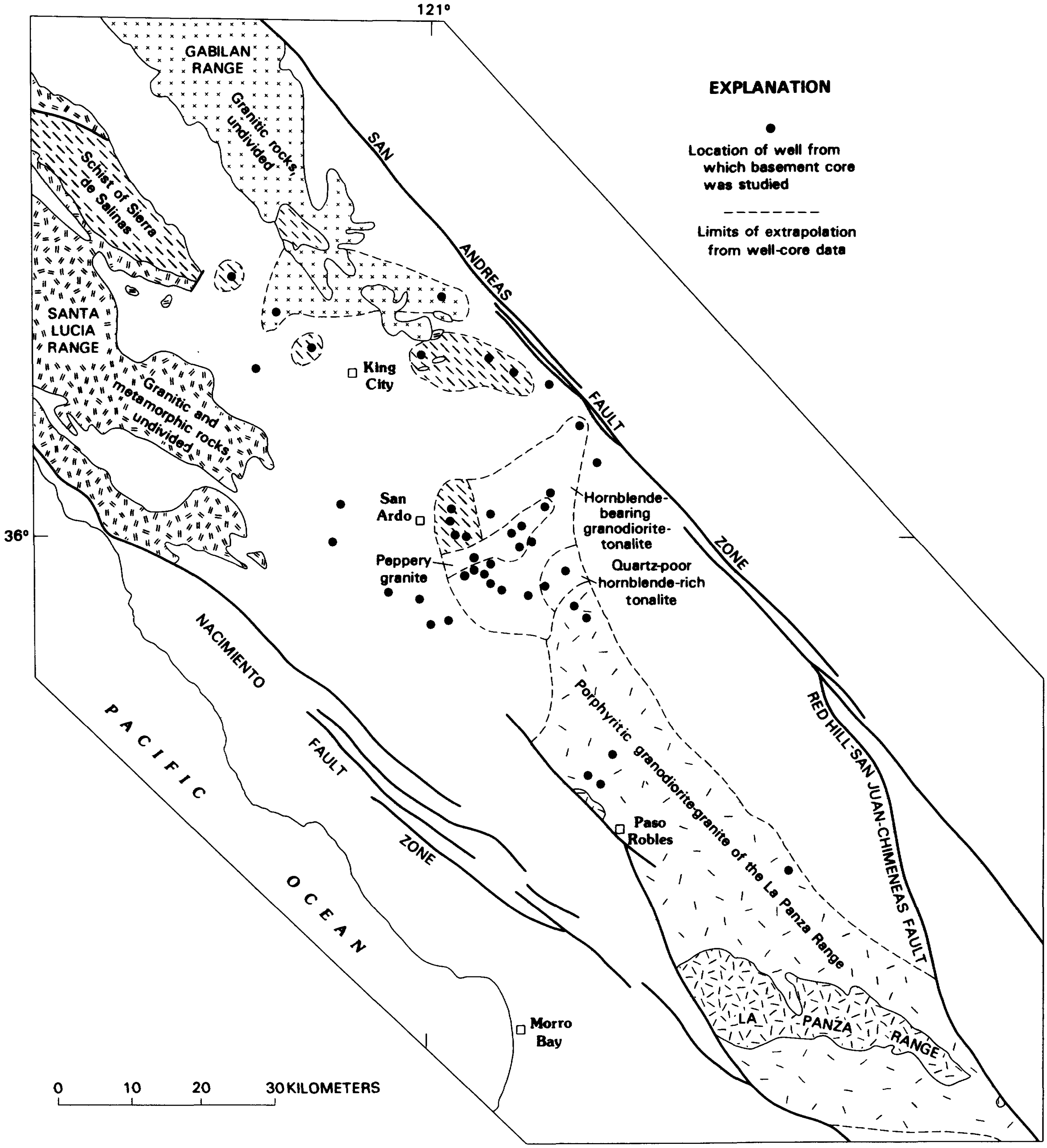

FIGURE 11.—Extrapolation from well-core data of some basement-rock units in the central Salinian block (modified from Ross, 1974).

to the schist of Sierra de Salinas that are evident in well-core material from the San Ardo oil-field area (figs. 5, 11).

Hypersthene-bearing tonalite and associated hypersthene-bearing granulite-grade metamorphic rocks are found in both the southernmost Sierra Nevada and the Santa Lucia Range. The tonalites and associated metamorphic rocks of both terranes have middle Cretaceous U-Pb radiometric zircon ages. In addition, coarse red garnet is characteristic of both terranes. The occurrence of granulite-grade metamorphic rocks also implies greater crustal depths than is common for batholithic terranes in California. At the least, these two unusual, coeval terranes appear to reflect a similar metamorphic and tectonic setting. The correlation of the two terranes is speculative but plausible. Further details of the comparison of these two terranes were discussed by Ross (1983).

Another large area of basement rock in the central Salinian block is the porphyritic granodiorite-granite of the La Panza Range (fig. 12). This body of rock probably extends southward, possibly discontinuously, from the San Ardo area to the La Panza Range and presumably even farther south (fig. 11), although no basement outcrops or subsurface data indicate its presence there (Ross, 1974). Much of this large and relatively homogeneous mass is distinctly porphyritic, and I have suggested (Ross, 1978) that it is correlative with the porphyritic granodiorite of Monterey (figs. 4, 5).

A body of porphyritic granitic rock in the Thermal Canyon area (fig. 1) was believed by Smith (1977) to be a possible correlative of the La Panza mass. I was also informed by S. E. Joseph (oral commun., 1979) that the rubidium-strontium data for the Thermal Canyon and La Panza rocks are similar. I have examined and sampled the granitic rocks in Thermal canyon and made modal analyses of seven stained slabs. In the field, these rocks strikingly resemble the granitic rocks of the La Panza Range. In modal composition (fig. 13), the Thermal Canyon samples are generally lower in quartz than the La Panza rocks, and the two fields are somewhat distinct, although they overlap. It is hard to evaluate the relation between these two bodies because I sampled only a small area in Thermal Canyon. More data are needed to confirm (or deny) the correlation between these two masses.

The present distance between the Thermal Canyon rocks and the nearest La Panza Range granitic outcrops is more than 400 km; this distance exceeds the amount of displacement required on the San Andreas fault if the Gabilan Range is to be refitted against the Sierra Nevada tail. However, for a considerable distance south of the La Panza Range no basement rocks are exposed, and the extent of the Thermal Canyon mass is also unknown. Thus, the separation may be somewhat less than 400 km. It seems unlikely, however, that the discrepancy in separation can be completely compensated for in this way. Smith (1977) has noted the problem and proposed some 175 km of right-lateral offset on a fault within the Salinian block, but I have trouble reconciling the basement-rock data with such a fault.

One additional obstacle stands in the way of a La Panza-Thermal Canyon correlation. The Thermal Canyon region seems to have a framework of Precambrian metamorphic and granitic rocks (Rogers, 1965; Jennings, 1967), whereas no Precambrian rocks have been found in the central Salinian block. However, small outcrops of an unusual gneiss have been noted in American Canyon (fig. 12) just south of the La Panza granitic outcrop. I have examined these outcrops and studied some thin sections and stained slabs from the specimens collected. The gneiss appears to be of relatively high grade and in part to have a distinctive purple color in weathered outcrop; at least in part, it appears to be an orthogneiss. These gneissic rocks resemble some of the gneissic rock at Red Hills or some of the "dioritized" gneiss of Mount Abel-Mount Pinos; their appearance is out of character for the central Salinian block. Further study of these rocks, particularly isotopic age dating, is needed. At this latitude, these gneisses may very well be Precambrian because a Gabilan Range-Sierran tail reconstruction would place the La Panza Range adjacent to known Precambrian terranes in the San Bernardino Mountain area (fig. 1).

RINCONADA-RELIZ-KING CITY FAULT ZONE

In previous reconstructions, the Rinconada fault has been considered to be a favorable structure along which to sliver and attenuate the Salinian block. For example, Smith (1977) called for some 170 km of right-lateral offset on this fault zone. Dibblee (1976), in a carefully documented study of the Rinconada and related faults, called for a more modest offset of Upper Cretaceous and lower Tertiary units, of about 60 km. Graham (1978), in a detailed study of Tertiary units and structures in the central Salinian block, postulated 45 km of right-lateral movement on the basis of offset shore-

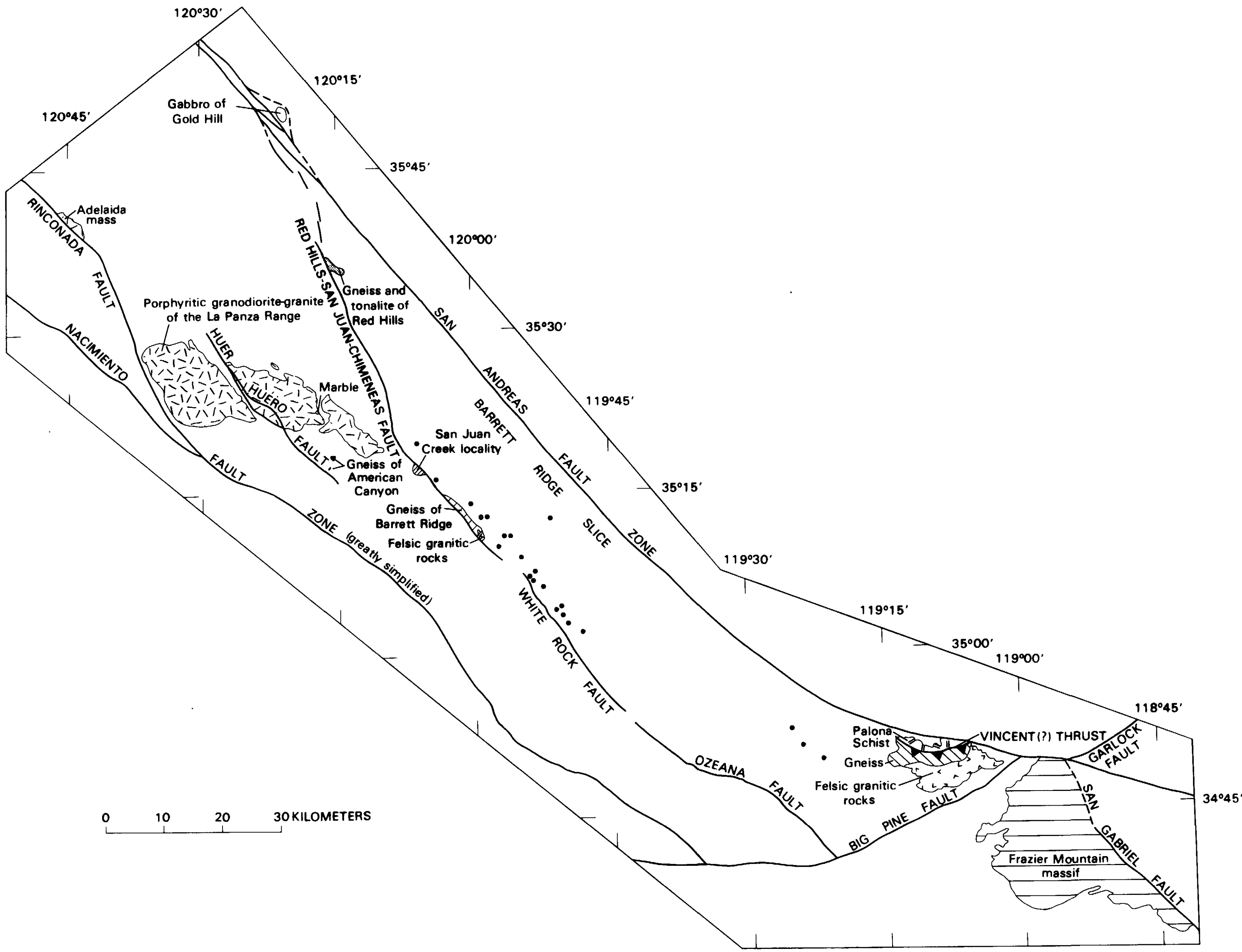

FIGURE 12.—Generalized geologic map of the southern Salinian block. Black dots denote locations where basement core material in the Barrett Ridge slice is gneiss and felsic granitic rocks, both of which are unlike basement rocks to the west in the central Salinian block. See Ross (1974) for description of core material.

lines and other features. He also believed that the distribution of the schist of Sierra de Salinas supports such an offset. On the basis of the present distribution of schist in the subsurface in the San Ardo oil field and in outcrops in the Sierra de Salinas (fig. 5), offsets of much as 50 km are possible.

I have noted that the major schist bodies in the Sierra de Salinas and in the Gabilan Range, together with all the other schist localities (except the isolated San Ardo area), form a somewhat discontinuous, relatively regular west-northwest-trending belt of schist that extends from the Sierra de Salinas to the San Andreas fault. I see no compelling reason to believe that this schist belt was significantly faulted or offset by the Rinconada fault zone.

I have long been perplexed by the isolated schist of the San Ardo area and its relation to the rest of the schist belt. The San Ardo rocks may be something other than the schist of Sierra de Salinas, but physically they are certainly similar. Given Graham's (1978) data on Tertiary shorelines, the basement may have been offset by the Rinconada-Reliz fault, though by no more than some 45 km. Interestingly enough, reversal of that amount of movement across this modest crack in the Salinian block would bring the porphyritic granodiorite of Monterey and its offshore continuation much closer to the northernmost outcrops of the porphyritic granodiorite in the Gabilan Range—a correlation I had suggested before Graham's study (Ross, 1978).

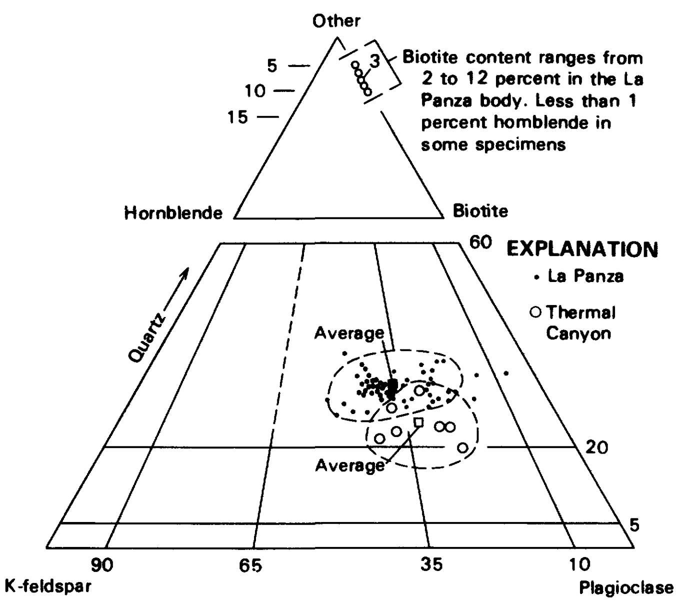

FIGURE 13.—Comparison of modally analyzed specimens of the porphyritic granitic rocks of Thermal Canyon and the porphyritic granodiorite-granite of the La Panza Range.

Presumably, the Rinconada-Reliz fault zone continues northwestward along the course of the much-discussed and sometimes controversial King City fault (Ross and Brabb, 1973). It may continue across Monterey Bay along one of several northwest-trending faults of the Monterey Bay fault zone of Greene and others (1973). Then, to the north, the Rinconada-Reliz-King City fault zone probably merges with the San Gregorio-Hosgri fault west of the basement outcrops in the Ben Lomond area (Ross and Brabb, 1973, fig. 4).

PROBLEMS OF SALINIAN-BLOCK RECONSTRUCTION THAT STILL REMAIN

Many basement-rock correlations seem to make good sense or, at least, provide compatible ties if the Bodega-Point Reyes basement is pulled southward along the San Gregorio-Hosgri fault zone to the Ben Lomond area and then the central block of the Salinian block is pulled southward along the San Andreas fault to the general area of the Sierra Nevada tail (San Emigdio Mountains). However, the following basement problems still persist, unresolved.

CORDILLERAN MIOGEOCLINAL ROCKS

The upper Precambrian and lower Paleozoic sedimentary rocks of the Cordilleran miogeocline have been traced southward from Nevada, through eastern California, across the Mojave Desert, and into the San Bernardino Mountains. Although the preservation of this belt is spotty and near its south limits is much disrupted by intrusive rocks and covered by younger rocks, there seems to be little doubt that it reaches, and is cut off by, the San Andreas fault zone. The distinctive rock types of this section—thick pure quartzite and thick limestone—have not been found in the Salinian block. If the Gabilan Range-Sierran tail correlation is valid, then such rocks might be expected to appear at about the latitude of the La Panza Range (figs. 11, 12).

The La Panza Range basement is almost entirely granitic; it contains only traces of biotite schist and marble, as well as a small amount of unusual-appearing gneiss just south of the main granitic basement outcrops. Admittedly, vast areas to the north and south of the La Panza Range granitic outcrops are covered by younger deposits that conceal the composition of the basement; nevertheless, it would have been reassuring to see at least a few quartzite or marble pendants in the exposed basement. Of considerable interest are the strikingly distinctive pure quartzite (orthoquartzite) cobbles and pebbles that are common in the Cretaceous beds which lap up on the south side of the La Panza granitic basement. These pure quartzite cobbles and pebbles are of a rock type that is virtually unknown in the Salinian block basement.

Howell and Vedder (1978) speculated that both the concentration of quartzite in the erosional product of the basement and its rarity in the present basement may reflect differential magmatic stoping. They proposed that the relatively light quartzite is selectively floated to the upper parts of the magma chamber, where it becomes an early erosional product, leaving the pluton relatively impoverished in quartzite, even though quartzite may have been abundant in the original metamorphic framework. Their mechanism suggests that upper Precambrian and lower Paleozoic Cordilleran miogeoclinal rocks may once have been present in the central Salinian block.

BEAN CANYON FORMATION

The Bean Canyon Formation forms discontinuous pendants for almost the entire length of the granitic outcrop south of the Garlock fault, from the San Andreas fault east for about 60 km (fig. 9) The Bean Canyon contains distinctive metavolcanic-rock layers and dark schist that, in part, is rich in coarse andalusite crystals. If the Gabilan Range is moved up against the Sierran tail, the Bean Canyon Formation might be expected to occur in the central or southern Gabilan Range; however, no metavolcanic or dark andalusite-bearing rocks have been seen there. Note, however, that the westernmost large exposure of the Bean Canyon is dominantly marble and contains neither metavolcanic-rock layers nor dark andalusite schist, and that the next most easterly marble-rich area of outcrop contains very minor amounts of andalusite-bearing schist and thin layers that may, or may not, be metavolcanic rocks. These volcanic and andalusite layers are probably absent to the west because of a facies change and so would not be expectable in the Gabilan Range. Scattered marble inclusions throughout the granitic terrane of the central and southern Gabilan Range may represent the Bean Canyon, but no distinctive associated lithologies occur to make a convincing tie.

TEMBLOR CLASTS

Directly related to the discussion of the Bean Canyon Formation is the problem of the Temblor clasts. Bouldery beds in the Miocene Santa Margarita Formation in the Temblor Range (fig. 1) appear to be cut off on the west by the San Andreas fault. Huffman (1972) suggested that the most plausible source terrane for these clasts is the northern Gabilan Range. In examining the Temblor clasts, I noted many metavolcanic and dark andalusite-bearing rocks (Ross, 1980). I have seen neither rock type in the Gabilan Range or anywhere in the Salinian block, but these two rock types generally characterize the Bean Canyon Formation. This dilemma will persist until these two rock types are found in the Gabilan Range basement. My studies, which admittedly were scattered and concentrated on the granitic rocks, leave much room for more detailed investigation, particularly of the metamorphic rocks of the Gabilan Range.

SIERRAN QUARTZITES

Within the metasedimentary rocks of the southern Sierra Nevada, pure quartzite (orthoquartzite) is distinctive and abundant enough to be noted and mapped in various localities. I have suggested that the absence of pure quartzite in the Salinian block was one of the reasons for questioning a match between the Salinian block and the southernmost Sierra Nevada. However, I have come to think that this distinction may have been overemphasized. Certainly, only minor amounts of pure quartzite occur near the San Andreas fault in pendants and inclusions in the granodiorite of Lebec and in the Bean Canyon Formation, whereas more seems to occur in the Kernville and Isabella Lake areas (fig. 1) farther to the north and east. The difference may be solely a matter of facies change or is an indication of irregular variation in a discontinuously exposed sedimentary section. I no longer think that the difference between the metasedimentary rocks of the Gabilan and Santa Lucia Ranges and those of the southernmost Sierra Nevada is great enough to argue against correlating these two terranes.

METALLIC-MINERAL DEPOSITS

In an earlier report (Ross, 1978), I noted the abundance and variety of metallic-mineral deposits in the southernmost Sierra Nevada, in contrast to the virtual absence of such deposits in the Salinian block. The Salinian block still appears to be anomalously barren.However, the number of developed and productive properties drops off sharply south of the latitude of Tehachapi (fig. 1), and mineral deposits are notably sparse in the Sierran tail—

that is, in the area where the proposed correlative join with the barren Gabilan Range would be. The difference in the amount of mineralization is considerably less if the Sierran tail alone is compared with the Salinian-block rocks. The normal vagaries of distribution of mineral deposits in similar terranes may also be a factor here.

The problems discussed thus far can all be accommodated, at least in part, by the proposed reconstruction. Four more serious problems remain, involving: (1) the Barrett Ridge slice (fig. 12), (2) Montara Mountain and the K-feldspar-rich sedimentary rocks of the Gualala area (figs. 3, 4), (3) a europium-anomaly contrast between the Salinian block and the southernmost Sierra Nevada, and (4) the unlocated west margin of the Salinian block.

BARRETT RIDGE SLICE

The Barrett Ridge slice (Ross, 1972a)—the anomalous basement terrane east of the Red Hills-San Juan-Chimeneas fault (fig. 12)—poses possibly the greatest problem for a fault-reconstruction model based only on reversal of currently acceptable displacements on the San Andreas and San Gregorio-Hosgri fault zones. A recapitulation here of the data from the Red Hills, Barrett Ridge, Mount Abel-Mount Pinos, and several well cores should help explain why the Barrett Ridge slice presents a problem.

In the Red Hills, a few square kilometers of gneissic basement rocks pokes up through the Cenozoic cover and appears to be truncated on the west against the Red Hills-San Juan-Chimeneas fault. Most of these outcrops consist of hornblende-biotite gneiss of tonalitic composition that is, in part, homogenized to a massive granitic rock. Less common are outcrops of augen gneiss, biotite-rich gneiss, hornblende schist, amphibolite, marble, and metasiltstone.

Barrett Ridge is an elongate rib of basement made up largely of quartzofeldspathic gneiss that is locally rich in biotite but poor in hornblende. The gneiss is thinly layered and strongly folded, in part ptygmatically. Near the south end of the ridge, a thick interbed of relatively pure quartzite and a plug of alaskite are present. Alaskite-aplite dikes are common in the gneiss and, at least in part, appear to be sweated out of the gneissic rocks. Several wells drilled north and south of Barrett Ridge have pierced the basement. Studies of core material from these wells (Ross, 1974) show the basement to be dominantly dark gneiss and granofels, with lesser amounts of amphibolite and felsic granite. In other words, the suite of subsurface samples generally resembles the outcrop areas of Barrett Ridge and Red Hills.

The inferred south end of the Barrett Ridge slice, and the southernmost basement exposure of the Salinian block, is the massif of Mount Abel-Mount Pinos (fig. 12). Although the geology is complex in detail, the overall pattern is simple. A southern belt is dominated by felsic granitic rocks. A central belt of high-grade banded gneiss, augen gneiss, migmatite, and amphibolite is characterized by gradations of the gneiss to homogeneous granitic rocks of tonalite and granodiorite compositions, much like those of the Red Hills. The central belt overlies a northern belt of the Pelona Schist along a thrust contact marked by an impressive mylonite zone which may be the westernmost exposure (on the southwest side of the San Andreas fault) of the Vincent thrust (Ehlig, 1968).

It is clear from this description that the Barrett Ridge slice differs significantly from the central Salinian block to the west. Plutons of tonalite and granodiorite seem to be absent to rare in the Barrett Ridge slice, and the granitic rocks generally contain patches of ghost gneiss and grade into gneissic rocks. Kistler and others (1973) obtained an anomalously high initial $^{87}Sr/^{86}Sr$ ratio of 0.7164 from a sample of homogenized gneiss from Mount Abel; they concluded that the gneiss is probably Precambrian. They also obtained an initial $^{87}Sr/^{86}Sr$ ratio of 0.7095 from homogenized gneiss from the Red Hills—a value significantly higher than from samples from the central Salinian block (west of the Barrett Ridge slice), but comparable to those obtained from gneissic samples from the San Gabriel Mountains to the southeast. These data confirm what the petrography had suggested—that a strong discordance exists between the Barrett Ridge slice and the rest of the Salinian block.

If an attempt is made to slide the Barrett Ridge slice back along the San Andreas fault zone, finding a parent terrane poses a real problem. Southeastward from the Portal-Ritter Ridge area (fig. 1) on the northeast side of the San Andreas fault, the Holcomb and Wrightwood basement rocks (Ross, 1972a) might be able to accommodate part of the Barrett Ridge slice, but surely the large plutonic bodies of the San Bernardino Mountains (fig. 1) and their probable Cordilleran miogeoclinal roof pendants would be strange company for the Barrett ridge slice. The basement sample from the Barrett Ridge slice is small; however, a good petrographic sample is available from the Red Hills along the west side of the slice to the Mount Abel-Mount Pinos area (fig. 12). These rocks are relatively similar and are distinctive over a large area.

If, instead of pushing the Barrett Ridge slice back along the San Andreas fault, that slice and the adjacent Mount Frazier area were to be pushed back along the south side of the San Gabriel lozenge and molded around it along the San Gabriel-Sierra Madre fault zone (fig. 1), a better match of rock types would be obtained. Also, the Pelona Schist at Mount Abel-Mount Pinos would end up south of, and almost adjacent to, the main outcrops of the Pelona Schist in the eastern San Gabriel Mountains. Although this reconstruction makes good lithologic sense, it brings about a structural problem that is virtually insurmountable. If the San Gabriel basement block originated opposite the Chocolate and Orocopia Mountains before San Andreas fault movement, as Crowell and Walker (1962) convincingly demonstrated on the basis of a correlation of several basement-rock units, then, to reach its present position, the Barrett Ridge slice would have had to travel some 200 km farther than the central block of the Salinian block. This movement would be necessary for both the correlations of Crowell and Walker (1962) and the one proposed here for the Gabilan Range-Sierra Nevada to be satisfied, and clearly it is implausible.

Howell and others (1980) suggested that the Red Hills-San Juan-Chimeneas fault is part of an old collision zone between two basement terranes that were accreted to the North American Continent at a latitude somewhere in southern Mexico. These two terranes drifted northward as a structural unit, beached in southern California, and subsequently were transported some 300 km by movement on the San Andreas fault system. This proposal nicely solves the apparent need for additional movement on the Barrett Ridge slice, but it suggests that we should see evidence of an impressive collision in the area of the Red Hills-San Juan-Chimeneas fault zone. Small samples of basement rocks from the Red Hills, San Juan Canyon, and Barrett Ridge have not revealed the types of major contortions and cataclastic deformation that I would expect to find associated with such a structural event. Nonetheless, it seems reasonable to view the Red Hills-San Juan-Chimeneas fault zone as a major structural discordance (possibly a strike-slip fault) that predates the San Andreas fault. The Barrett Ridge slice and its west-bounding fault present a serious—if not insurmountable—problem for a simple 300 to 350 km of basement reconstruction.

MONTARA MOUNTAIN AND GUALALA GRANITIC CLASTS

The proposed reconstruction that places the Gabilan Range opposite the Sierra Nevada tail also presumes that oceanic basement is present north of the Vergeles-Zayante fault. This reconstruction (fig. 14) leaves the granitic basement of Montara Mountain marooned considerably north of the Bodega Head-Ben Lomond granitic basement. This anomaly calls for the Montara mass to be either a structurally isolated block or an intrusion into oceanic basement.

The K-feldspar arkose of Gualala (fig. 3), with its coarse granitic debris, must have been derived from a continental source. According to my reconstruction, however, these sedimentary rocks are also cut off from a granitic basement source. Both the granitic rocks of Montara Mountain and the K-feldspar-rich sedimentary rocks of the Gualala area can be accommodated more easily if the basement is continental north of the Butano fault; however, such a situation would cast considerable doubt on the correlation of the Pastoria and Vergeles-Zayante fault zones.

EUROPIUM-ANOMALY CONTRAST

Trace-element patterns for the granitic rocks of the Salinian block and the southernmost Sierra Nevada present possibly significant contrasts. Europium anomalies in the rocks of the southernmost Sierra Nevada not only occur in the granites, as they do in most granitic suites, but also are surprisingly common in the granodiorites and even in some of the tonalites. In the Salinian block as well as in the central Sierra Nevada (Dodge and others, 1982), pronounced europium anomalies are found only in the granites. A graphic comparison of the trace-element patterns of these three regions was shown by Ross (1982).

The Salinian-block data, though sparse (14 samples), cover a wide range of chemical compositions and a wide geographic range, and so they are probably representative. The sampling in the southernmost Sierra and, even more so, in the central Sierra is much more extensive and surely reflects an actual difference in trace-element patterns.

The contrast in trace-element patterns between the Salinian block and the southernmost Sierra Nevada is incompatible with the correlation of these two terranes. At present, however, the full significance of this contrast is not fully understood. More trace-element data for the gap between the central and southernmost Sierra Nevada are

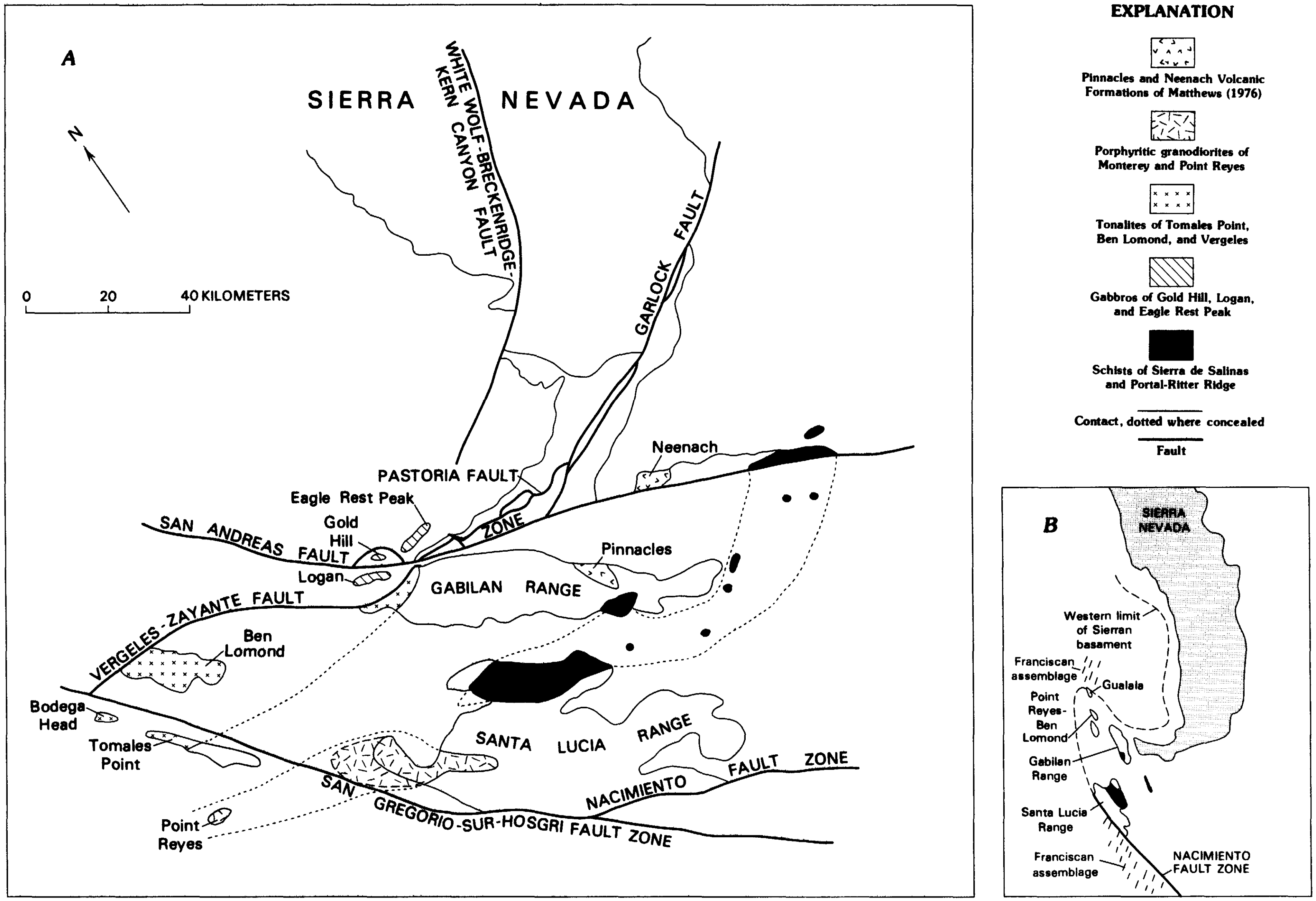

FIGURE 14.—Possible reconstructions of the northern and central Salinian block before San Andreas fault movement. *A*, Distribution of key basement-rock units after commonly accepted movements on the San Andreas and San Gregorio-Hosgri fault zones are removed. *B*, Major oroclinal bend proposed by Burchfiel and Davis (1980) and their interpretation of the distribution of selected areas of basement rocks of the Salinian block before movement on the San Andreas fault. Simplified from Burchfiel and Davis (1980, fig. 9-9).

needed to determine the geographic extent of europium anomalies and their values over a broad range of granitic rock compositions.

UNLOCATED WEST FLANK OF THE SALINIAN BLOCK

The Salinian block, as presently exposed, is notably thinner than other parts of the Cordilleran plutonic arc, from which arc it is generally assumed to have been derived. For example, in comparison with the southern California batholith or the central Sierra Nevada batholith, the Salinian block appears to lack a west flank that elsewhere in the Cordilleran plutonic arc includes abundant tonalite, trondhjemite, and gabbro as well as metamorphic framework rocks rich in volcanic material and volcanoclastic debris. Page (1982), in his comprehensive review of the migration history of the Salinian block, emphasized its anomalous thinness and suggested that the disappearance of the west flank is the result of either (1) megatransport at the Earth's surface or (2) destruction by piecemeal subduction (tectonic erosion).

If the present west limit of the Salinian block (the Nacimiento fault) marks a zone where oceanic material has collided with a continental margin, the surviving continental-margin rocks would be expected to preserve some evidence of this strongly compressive event. However, the westernmost granitic exposures in the La Panza Range, adjacent to the Nacimiento fault zone, do not appear to be strongly deformed or melanged, and Page (1982) noted that Salinian granite, essentially in contact with oceanic and pelagic sedimentary rocks, shows no evidence of interaction. It seems unlikely that piecemeal subduction of lighter continental material downward into denser oceanic material could have occurred here (or anywhere) on a large scale without leaving evidence of such an impressive event.

The abrupt west termination of the granitic basement of the Salinian block against oceanic material, seen in both the La Panza and Santa Lucia Ranges, more likely reflects a strike-slip fault zone. If the missing western part of the original Salinian block has, indeed, been stripped away by megatransport to a site as yet unknown, it is plausible that—as Howell and others (1980) proposed—the east margin of the block may also have undergone megatransport, of which modest movements along the San Andreas and San Gregorio-Hosgri fault zones are only the most recent events. However, the possibilities of correlation between the central Salinian block and the southernmost Sierra Nevada cannot be lightly dismissed. As we continue to search for the source of the Salinian block, so also must we continue to search for its sheared-off west margin.

CONCLUSIONS

Figure 14*A*, which shows selected key units of basement rock of the Salinian block reconstructed along the southwest side of the present San Andreas fault, indicates a possible distribution of basement before movement along the San Gregorio-Hosgri and San Andreas fault zones. Figure 14*B* shows a similar reconstruction, including the oroclinal bend proposed by Burchfiel and Davis (1980). Their reconstruction connects the Nacimiento fault around the oroclinal bend with the contact, now buried, between Sierran basement on the east and the Franciscan-assemblage basement on the west. Note that the reconstruction by Burchfiel and Davis (1980) places the Santa Lucia Range about 50 km south relative to the Gabilan Range, so as to take account of the movement proposed by Graham (1978) across the Rinconada-Reliz-King City fault (fig. 5). Either way (fig. 14*A* or 14*B*), there is a good juxtaposition of the schists of Sierra de Salinas and Portal-Ritter Ridge. The combined Pastoria and Vergeles-Zayante fault zone would presumably bend southward, with the oroclinal flexure somewhere seaward of Bodega Head and Cordell Bank to join the Nacimiento fault zone. However, the dilemma of the isolation of the Gualala area and Montara Mountain north of the other continental (granitic) basement remains, and its solution demands more data on the characteristics of the basement at the north end of the Salinian block.

A reconstruction that depends on some 300 to 350 km of right-lateral offset on the San Andreas fault and some 130 km of similar movement on the San Gregorio-Hosgri fault brings into alignment several basement-rock units and structures in the central Salinian block with similar features in the southernmost Sierra Nevada. Correlations of individual granitic and metamorphic basement rocks can never be truly unequivocal because similar basement-rock types and textures are apt to recur. However, the occurrence of a cluster of correlative basement-rock units in the Gabilan-Santa Lucia Ranges and the southern Sierra Nevada region cannot be dismissed lightly.

In summary, that cluster of possibly correlative units and features includes (1) an unusual and distinctive metagraywacke (schists of Sierra de Salinas and Portal-Ritter Ridge), (2) mineralogically unusual hornblende quartz gabbros and coarse anorthositic gabbros (in the Logan, Gold Hill, and Eagle Rest Peak areas), (3) several granitic units, (4) a similar east-west structural grain, and (5) a structural break between oceanic and continental basement terranes (the Vergeles-Zayante and Pastoria fault zones).

The reconstruction that fits the central part of the Salinian block to a potentially correlative terrane is far more uncertain for the northern part of the Salinian block. There, the composition of the basement rocks is of critical importance, but large areas are now covered by sedimentary rocks and ocean water. Furthermore, whether this northern basement is oceanic or continental, some correlation problems still remain. To the south is an even greater problem—the Salinian block-Sierra Nevada reconstruction places part of the Barrett Ridge slice opposite the San Bernardino Mountains in an untenable juxtaposition of dissimilar basement rocks.

By themselves, movements on the San Andreas and San Gregorio-Hosgri fault zones do not seem to resolve the problem of the origin of the Salinian block. Such movements solve some problems, but they create other, greater ones. As already discussed, Howell and others (1980) proposed much larger movement for a composite block of coastal California that includes the Salinian block. This movement, premised in part on the paleomagnetic studies by Champion and others (1980), would predate San Andreas movement. Early in the preparation of this report, when I first heard this model described, I was nearly convinced that data on offsets of the San Gregorio-Hosgri fault zone (Graham and Dickinson, 1978a, b), my new ideas concerning an ancient ocean margin in the Sierra Nevada tail, and the conventionally accepted amounts of movement on the San Andreas fault zone would enable a resolution of the origin of the Salinian block. Therefore, I gave the model of Howell and others (1980) short shrift. However, as I pursued the problem, it became apparent that my initial model was inadequate and that theirs might be right.

Nevertheless, the match of several basement-rock units and features in the central Salinian block with the southern Sierra Nevada region (fig. 14) cannot be readily dismissed. Are all of those correlations only the fortuitous superpositions of undiagnostic features? Or do all of the correlative features occur within a large, composite, exotic coastal block that was offset only by the later San Andreas movement? For example, the schists of Sierra de Salinas and Portal-Ritter Ridge could both be part of a composite coastal terrain that was split apart by later San Andreas movement. However, the granitic rocks, structures, and structural grain in the Sierran tail are firmly tied to the main Sierra Nevada block and are separate from any composite coastal block. The presence, which I have suggested, of correlatives of these features in the central Salinian block could pose problems for the model of Howell and others (1980). Their model would then call for the present Gabilan Range to be beached (after its long journey from southern Mexico) adjacent to some nearly identical rocks and structures in the southern Sierra Nevada—and that would imply a degree of coincidence that is hard to credit.

In conclusion, the problem of the origin of the Salinian block does not seem to be resolved. I had hoped that this study would resolve the problem; instead, these reconnaissance studies have merely provided tantalizing clues that need to be pursued. Neither the model that calls for some 300 km of San Andreas fault movement supplemented by San Gregorio-Hosgri fault movement, nor the model of Howell and others (1980), which calls for a pre-San Andreas movement of a large composite terrane, provides all the answers. Both models create some new problems even as they appear to solve others. Further detailed basement-rock studies of both the central Salinian block and the Sierran tail should help decide whether there is a valid correlation between these two areas or merely a juxtaposition of several of similar-appearing but unrelated basement-rock units.

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SUPPLEMENTAL INFORMATION

COMPARISON OF THE PORPHYRITIC GRANODIORITES OF POINT REYES AND MONTEREY

The granitic rocks at Point Reyes and on the Monterey Peninsula (fig. 15) are generally similar in appearance. Both contain conspicuous euhedral K-feldspar phenocrysts, but the rocks are not everywhere porphyritic (seriate). The phenocrysts in the Point Reyes granitic rocks do not exceed 5 cm in length, whereas those in phenocrysts of the Monterey granitic rocks are as much as 15 cm long. This extreme development of coarse phenocrysts, however, occurs only locally in the Monterey mass; commonly, the phenocryst size in both masses is similar. The modal mineralogies of the two masses are also similar (fig. 16); the variations are well within the limits found in normal plutonic units.

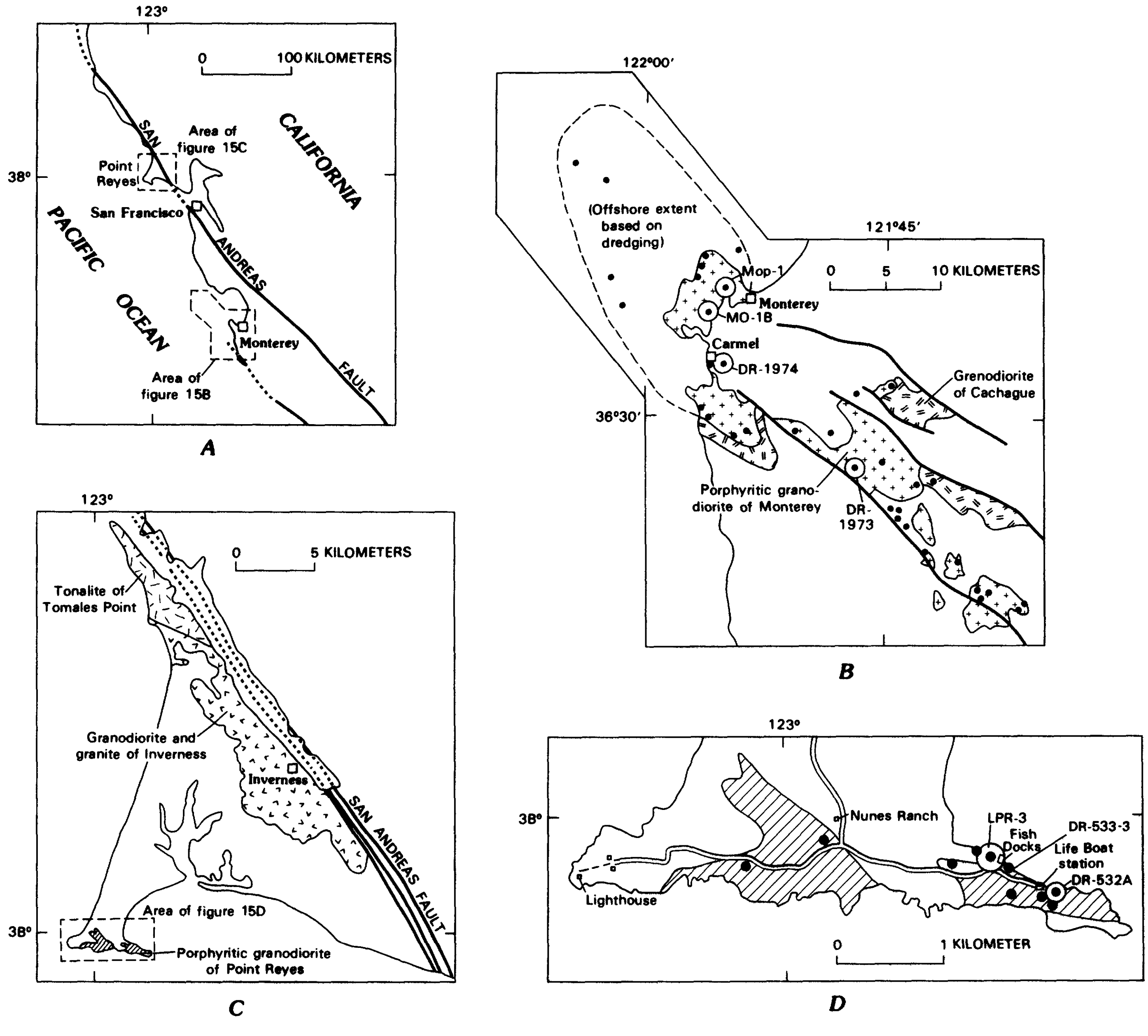


FIGURE 15.—Locations of the porphyritic granodiorites of Point Reyes and Monterey. *A*, Locations of study areas at Point Reyes and Monterey. *B*, Locations of modally analyzed samples (dots) and chemically analyzed samples (circles) of the porphyritic granodiorite of Monterey. *C*, Location of the porphyritic granodiorite of Point Reyes. *D*, Locations of modally analyzed samples (dots) and chemically analyzed samples (circles) of the porphyritic granodiorite of Point Reyes. Numbers refer to samples listed in table 2.

One possibly significant difference is that the specimens of the Point Reyes mass that I have examined contain about 1 percent of hornblende, whereas I have seen no hornblende in the Monterey mass. Also, the Monterey mass has what appears to be primary muscovite, which is absent in the Point Reyes mass. However, the granodiorite of Cachagua, which I consider to be in gradational contact with the Monterey mass, contains hornblende, as does a suspected correlative of the Monterey mass in the La Panza Range (fig. 12). Thus, both the overall physical appearance and the modal mineralogy suggest that these two masses are compatible and are potential correlatives.

Chemically, the two masses also appear to be approximately comparable (fig. 17; table 1). Although

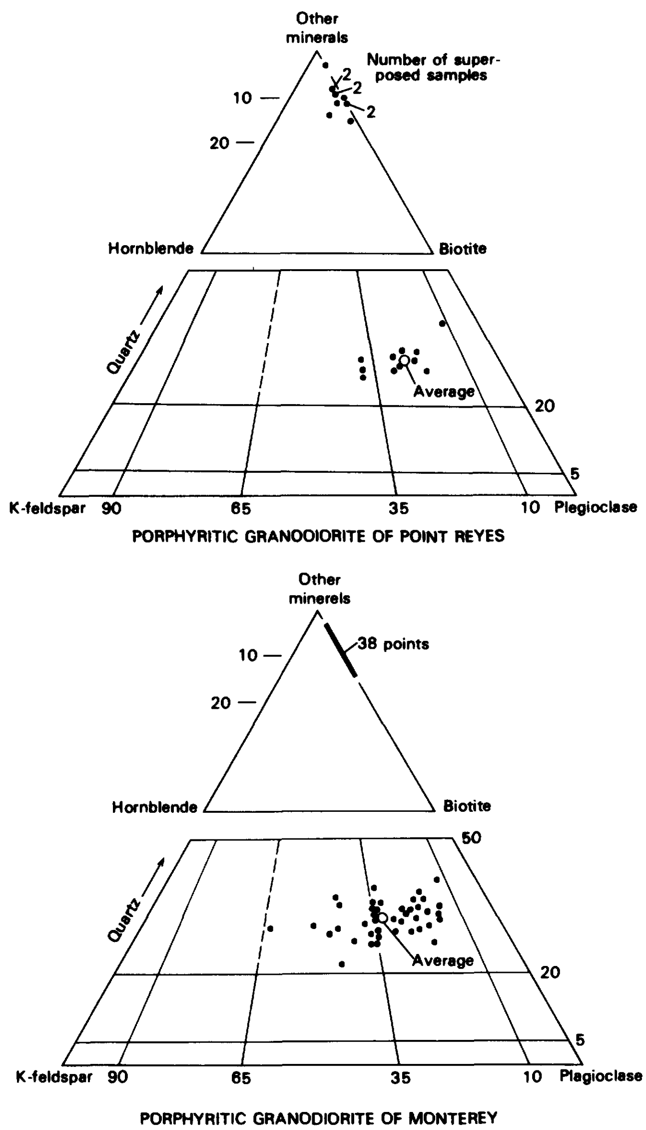


FIGURE 16.—Modes of the porphyritic granodiorites of Point Reyes and Monterey.

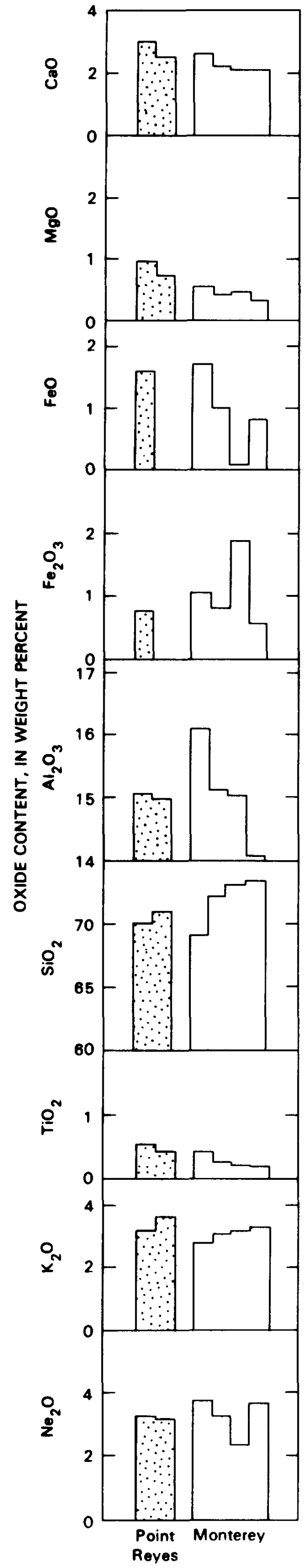


FIGURE 17.—Histograms showing chemical analysis of the porphyritic granodiorites of Point Reyes and Monterey.

only two analyses are available from the Point Reyes mass, they probably are representative of the small exposed part of the mass. Oxide contents are comparable to the average value for the four specimens from the Monterey mass. The Point Reyes mass is somewhat richer in CaO and poorer in SiO_2, but these differences do not seem to be significant. The chemical similarity of the two masses is further accentuated by the ternary plots Q-Or-(Ab+An), Or-Ab-An, and Alk-F-M (fig. 18). Of possible significance is the fact that both masses have normative corundum: 1.4 percent for the Point Reyes and about 3.0 percent for the Monterey. The average abundance of normative quartz is higher in the Monterey mass (34 percent), than in the Point Reyes mass (31 percent), but values for Monterey samples overlap those for the Point Reyes samples.

The exposures of granitic rocks on Point Reyes lie 10 km from the nearest granitic exposures of the Inverness area. I had originally (Ross, 1972a) considered the Point Reyes granitic rocks to be part of the granodiorite and granite of Inverness (fig. 15). The porphyritic texture of the Point Reyes granitic rocks, and their hornblende content, indicate that they are at least a separate facies of the Inverness granitic rocks; they could even represent a separate granitic body.

Just east of the Fish Docks is an exposure of darker granitic rock (sample 533-3, fig. 19) that contains conspicuous abundant hornblende and numerous small ellipsoidal mafic inclusions. The dark rocks sharply contact the lighter Point Reyes granitic rocks (which here are not porphyritic), but the age relation is not obvious. These dark rocks, which contain 11 percent biotite and 9 percent hornblende, I interpret to be a large inclusion of the tonalite of Tomales Point within the porphyritic granodiorite of Point Reyes. The granitic rocks of Point Reyes may well be connected physically at depth with the tonalite of Tomales Point and the granodiorite and granite of Inverness. However, the physical and chemical compatibility of the Point Reyes and Monterey granitic rocks leaves open the possibility of their correlation and of a structural break between the Point Reyes and Inverness masses. The dark rocks near the Fish Docks could as well be an inclusion of the tonalite of Soberanes Point, which is widely exposed in the Santa Lucia Range south of Monterey.

Nothing at Point Reyes rules out a correlation with the granitic rocks at Monterey. I think that the granitic rocks at Point Reyes are related to the Tomales Point-Inverness basement. At Kehoe Beach, about 17 km north of Point Reyes, darker rocks resemble some of the rocks at Point Reyes. Also, near Inverness, hornblende-bearing granitic rocks occur that are physically and modally nearly

TABLE 1.—*Chemical analyses of selected granitic rocks from the Point Reyes and Monterey areas, California*

[All values in weight percent; n.d., not determined. Sources of chemical data: sample DR-532A, Ross (1972a); sample LPR-3, Clark and others (1984); samples Mo-1B, DR-1973, DR-1974, and Mop-1, Ross (1977b). See figure 15 for sample locations]

	Point Reyes			Monterey				
Sample----	DR-532A	LPR-3	Average	Mo-1B	DR-1973	DR-1974	Mop-1	Average
SiO_2-------	70.2	71.02	70.6	73.5	69.2	72.3	73.2	72.1
Al_2O_3------	15.4	15.00	15.2	14.4	16.5	15.6	15.3	15.5
Fe_2O_3------	.74	} 2.80	} 2.6	.53	1.2	.80	1.9	1.1
FeO--------	1.6			.83	1.7	1.0	.08	.9
MgO--------	.97	.75	.86	.33	.56	.42	.45	.44
CaO--------	3.0	2.50	2.8	2.1	2.6	2.2	2.1	2.3
Na_2O-------	3.3	3.27	3.3	3.7	3.8	3.3	2.4	3.3
K_2O--------	3.2	3.63	3.4	3.3	2.8	3.1	3.2	3.1
H_2O^--------	.09	n.d.	.1	.09	.24	.24	.39	.2
H_2O^+-------	.64	n.d.	.6	.68	.67	.50	.34	.6
TiO_2-------	.59	.43	.5	.20	.43	.26	.23	.3
P_2O_5-------	.14	.10	.12	.05	.10	.06	.06	.07
MnO--------	.11	.04	.07	.08	.06	.06	.06	.07
Total---	100.00	99.54	100.2	99.8	99.9	99.8	99.7	100.0

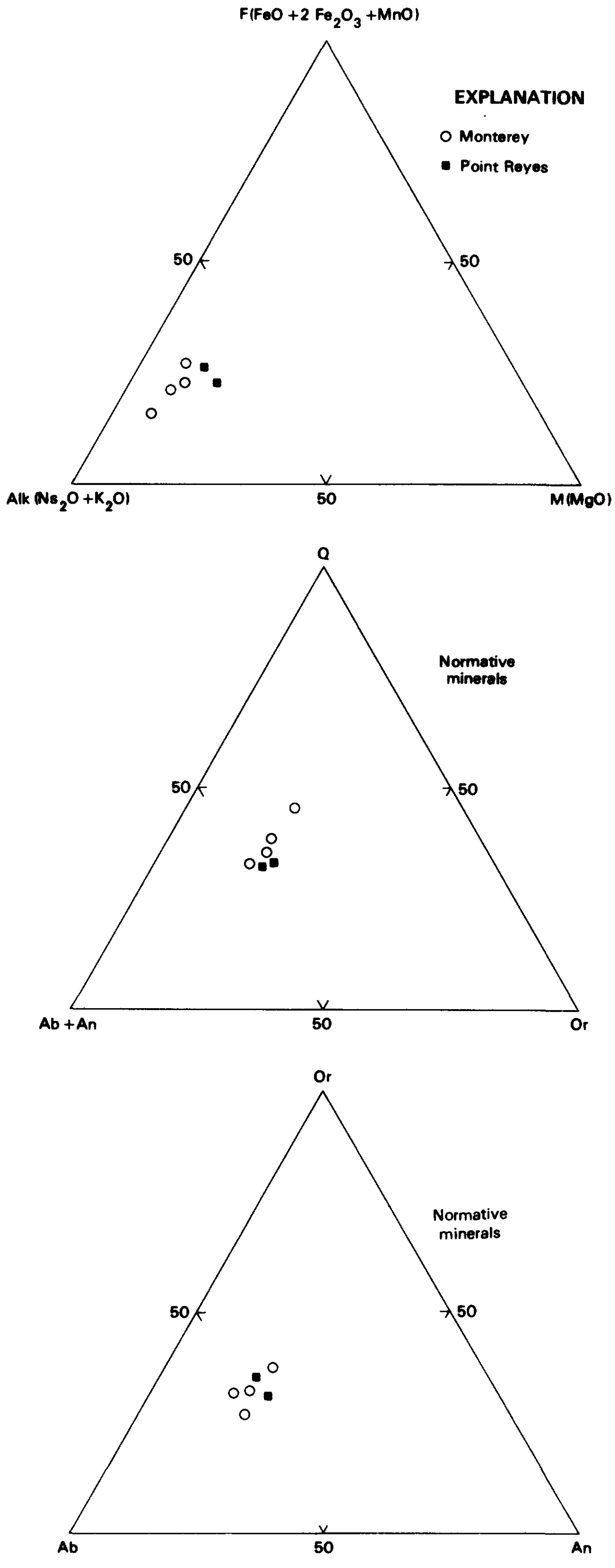


FIGURE 18.—Chemical compatibility of the porphyritic granodiorites of Point Reyes and Monterey.

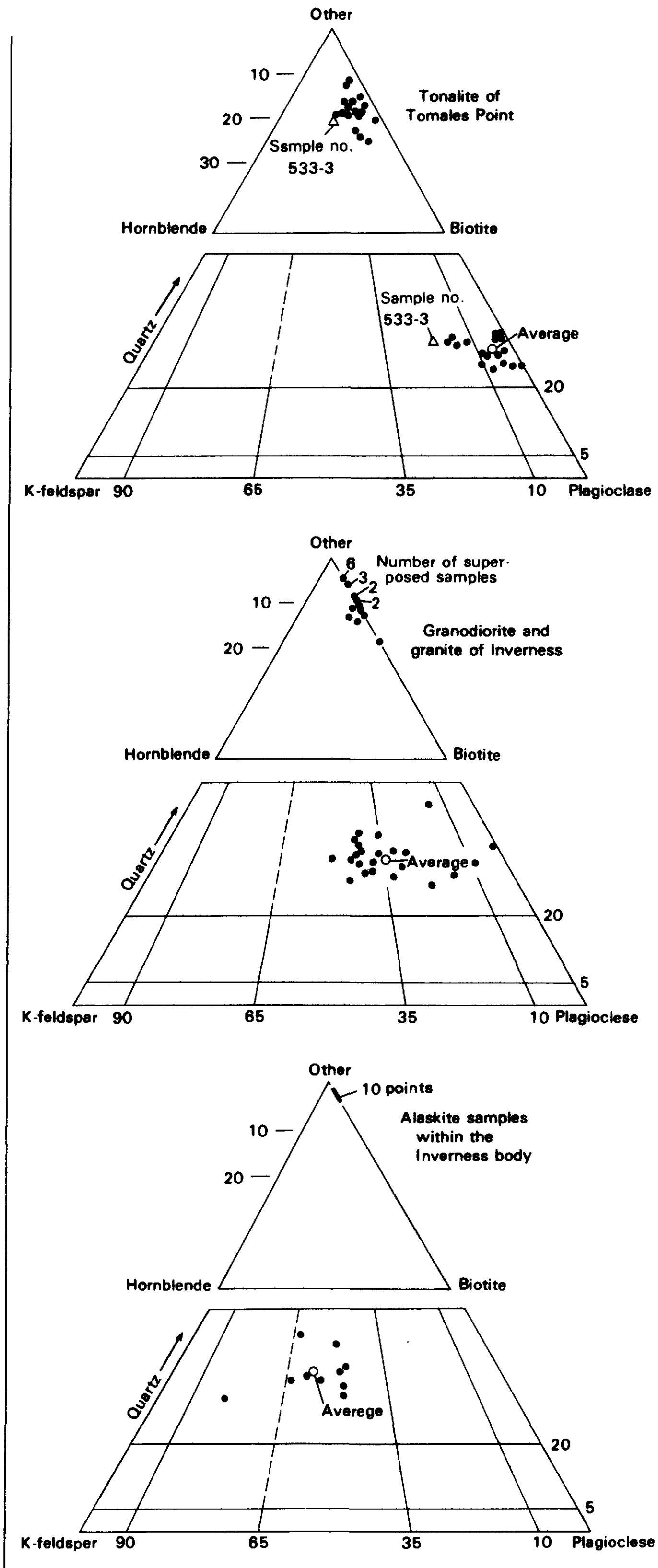


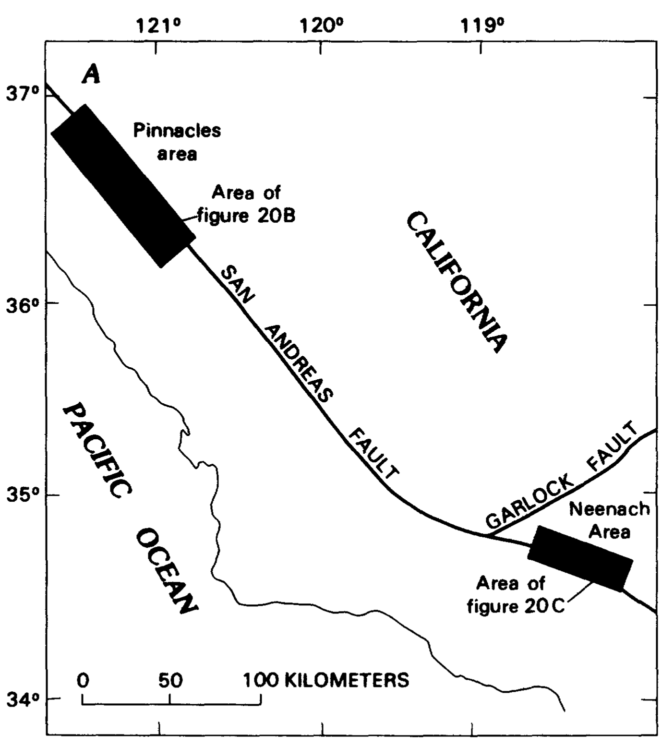
FIGURE 19.—Modes of the Tomales Point and Inverness granitic bodies.

identical to those at Point Reyes. This whole discussion illustrates the frustrations of attempting to make positive correlations of granitic basement terranes.

COMPARISON OF THE GRANITIC ROCKS NEAR THE PINNACLES AND NEENACH VOLCANIC FORMATIONS OF MATTHEWS (1976)

The Pinnacles and Neenach Volcanic Formations of Matthews (1976) (fig. 20*A*) are both closely associated with various granitic rocks. In the Pinnacles area (fig. 20B) the tonalite and granodiorite of Johnson Canyon, the granite of Bickmore Canyon, and associated felsic rocks crop out over a large area adjacent to the Pinnacles Volcanic Formation. Petrographically and chemically comparable granitic bodies, the granodiorites of Fairmont Reservoir and Burnt Peak, and a felsic variant(?) are exposed near the Neenach Volcanic Formation (fig. 20*C*).

Granitic data from the Pinnacles area were collected early in the 1970's and summarized by Ross (1975). Data from the Neenach area are a combination of an earlier reconnaissance study of the Transverse Ranges (Ross, 1972a) and more detailed mapping and sampling near the Neenach Volcanic Formation in 1982 (fig. 20*C*; table 2). Present



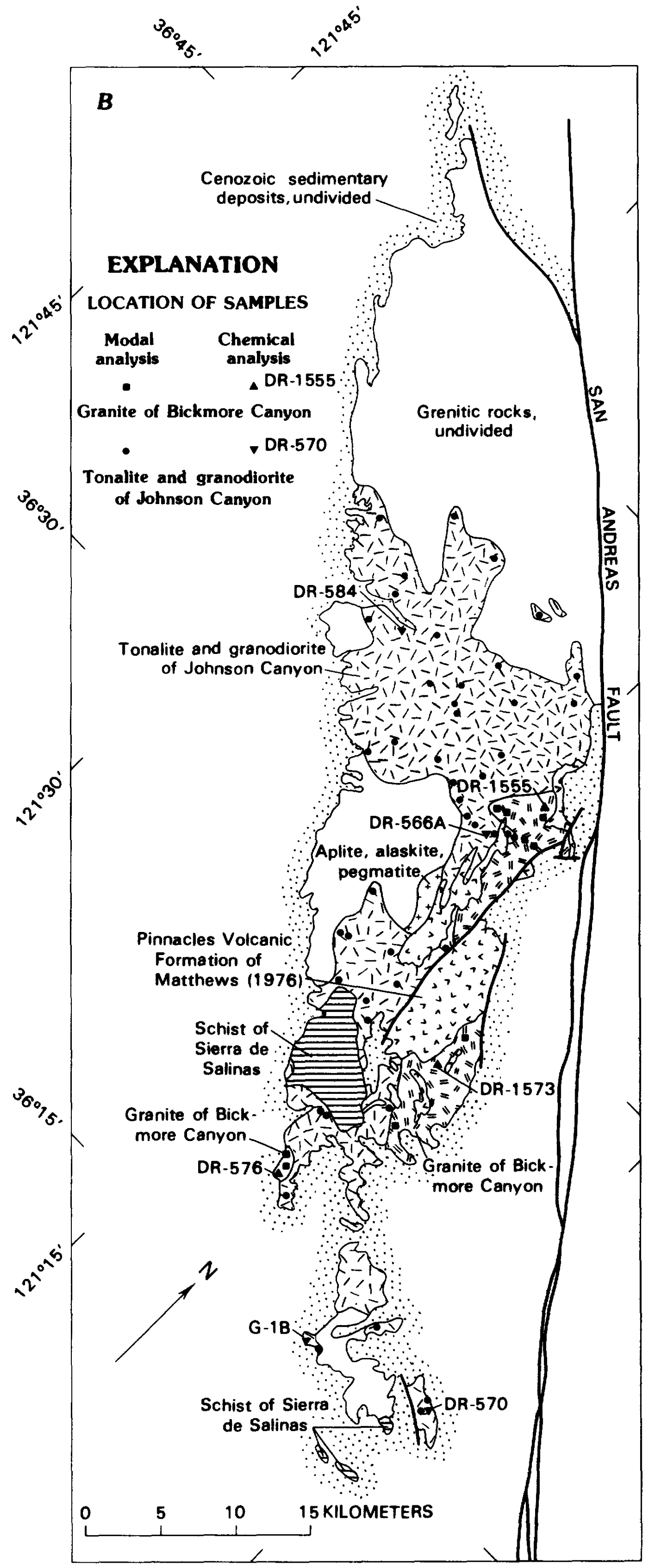


FIGURE 20.—Granitic rocks of the Pinnacles and Neenach areas. *A*, Locations of generalized geologic maps of the Pinnacles and Neenach areas. *B*, Locations of modally and chemically analyzed samples of the Pinnacles area. Numbers refer to samples listed in table 3. *C*, Locations of modally and chemically analyzed samples of the Neenach area. Numbers refer to samples listed in tables 2 and 3; unnumbered sample locations are from Ross (1972a).

modal data probably are sufficient to characterize the various granitic units, but more details are needed to better define the relation between the Gabilan Range units (Johnson Canyon and Bickmore Canyon) and the Neenach units (Burnt Peak and Fairmont Reservoir). Chemical data are admittedly sparse and certainly need augmenting, as do the radiometric ages and Rb/Sr analyses.

The modal field of the Johnson Canyon mass (fig. 21*A*) in the Pinnacles area is similar to the field of the combined Fairmont Reservoir and Burnt Peak units (figs. 21*B*, 21*C*) in the Neenach area. The modal field of the Johnson Canyon body is somewhat more spread out, but considering that it represents samples taken from a much wider area than that of the Fairmont Reservoir-Burnt Peak pair, this spread is not surprising in such varying plutonic bodies. Particularly noteworthy is the horizontal trend of these modal fields, which reflects a generally similar quartz content over a wide range of plagioclase/K-feldspar ratios.

My recent (1982) work in the Neenach area confirmed that—as I had suspected earlier (Ross, 1972a)—there are two mappable granodiorite bodies (the Burnt Peak and Fairmont Reservoir). The dashed contact shown separating them on figure 20*C* gives a picture that may appear more definitive than I would desire. The contact was not seen, nor were any diking relations seen to confirm the occurrence of two separate intrusive bodies. Instead, the observable evidence includes gradational lithologies and suggests that this may be a single granodiorite pluton with a somewhat fine grained core (Fairmont Reservoir). Certainly the Burnt Peak and Fairmont Reservoir masses are petrographically nearly identical and are closely related.

The granite of Bickmore Canyon in the Pinnacles area (fig. 20B) is a felsic rock that was mapped separately from the Johnson Canyon unit. No contacts were seen, however, and the only diking relation of the Bickmore Canyon into the Johnson Canyon that suggested the occurrence of two separate bodies may have been an alaskite rather than a Bickmore Canyon dike. Aplite, alaskite, and pegmatite are abundant in the Bickmore Canyon area; and distinctions, particularly between the alaskite and the granite of Bickmore Canyon, are difficult. Furthermore, darker rocks within the Bickmore Canyon mass show considerable modal overlap with the Johnson Canyon mass (fig. 21*C*). The Johnson Canyon-Bickmore Canyon pair may be a zoned pluton somewhat analogous to the Burnt Peak-Fairmont Reservoir pair.

Another general similarity between the Pinnacles and Neenach areas is the abundance of aplite, alaskite, and pegmatite in both areas. Mostly, these rock types occur in isolated dikes or dike swarms and are not mappable, but just west of the Pinnacles Volcanic Formation (fig. 20B) a large mass could be delineated. The granite of Antelope Buttes and numerous other felsic rocks in the Neenach area (fig. 20*C*; table 3) are also similar in this respect. Aplite, alaskite, and pegmatite are

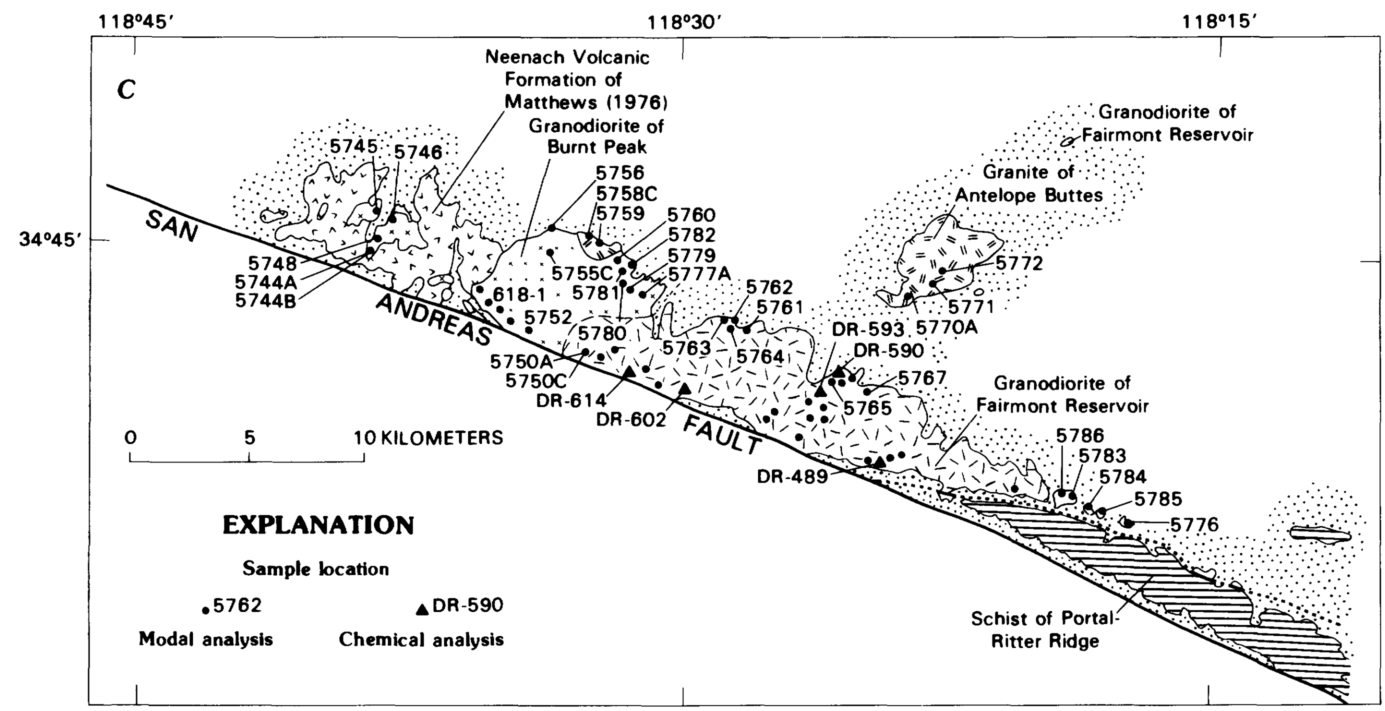


FIGURE 20.—Continued

widespread in varying amounts in many granitic terranes; it is only their relative abundance and even local dominance in the Neenach and Pinnacles areas that is supportive of correlation.

TABLE 2.—*Modes of selected granitic-rock samples from the Neenach area, California*

[All values in modal percent. Others: O, opaque minerals; S, sphene. All samples were collected in August 1982 except samples BP-2, 590, 592, 595B, 600A, 617, and 618, which are from Ross (1972a). See figure 20 for locations of samples]

Sample	Plagioclase	K-feldspar	Quartz	Biotite	Hornblende	Others
Granodiorite of the Fairmont Reservoir						
5750A------------	49	15	26	9	0.5	0.5(S)
5750C------------	48	13	26	11	1	1(O,S)
5761-------------	47	16	27	9	--	1(O,S)
5763-------------	48	18	26	8	--	<1(O)
5764-------------	52	9	27	11	--	1(O,S)
5765-------------	43	21	23.5	9.5	2	1(S)
5767-------------	54	7	26	10	2	1(O,S)
5776-------------	46	19	26	8	--	1(S)
5783-------------	45	23	21	11	--	<1(O)
5784-------------	52	7	24	15	1	1(O,S)
5785-------------	53	7	23	15	2	<1(S)
5786-------------	48	13	23	12	3	1(S)
Average----------	49	14	25	10.5	1	.5
Standard deviation.	3.4	5.6	1.9	2.4	1.1	.5
Average (Ross, 1972a).	51	10	24	11	2	2
Grand average----	50	12	24	11	2	1
Granodiorite of Burnt Peak						
618R-------------	33	27	30	7	3	<1(S)
618-1------------	50	9	29	8	3	1(S)
5744A------------	33	25	29	7	6	<1(S)
5744B------------	53	<1	18	17	12	<1(S)
5748-------------	46	9	23	17	5	<1(S)
5752-------------	50	12	21	14	3	<1(S)
5755C------------	45	13	20	11	11	<1(S)
5756-------------	51	9	24	9	6	1(S)
5760-------------	46	14	21	13	5	1(S)
5777A------------	50	12	26	8	2	2(S)
5779-------------	50	9	24	11	6	<1(S)
5780-------------	43	18	26	9	4	<1(S)
5782-------------	41	16	27	11	5	<1(S)
Average----------	46	13	25	11	5	<1(S)
Standard deviation.	6.5	7.1	3.8	3.5	3.0	--
BP-2-------------	42	20	25	6	6	1(S)
617--------------	42	11	26	15	5	1(S)
618--------------	36	25	26	7	4	2(S)
Average----------	40	19	26	9	5	1(S)
Grand average.	45	14	25	10	5	1(S)
Standard deviation.	6.4	6.6	3.4	3.7	2.7	.7(S)
Felsic rocks intruding the granodiorites of the Fairmont Reservoir and Burnt Peak						
5745-------------	31	34	34	1	--	<1(O)
5746-------------	20	44	35	1	--	--
5758C------------	26	41	33	--	--	--
5759-------------	15	46	38	.5	--	.5(O)
5762-------------	13	36	50	1	--	--
5781-------------	52	14	32	2	<1	--
Average----------	26	36	37	1	<1	--
590--------------	32	28	34	6	--	<1(O)
592--------------	29	25	42	3	--	1(O,S)
595B-------------	36	31	30	3	--	--
600A-------------	30	33	33	4	--	--
Average----------	32	29	35	4	--	--
Grand average----	29	33	36	2	<1	<1
Granite of Antelope Buttes						
5770A------------	29	36	33	2	--	--
5771-------------	33	31	34	2	--	--
5772-------------	22	39	38	1	--	--
Average----------	28	35	35	2	--	--

The granitic rocks of the Neenach and Pinnacles areas are not petrographically unusual, but they do have some features that may increase their correlative possibilities. Small salmon-pink K-feldspar phenocrysts, as much as 2 cm long, are noteworthy in the Bickmore Canyon, Burnt Peak, and Fairmont Reservoir bodies and are present, but less common, in the Johnson Canyon mass. More distinctive may be the subhedral to euhedral sphene crystals that contain opaque-mineral inclusions in intriguing shapes that resemble arabic or runic written characters. These distinctive sphene crystals are present in the Johnson Canyon, Burnt Peak, and Fairmont Reservoir bodies. By itself, the occurrence of these crystals is probably only of small correlative merit because I have seen similar inclusion-laden sphene crystals in other granitic bodies. Nevertheless, the feature is sufficiently uncommon to support the correlation of these otherwise-compatible bodies. Metallic opaque minerals are also rare or absent in many samples of granitic rocks from these two areas that contain abundant biotite and hornblende, although opaque minerals would be expected.

The chemical analyses of selected specimens from the Fairmont Reservoir and Johnson Canyon bodies are much alike (fig. 22, table 3). Two samples of the Johnson Canyon mass contain more FeO and MgO than the other samples, indicating the higher content of mafic minerals in that mass. The other two samples of the Johnson Canyon body, however, are similar in their contents of those two oxides to the Fairmont Reservoir samples.

The Bickmore Canyon samples are similar in oxide content to the one felsic rock sample from the Fairmont Reservoir mass. The two sets of comparisons (the Fairmont Reservoir with the Johnson Canyon and the Bickmore Canyon with the Fairmont Reservoir felsic variant rocks) are by no means conclusive for correlation, but the data certainly are compatible and permit correlation. Similarly, a comparison of the modes of the analyzed specimens (fig. 23) clearly shows a grouping of the two pairs of bodies, which supports correlation.

Three selected ternary plots also accentuate the compatibility of the tonalite and granodiorite of Johnson Canyon with the granodiorite of Fairmont Reservoir, and the compatibility of the granite of Bickmore Canyon with the felsic variant of the Fairmont Reservoir body (fig. 24). The Alk-F-M diagram shows the higher alkali content of the granite of Bickmore Canyon and the felsic variant of the Fairmont Reservoir mass relative to the two granodiorite bodies. Both of the normative-mineral

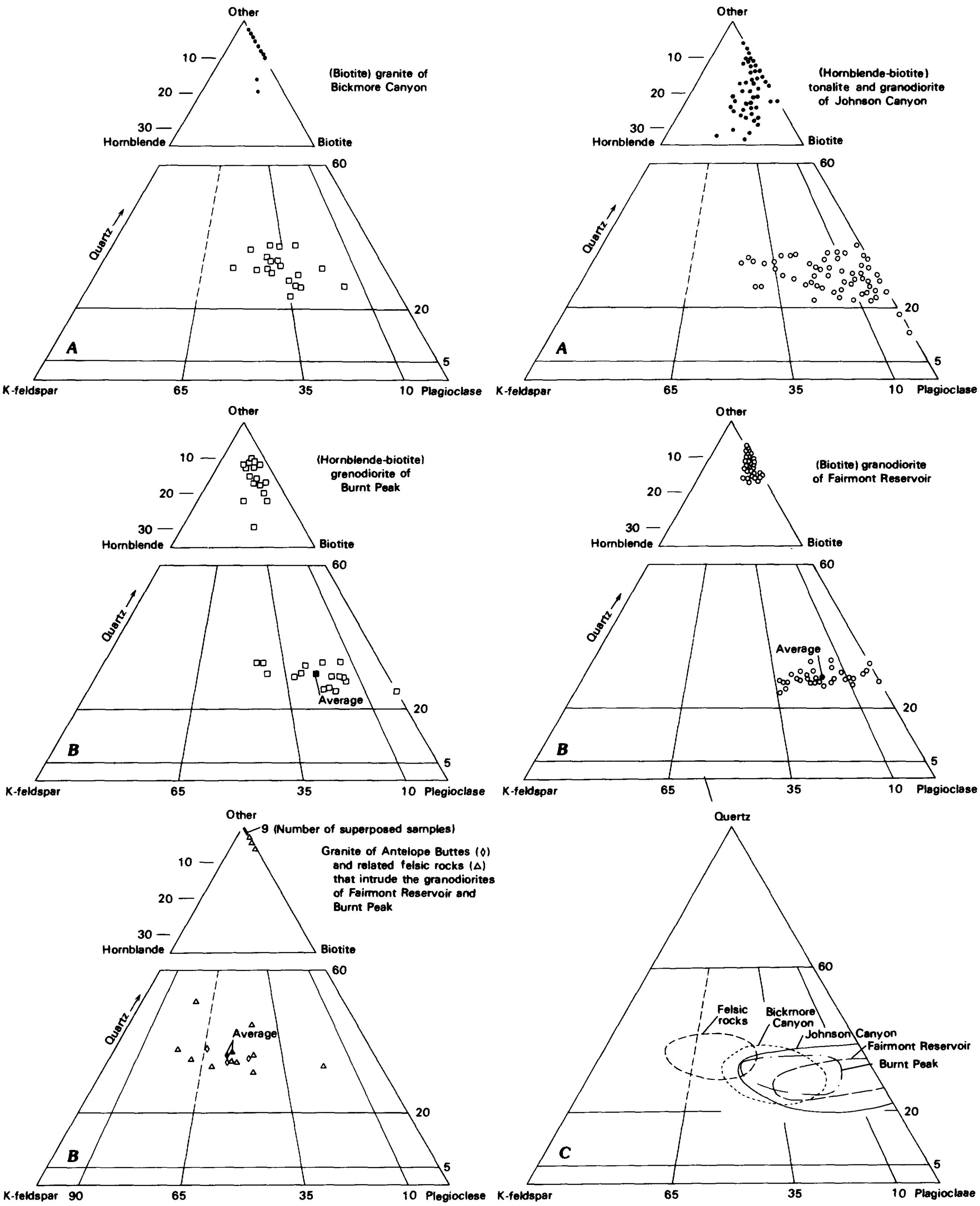


FIGURE 21.—Modes of granitic rocks of the Pinnacles and Neenach areas. *A*, Modal plots of granitic rocks of the Pinnacles area. *B*, Modal plots of granitic rocks of the Neenach area. *C*, Comparison of modal fields of granitic rocks of the Pinnacles and Neenach areas.

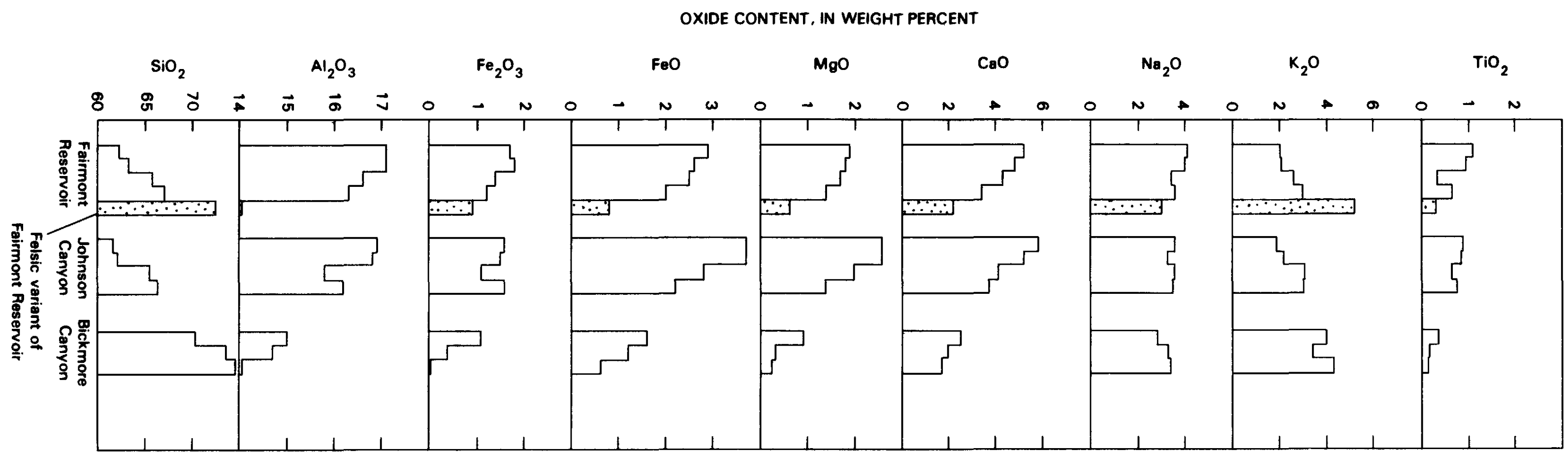


FIGURE 22.—Comparisons of chemical analyses of samples of the tonalite and granodiorite of Johnson Canyon with those of samples of the granodiorite of Fairmont Reservoir, and of chemical analyses of one sample of the felsic variant of the Fairmont Reservoir body with those of samples of the granite of Bickmore Canyon.

TABLE 3.—*Chemical analyses of selected samples of the tonalite and granodiorite of Johnson Canyon, the granodiorite of the Fairmont Reservoir, the granite of Bickmore Canyon, and the felsic variant of the Fairmont Reservoir body*

[All values in weight percent. Sources of chemical data: samples DR-489, DR-590, DR-593, DR-602, and DR-614, Ross (1972a); all other samples, Ross (1975). See figure 20 for sample locations]

	Tonalite and granodiorite of Johnson Canyon					Granodiorite of the Fairmont Reservoir					Granite of Bickmore Canyon				Felsic variant of the Fairmont Reservoir body
Sample-----	DR-570	DR-584	DR-566A	G-1B	Average	DR-602	DR-593	DR-489	DR-614	Average	DR-1555	DR-1573	DR-576	Average	DR-590
SiO_2-------	61.6	62.1	65.5	66.4	63.9	62.3	63.3	65.8	67.0	64.6	70.3	73.5	74.6	72.8	72.5
Al_2O_3------	16.9	16.8	15.8	16.2	16.4	17.1	17.1	16.6	16.3	16.8	15.0	14.7	14.0	14.6	14.0
Fe_2O_3------	1.6	1.5	1.1	1.6	1.5	1.7	1.8	1.4	1.2	1.5	1.1	.38	.00	.5	.92
FeO--------	3.7	3.7	2.8	2.2	3.1	2.9	2.6	2.5	2.0	2.5	1.6	1.2	.61	1.1	.80
MgO--------	2.6	2.6	2.0	1.4	2.2	1.9	1.8	1.7	1.4	1.7	.93	.31	.26	.50	.65
CaO--------	5.8	5.2	4.1	3.7	4.7	5.2	4.8	4.3	3.4	4.4	2.5	1.9	1.7	2.0	2.2
Na_2O-------	3.6	3.3	3.6	3.5	3.5	4.1	4.0	3.4	3.6	3.8	2.8	3.3	3.4	3.2	3.0
K_2O--------	1.9	2.2	3.1	3.0	2.6	2.0	2.1	2.6	3.0	2.4	4.0	3.4	4.3	3.9	4.6
H_2O^--------	.07	.12	.09	.02	.08	.06	.06	.08	.06	.07	.09	.12	.05	.09	.09
H_2O^+-------	1.0	1.2	1.0	.88	1.0	.90	1.0	1.1	1.0	1.0	.91	1.0	.77	.9	.65
TiO_2-------	.90	.87	.65	.78	.80	1.1	.95	.34	.67	.8	.37	.15	.12	.21	.31
P_2O_5-------	.24	.20	.17	.18	.20	.32	.28	.13	.22	.24	.12	.05	.05	.07	.16
MnO--------	.12	.10	.10	.05	.09	.12	.06	.10	.10	.10	.07	.07	.07	.07	.08
CO_2--------	<.05	<.05	<.05	<.05	<.05	.16	<.05	<.05	<.05	.04	<.05	<.05	<.05	<.05	<.05
Total---	100.00	99.9	100.0	99.9	100.1	99.9	99.9	100.1	100.0	100.0	99.8	100.1	99.9	99.9	100.0

plots, Q-Or-(Ab+An) and Or-Ab-An, clearly show grouping and separation of the two pairs of bodies. The ternary diagrams accentuate the picture of chemical compatibility that was evident in the histogram (fig. 22).

The trace-element abundances for the chemically analyzed samples are plotted here on a histogram for easy reference and comparison (fig. 25). The data were derived from semiquantitative spectroscopic analyses. The data plotted in figure 25 are arbitrary midpoints of the steps shown, from which the actual concentration may vary by one or two steps. The comparison of values between the Johnson Canyon and Fairmont Reservoir masses clearly shows similarity. Levels of nickel (Ni) and, to a lesser extent, scandium (Sc) and chromium (Cr) are somewhat higher in the Johnson Canyon samples. This relatively high concentration probably reflects the generally higher mafic-mineral content of the Johnson Canyon mass—Ni, Sc, and Cr are all relatively concentrated in mafic minerals. Expectably, the samples from the Bickmore Canyon body and the one felsic sample from the Fairmont Reservoir area are generally about the same, or somewhat lower, in most trace elements than are the granodiorite samples. Exceptions are barium, which is slightly higher in the granites (probably because they contain relatively more K-feldspar), and lead, which is also slightly higher in the granite specimens. Such differences—of one or, at most, two steps—are probably not significant in semiquantitative spectroscopic

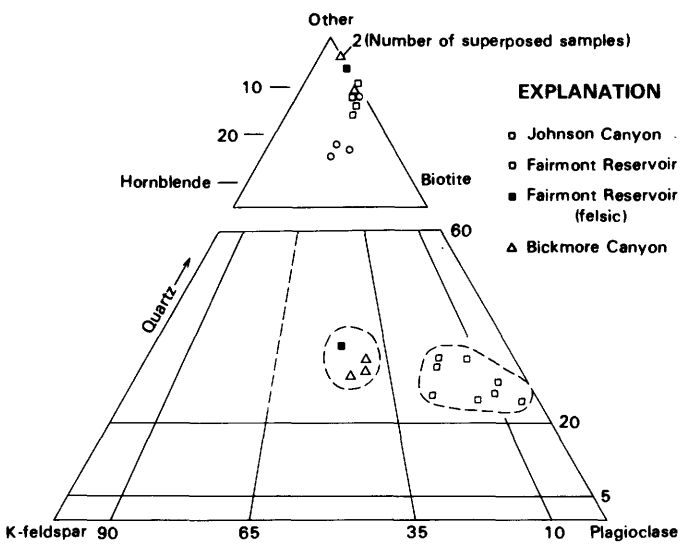


FIGURE 23.—Modes of chemically analyzed samples of the granodiorite of Fairmont Reservoir, the granite of Bickmore Canyon, the tonalite and granodiorite of Johnson Canyon, and the felsic variant of the Fairmont Reservoir body.

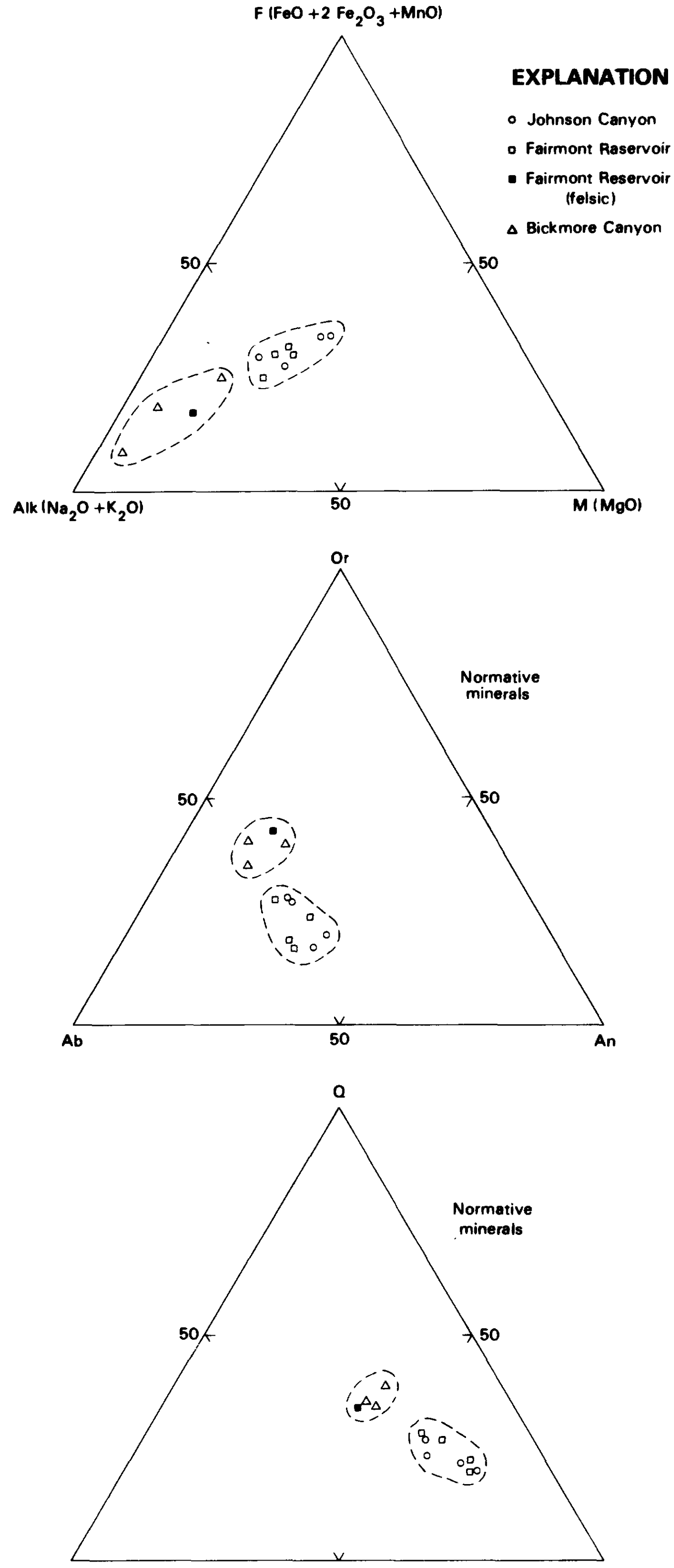


FIGURE 24.—Chemical compatibility of the tonalite and granodiorite of Johnson Canyon with the granodiorite of Fairmont Reservoir, and of the granite of Bickmore Canyon with the felsic variant of the Fairmont Reservoir body.

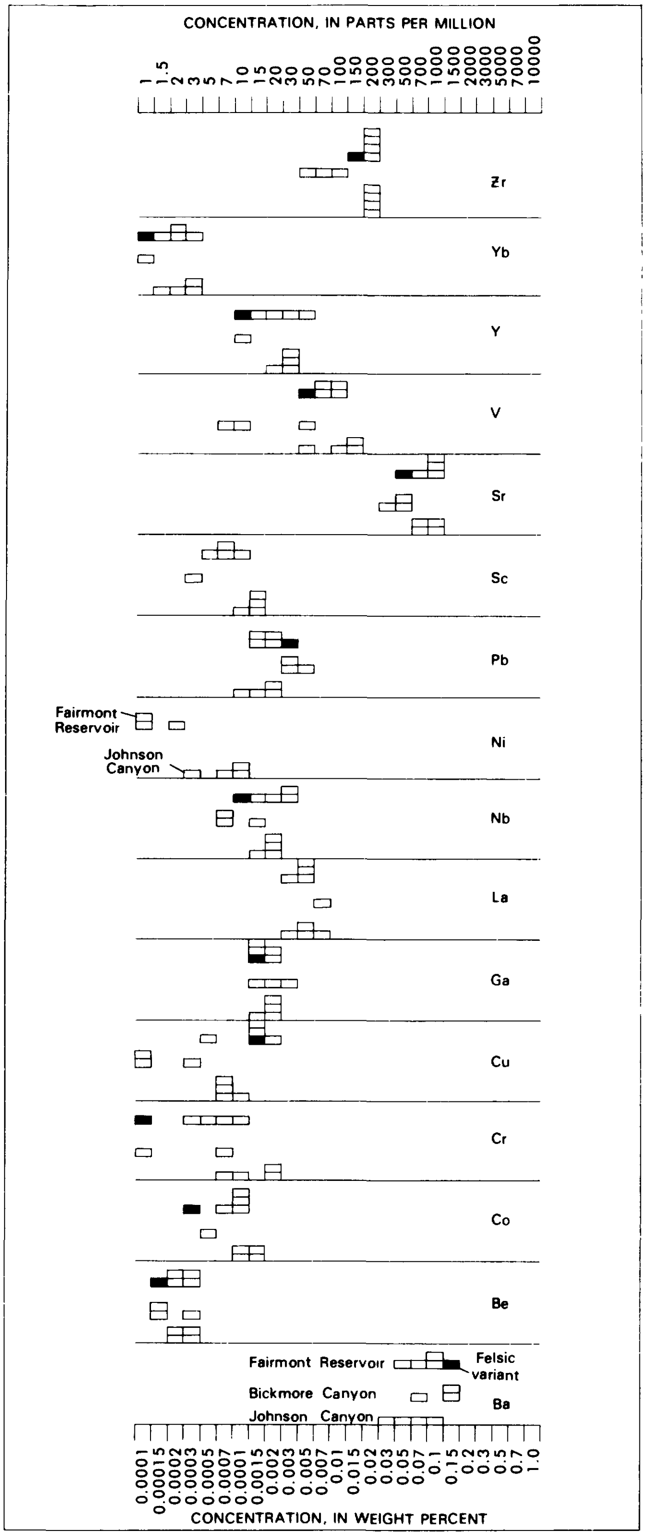


FIGURE 25.—Histograms showing semiquantitative-spectroscopic-analysis "midpoints" of trace-element concentrations in samples of the tonalite and granodiorite of Johnson Canyon, the granodiorite of the Fairmont Reservoir, the granite of Bickmore Canyon, and the felsic variant of the Fairmont Reservoir body.

data. Nevertheless, comparison of the trace-element concentrations in the Johnson Canyon and Fairmont Reservoir masses, and of the Bickmore Canyon mass with felsic specimens from the Fairmont Reservoir area, supports the contention that these two pairs are correlative.

Sparse Rb/Sr data suggest compatibility between the granitic rocks of the Neenach and Pinnacles areas, although, clearly, more work is needed. Three samples from the Johnson Canyon body and one from the Bickmore Canyon unit give an initial strontium-isotopic ratio of 0.7082 (R. W. Kistler, in Ross, 1972b). A single sample from the Fairmont Reservoir mass gives an initial strontium-isotopic ratio of 0.7083 (Kistler and others, 1973).

Dikes of Tertiary volcanic rocks that are almost certainly satellitic to the main intrusive center of the Pinnacles Volcanic Formation are abundant and widespread in granitic rocks of the Pinnacles area. The relation leaves little doubt that the volcanic rocks intruded the surrounding granitic rocks. By contrast, I have seen no volcanic dikes in granitic rocks of the Neenach area. I do not know the reason for this anomaly. Could it be caused by structural discordance between the volcanic and granitic rocks of the Neenach area? The pattern that is apparent on the map (fig. 20*C*) does not suggest an abrupt break between the two rock types. However, exposures in this area are very poor—for example, most of the area underlain by granitic rocks and surrounded by volcanic rocks near the west end of the Neenach map area is a low rolling grassy slope with scattered felsic granitic rock fragments and a small exposure of the granodiorite of Burnt Peak at its south tip. Matthews (1973) noted that poor exposures hindered delineation of the volcanic and granitic units, and he resorted to showing vertical fault contacts on a cross section. This expedient fails to solve the problem; it merely points out that a problem exists. My reconnaissance work with the granitic rocks suggests that they are relatively cohesive and that the faults shown within them (Dibblee, 1967) do not seriously disrupt the granitic rocks. Nevertheless, the question of why volcanic dikes are absent in the granitic rocks of the Neenach area needs an answer!

In conclusion, the granitic rocks near the Pinnacles Volcanic Formation are compatible, both modally and chemically, with the granitic rocks near the Neenach Volcanic Formation. The expectable uncertainties of correlating granitic masses persist, but the further work suggested in this report may reduce these uncertainties considerably.

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