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RECONNAISSANCE GEOLOGIC MAP OF PRE-CENOZOIC BASEMENT ROCKS, NORTHERN SANTA LUCIA RANGE, MONTEREY COUNTY, CALIFORNIA

By Donald C. Ross

INTRODUCTION

The northern Santa Lucia Range rises abruptly from the Pacific Ocean shoreline to a coastal ridge as high as 1000 m; the highest point is Junipero Serra Peak at 1786 m (5862 ft). The range is strongly dissected by canyons with steep slopes that commonly are densely covered with vegetation. Outcrops range from poor to locally very good, but vegetation limits access to many outcrop areas. Roadcuts and trails and some of the canyon bottoms provide the best places to study and sample the rocks of the range.

The outcropping rocks of the northern Santa Lucia Range are largely medium- to high-grade metamorphic rocks and granitic rocks. Overlying Cretaceous and Tertiary sedimentary rocks are preserved chiefly as downfaulted remnants of a presumably extensive blanket that once overlay the basement block. There are also a few small scraps of Miocene volcanic rock preserved within the range. The metamorphic and granitic rocks of the range (east of the Sur fault zone) are the focus of this map text.

The coverage of the reconnaissance study is generally indicated on figure 1, which notes my data points in the range. This work was greatly supplemented by published reports and by specimens and information from the authors specified below.

Studies of these rocks began as long ago as 1893 when Lawson published a report on the geology around Carmel Bay (fig. 2). He named and described the Santa Lucia Granite, the unit here termed the porphyritic granodiorite of Monterey. Unfortunately Lawson's name "Santa Lucia" was later applied indiscriminately to all the many granitic units in the range, and its use was even extended into the Gabilan Range. Now the term has no precise or even general meaning, and I suggest that it be abandoned.

Three thesis studies led to later publication of geologic maps and brief descriptions of the basement rocks of the Point Sur quadrangle (Trask, 1926), Lucia quadrangle (Reiche, 1937), and Jamesburg quadrangle (Fiedler, 1944) (fig. 2). Though these reports differentiated only three basement units (granitic rocks, marble, and other metamorphic rocks), they did provide valuable data on the distribution of the basement and the major faults cutting it. Considering what the logistical problems must have been when those studies were made, they are indeed remarkable. Both Reiche's and Fiedler's thesis studies contained numerous modal analyses of granitic and metamorphic rocks; more than 100 thin sections of these rocks were made available to me by the Geology Department of the University of California at Berkeley.

Trask (1926, p. 134) proposed the name Sur Series "as a comprehensive name for the schist series of the Southern Coast Ranges." The term has indeed become comprehensive and now is synoymous for "metamorphic rocks of the Salinian block"--it now masks real differences in the metamorphic suite, and I suggest that its use also be discontinued.

Geologic mapping of the basement rocks of the Junipero Serra quadrangle by Compton led to a summary paper (Compton, 1966a) and a map compiled jointly with T. W. Dibblee, Jr. (1973). Specimens of typical granitic rocks from this quadrangle kindly lent to me by Compton provided much of the basis for delineation of the granitic formations in that area.

In the mid-1960's the most detailed study to date in the range was made by Wiebe (1970a,b). He delineated several plutons in the Ventana Cones area and proposed the first mappable "formation" in the all-encompassing Sur Series. Wiebe also generously lent me samples and thin sections of typical rocks from several of the plutons he recognized. There have also been specialized studies of the basement rocks such as Compton's (1960) on the charnockitic tonalite and veins near Cone Peak and Hutton's (1959) on heavy minerals from the basement rocks in the Monterey area.

A study of the Ventana Wilderness area by Pearson, Hayes, and Fillo (1967), largely a sampling program to evaluate the mineral potential of the area, provided me with a number of semiquantitative spectrographic analyses of plutonic rocks (R. C. Pearson, written commun., 1968), but no new mapping or delineation of plutonic or metamorphic units resulted from this study.

METAMORPHIC ROCKS

Strongly deformed medium- to high-grade metamorphic rocks underlie more than 900 km^2 of the northern Santa Lucia Range, making this by far the most extensive metamorphic terrane in the Salinian block. Both Compton (1966a) and Wiebe (1970a), who have done the most detailed work on the metamorphic rocks, noted the predominance of quartzofeldspathic granofels and gneiss and impure biotite-feldspar quartzite. Marble, calc-hornfels, and amphibolite (at least in part derived from carbonate rocks) are locally abundant. Schist is definitely subordinate except for the belt of metamorphic rocks on the Sierra de Salinas, where virtually the only rock type is biotite quartzofeldspathic schist.

Most of the metamorphic rocks appear to be high in the amphibolite facies and contain widely distributed sillimanite and red garnet. West of the Palo Colorado-Coast Ridge fault zone sillimanite is absent, but hypersthene is found both in the gneiss and in associated "charnockitic" plutonic rocks, suggesting that at least locally the granulite facies (Compton, 1960) was reached.

One of the major frustrations for most workers in this metamorphic terrane has been the lack of marker beds and the consequent inability to establish a stratigraphic section. Compton (1966a), in what he described as "a fairly thorough study of the Junipero Serra area," noted that "only one marble and one quartzite unit proved thick and distinctive enough to be mapped readily across the brushy terrain." He was able to follow these two units for about 5 km. These two parallel units are shown trending eastward along the northern part of the Junipero Serra Peak quadrangle (sheet 1). Wiebe (1970b) made a breakthrough when he was able to trace a distinctive graphite-bearing unit for more than 30 km; this unit ("graphitic and pyritic belt" on sheet 1) is described in the following section.

My reconnaissance suggests that the metamorphic terrane in the northern part of the map area can be subdivided into seven subparallel lithologic belts that may represent stratigraphic units (fig. 3). Belts 1, 3, and 6 are largely quartzofeldspathic gneiss and granofels that probably would not be separable except for the more distinctive intervening lithologic belts. The "section," though highly folded and faulted, shows no large-scale repetition of the more distinctive lithologic belts. Three of the unit contacts are probably marked by faults whose magnitude is uncertain (between units 1 and 2, postgranitic faulting; between units 2 and 3, probably major pregranitic faulting; and between units 6 and 7, postgranitic faulting).

Beyond these speculations about lithologic belts that may have formational significance, we know little about the original sedimentary section. No fossils, top-determining features, or other features to hint at the age or the relative age of any part of the section have been reported from these rocks. The general character of the metamorphic rocks, except for the schist of Sierra de Salinas, suggests that they were derived from a generally well bedded sequence of relatively quartz-rich clastic rocks and locally abundant carbonate rocks--sandstone, siltstone, shale, marly beds, and limestone, that may once have been part of the lower and middle Paleozoic section of the Cordilleran miogeosyncline. In striking contrast, the schist of Sierra de Salinas, probably a metagraywacke, may be Mesozoic, as such rocks are virtually unknown in Paleozoic sections of the region. The significance of this possibly exotic schist in the Salinian block is discussed in more detail in a separate report (Ross, in press).

Metamorphic units

Graphitic and pyritic belt (Los Padres unit of Wiebe, 1970b)--The graphitic and pyritic belt has been traced by Wiebe (1970b) for more than 30 km. It is the only relatively continuous lithologic marker so far discovered in the metamorphic section. It is distinguished by locally abundant black shiny graphite flakes sprinkled through quartzite, calc-hornfels, and quartzofeldspathic gneiss. Pyrite is also locally common, which probably accounts for the common red color of weathered exposures in this belt. Wiebe (1970b) also noted several thin lenses of conglomerate in this unit consisting of quartzite pebbles in a quartzite matrix. He interpreted the unit as a shallow-water, quartz-rich deposit that was deposited in a reducing environment. Though the graphitic and pyritic belt is sharply defined, interfingering contacts can be seen with the adjoining rocks, suggesting gradational contacts. Thin graphitic schist lenses are also found within the quartzofeldspathic rocks adjacent on the west, the unit that also bears a conspicuous lens of quartz conglomerate.

Schist of Sierra de Salinas--The schist of Sierra de Salinas is the only predominantly schist unit in the Santa Lucia Range. It is a monotonously similar biotite quartzofeldspathic schist covering an area of about 220 km^2 whose appearance and chemical composition suggest derivation from graywacke. In contrast to the metamorphic terranes to the east and west, which are intimately intruded by and mixed with granitic material, the schist is virtually devoid of granitic rock. The schist commonly contains prominent vein quartz and simple pegmatite, which appear to be at least in part locally sweated out of the schist.

Though the schist is lithologically quite distinct from the gneissic terranes to the east and west, it is of about the same metamorphic grade (amphibolite), as it locally contains red garnet and sillimanite as well as some coarse graphite.

Pelitic schist belt--Wiebe (1970b) noted that the rocks immediately east of his Los Padres unit were dominantly "pelitic." In a comparatively detailed traverse along the Jamesburg-Tassajara Springs Road I also noticed the relative abundance of biotite-rich layers in the metamorphic section east of the Los Padres unit. Even though gneiss and admixed granitic rocks are locally abundant in the pelitic schist belt, it appears to be a distinct unit that was a more shaly (pelitic) part of the original sedimentary section. The eastern contact is arbitrary and almost surely gradational into the quartzofeldspathic rocks. The pelitic schist belt as well as the graphitic belt appear to thin markedly to the south. Neither unit has been found south of the Willow Creek fault, but admittedly the search has been very limited. Perhaps there is a facies change to the south in these two units, but in this structurally complex terrane that is sheer speculation.

Coast Ridge belt--West of the Palo Colorado and Coast Ridge faults and their possible extensions the Coast Ridge belt is characterized by the general abundance of marble, in contrast to locally abundant marble elsewhere in the range. The Coast Ridge belt is also marked by hornfels and granofels that appear to be generally less well banded than the gneissic rocks to the east. Also, coarse flakes of graphite are characteristic in impure quartzites and quartzofeldspathic granofels, as well as in the marble, and the graphite appears to be more widespread and possibly coarser than in the rocks to the east. Amphibolite is also relatively abundant. Probably the association of abundant marble and abundant amphibolite is no coincidence--field relations suggest that some amphibolite is probably derived from marble. I suspect that most of the amphibolite is not derived from mafic volcanic rocks, as is commonly assumed in such metamorphic terranes. No definite volcanic or volcaniclastic units have been identified, and the general lithology of the section makes the presence of this kind of rock unlikely here.

Quartzofeldspathic rocks--The quartzofeldspathic unit is essentially what is left over after all of the more distinct metamorphic units have been subtracted from the section. It is made up of the kinds of rocks both Compton (1966a) and Wiebe (1970a) consider to be predominant in the metamorphic terrane: quartzofeldspathic gneiss and granofels, and biotite-feldspar quartzite, with minor schist, marble, calc-hornfels, and amphibolite. These rocks are characteristically well banded with contrasting lithologies that commonly suggest an originally thin-bedded sedimentary parent rock.

As stated above, it is possible that this unit is made up of three "stratigraphic units." East of the schist of Sierra de Salinas, outcrops of gneiss, schist, and rather abundant bodies of marble are physically separated from the rest of the metamorphic terrane--thus their relations are as yet unknown. West of the schist of Sierra de Salinas are two belts of quartzofeldspathic rocks that would probably be indistinguishable if there were not graphitic and pelitic units between them. In fact these two quartzofeldspathic belts probably do exist, undistinguished, in the Junipero Serra Peak quadrangle.

Marble--Marble has been delineated on even the oldest geologic maps of the Santa Lucia Range for it is easily recognized, tends to be well exposed, and has potential economic value. Marble is distinguished on the geologic map (sheet 1) because it also has value as a stratigraphic marker--at the least, its relative abundance has stratigraphic significance. Many of the smaller bodies are undoubtedly exaggerated on the geologic map, but there are some very large masses of marble, particularly in the Coast Ridge belt. For example, a probably conservative estimate of marble reserves for part of the Pico Blanco deposit (the large amoeboid marble body about 8 km east of Point Sur) is 600,000,000 tons (M. E. Maddock in Hart, 1966, p. 65).

Quartzite--One belt of quartzite has been delineated in the Santa Lucia Range. Compton (1966a) noted that it and a parallel marble bed were the only marker units he was able to follow in the brushy terrain of the Junipero Serra Peak quadrangle.

The quartzite was traced by Compton for about 5 km on the north side of Pinyon Peak striking in an easterly direction. Judging by Compton's map pattern the quartzite must be about 150 to 300 m thick. Compton gives no data on the unit, and I have not visited the locality.

PLUTONIC ROCKS

Plutonic rocks dominate the northern part of the range, where they form large, relatively homogeneous bodies. To the southeast they tend to string out into smaller, more heterogeneous bodies that are subordinate to the metamorphic rocks.

The plutonic formations of the Santa Lucia Range represent areas of relatively "pure" plutonic material with very little included metamorphic material. Some granitic units are quite homogeneous and distinct (for example, the porphyritic granodiorite of Monterey), whereas others are much more variable. Much granitic material is intruded into the metamorphic rocks, and strictly for convenience areas of mixed granitic and metamorphic rocks are shown as metamorphic on the geologic map. The proportion of granitic material in the metamorphic rocks was estimated by Compton (1966a) to be at least 5 to 15 percent in most metamorphic outcrops in the Junipero Serra quadrangle and more than 50 percent over wide areas (fig. 4). I observed similar abundances elsewhere in the range with the notable exception of the schist of Sierra de Salinas, which is virtually devoid of granitic intrusive rocks. Considering the amount of granitic material included in the areas that are mapped as metamorphic rocks (fig. 4), the actual area of granitic outcrop may equal or exceed the area of metamorphic rocks.

In such a mixed terrane where exposures are variable, contacts are not everywhere placed with the same degree of confidence. Here, as in the Gabilan Range (Ross, 1972), I have a fair degree of confidence in the general distribution pattern of the granitic units, but little information on contacts and relations between granitic units. I have some evidence that gradational contacts may exist between some of the major granitic formations (see, in particular, the discussion under "granodiorite of Cachagua").

Granitic rocks make up about 735 km^2 of the basement terrane. The distribution by rock types is approximately: quartz monzonite, 180 km^2; granodiorite, 245 km^2; and quartz diorite, 310 km^2 (fig. 5). The volumetrically unimportant mafic and ultramafic rocks underlie 10 to 15 km^2. For the purposes of this areal generalization, each plutonic unit was assigned solely to one of the three major rock types. In reality there is significant granodiorite in some of the quartz diorite units and significant quartz monzonite in the granodiorite units. Also, much of the granitic material mixed with the metamorphic rocks is relatively felsic; therefore if it were included in the histogram on figure 5, it would probably increase the quartz monzonite relative to the other two rock types. Thus the areas by rock type, shown by histogram on figure 5, are biased toward the quartz diorite. The important point to make from this illustration is that quartz diorite does not dominate the granitic basement of the Santa Lucia Range.

Dredging and reflection seismic work (Martin and Emory, 1967; and H. G. Greene, written commun., 1972) have shown that granitic rocks crop out on the sea floor over an area of at least 250 km^2 in the Monterey Bay area (sheet 1). Dredge samples furnished me by Greene from this area proved to be largely similar to the porphyritic granodiorite of Monterey. If this submarine area were added to the histogram of figure 5, it would roughly double the outcrop area of granodiorite.

The following is a brief description of the granitic units shown on the geologic map and some notes on special features of each unit. Because there is so little information on the relative age of these granitic units they will be discussed arbitrarily from the most mafic to the felsic rocks.

Plutonic units

Ultramafic rocks and serpentinite--The ultramafic rocks and serpentinite unit consists of three somewhat serpentinized ultramafic bodies and 32 serpentinite bodies that are located on the map by a symbol because they are too small to show at the map scale. The relations of these bodies to the surrounding rock are generally uncertain. Compton (1966a) refers to them being "emplaced" at various times during plutonism, and both Fiedler (1942) and Wiebe (1966) describe some bodies as "dike-like." Yet both also noted the occurrence of lenticular masses along faults, sheared contacts, and Fiedler (1942) commented on the lack of contact effects. A large number, if not all of these masses, may be cold intrusions. The serpentinite masses I examined and sampled contained no clues as to their relations to the country rock--some are just "blobs" that certainly do not resemble normal intrusions.

The unserpentinized parts of these bodies contain various proportions of olivine, orthopyroxene, clinopyroxene, amphibole, and plagioclase, with minor spinel, magnetite, and chromite. Compton (1966a) noted a "zonal arrangement" of these rocks with gabbroic rocks, and Wiebe (1966) noted local association with layered gabbro. The serpentine minerals were determined by X-ray diffraction to be lizardite and clinochrysotile in the 16 samples I collected. The complete absence of antigorite was somewhat unexpected in this much-sheared terrane.

These serpentinized rocks are an enigmatic unit in the Salinian block basement. The ultramafic rocks and their serpentinized offspring could all be related to the gabbroic rocks, but it seems more likely that they are at least in part exotic. Serpentinite pods are unknown in the basement rocks elsewhere in the Salinian block, suggesting some special conditions under the Santa Lucia Range. The lenticular shapes of the pods, the sheared margins, and the occurrences as horses in fault zones together suggest the possibility of squeezing up from some underlying layer. One might speculate that the range is rootless and is underlain at relatively shallow depths, below a gently dipping structural discontinuity (thrust fault or subduction zone), by oceanic crust and Franciscan rocks--the most likely source in this region for serpentinite.

Gabbro and diorite--Gabbro and diorite, largely composed of hornblende and plagioclase, are most abundant in the area mapped by Wiebe (1966, 1970a) where in part they are extensively diked by granitic rocks. Several smaller bodies are also present in the Junipero Serra quadrangle (Compton, 1966a). It is perhaps significant that most of the gabbro and diorite is shown in the parts of the range mapped in most detail--I have found several smaller bodies, and it is likely more detailed work would delineate more.

Compton (1966a, p. 282) noted that the gabbros "probably once formed sizable bodies but are now reduced to a few large relics and to hosts of dark inclusions in subsequent quartz diorite intrusions." Wiebe (1970a, p. 114) also suggested that some large masses of quartz diorite and granodiorite may have originated from the mixing of early quartz monzonite and gabbroic material.

The smaller bodies of "gabbro and diorite" that are in part foliated may well be metamorphic rocks (amphibolite). A similar metamorphic origin is likely for at least some of the dark inclusions.

Charnockitic tonalite of Compton (1960) and related(?) rocks--Six masses along the west edge of the Santa Lucia Range constitute the charnockitic tonalite of Compton (1960). The northern part of the larger central body was studied by Compton (1960). It is made up of plagioclase, hornblende, orthopyroxene and related uralitic alteration products, and quartz in decreasing order of abundance; minor amounts of K-feldspar, biotite, and metallic opaque minerals are also present. Red garnet is locally abundant. The four smaller bodies to the southeast are described as "similar" by Compton (1960, p. 614), but he also noted they are "less uniform" than the larger central body and "exposed rather poorly," which understates the case. These four bodies, first delineated by Reiche (1937), appear to be much mixed with gneiss, and although some granitic material does look like the large body to the north no orthopyroxene was noted. The northernmost granitic body in this belt (east of Point Sur) was not considered part of the charnockitic tonalite by Compton (1960). Yet it is similarly poor in quartz relative to the granitic terrane to the east and contains some coarse red garnet. Though I noted no orthopyroxene, the mass does have some uralitic alteration products that seem to mimic pyroxene.

It is questionable whether these six somewhat diverse bodies really constitute an intrusive formation, but they are texturally similar, are poor in quartz, and generally have hornblende equal to or in excess of biotite unlike the granitic units east of the Palo Colorado and Coast Ridge fault zones.

Hornblende-biotite quartz diorite-diorite of Corral de Tierra--The hornblende-biotite quartz diorite-diorite of Corral de Tierra consists of two small masses on the north and west sides of the schist of Sierra de Salinas. It is characteristically a dark rock with 20 to 30 percent mafic minerals (hornblende and biotite) yet most specimens contain 15 to 20 percent quartz. Both masses range from biotite- to hornblende-rich diorite, and both are locally pegmatitic with coarse hornblende crystals several centimetres long.

The contact of the northern mass with the schist of Sierra de Salinas is marked by strongly foliated granitic rock containing schist slivers, as well as coarsened schist layers studded with hornblende crystals across a zone about 100 m wide. Although the schist contact is not exposed at the west mass, there are coarsened schist layers nearby containing hornblende crystals, suggesting similar assimilation or granitization.

I suspect that the Corral de Tierra body is a local facies of the Paraiso-Paloma quartz diorite mass. The contact I show between them is arbitrary, and specimens collected near the "contact" suggest mixing and gradation between the two units.

Granodiorite-quartz diorite of Bear Mountain--A number of arcuate bodies in the Junipero Serra Peak quadrangle have been included in the granodiorite-quartz diorite unit on the basis of samples lent me by Compton, and supplemented by samples I collected. Most of the quartz diorite mapped by Compton (Dibblee, 1973) is lumped together in this unit. I have some confidence that the larger bodies constitute an intrusive formation--some of the smaller bodies are arbitrarily included.

This unit in part forms envelopes around more felsic bodies and in some places is quite gneissoid. It is a typical fairly dark hornblende-biotite quartz diorite with no special characteristics. The resemblance of this unit to the Paraiso-Paloma quartz diorite as well as to the quartz diorite of Soberanes Point suggests that these may all be parts of one widely occurring plutonic formation.

Porphyritic granodiorite of Junipero Serra Peak--The distinctive porphyritic granodiorite of Junipero Serra Peak, in part gneissoid, with somewhat pinkish K-feldspar phenocrysts up to 15 mm long, occurs discontinuously along a narrow belt in the Junipero Serra quadrangle. These rocks, though porphyritic, are unlike the porphyritic granodiorite of Monterey.

This unit is based on a very few specimens, and its outline is somewhat arbitrary. It seemed worthwhile to note this rock type because it closely resembles the porphyritic granodiorite of Sand Creek, and they may be correlative.

Quartz monzonite of Pinyon Peak--The quartz monzonite of Pinyon Peak consists of a number of felsic bodies of variable grain size and texture in the Junipero Serra quadrangle. These rocks are in part alaskite and aplite. The large circular outcrop of the Pinyon Peak area typifies this unit, which may be the youngest in a sequence starting with the Bear Mountain and Junipero Serra Peak granodiorites. Many of the bodies are elongate and sill-like; numerous smaller masses of similar lithology, but too small to show at the scale of the map, are present throughout the northern Santa Lucia Range. This type of rock makes up the bulk of the granitic fraction of the abundant migmatitic rocks. Some of the rocks of the Big Pines and Island Mountain masses of Wiebe (1966) and the heterogeneous granitic complex of Wiebe (1966) may be correlative with the Pinyon Peak unit.

Hornblende-biotite quartz diorite of the Paraiso-Paloma area--The hornblende-biotite quartz diorite of the Paraiso-Paloma area is an elongate body extending for about 30 km along the west side of the schist of Sierra de Salinas. It forms a belt intrusive between two distinctly different metamorphic terranes. The form and position of the mass suggest that it may be intruded along a pre-granitic fault zone. The contact with the schist of Sierra de Salinas is generally very abrupt and in part surprisingly little effect is seen; locally there is a mixed zone across tens of metres where the schist is coarsened and contains hornblende, but almost no granitic apophyses are found. In contrast the Paraiso-Paloma rock is mixed migmatitically with the metamorphic rocks to the west over a broad and complex zone--the west contact is arbitrary.

The Paraiso-Paloma unit is variable particularly in the percentage and proportion of the dark minerals (biotite and hornblende); some specimens have enough K-feldspar to be called granodiorite, yet the recurring lithology of abundant hornblende and little or no K-feldspar suggests this is the "parent stock" that may lose its homogeneity locally due to mixing with metamorphic material.

Porphyritic granodiorite of Sand Creek--The south end of the belt of outcrop of the Paraiso-Paloma unit is disrupted by the porphyritic granodiorite of Sand Creek, a large mass of rock characterized by distinctive salmon-pink K-feldspar phenocrysts as long as 30 mm, but more commonly 10 to 15 mm in largest dimension. Except for the presence of K-feldspar this rock closely resembles the Paraiso-Paloma unit. I have not seen a contact of the Sand Creek unit and therefore cannot conclude whether it is a gradational facies of the Paraiso-Paloma unit or a separate and presumably younger intrusive rock. The resemblance of the Sand Creek unit to the Junipero Serra Peak granodiorite, coupled with the resemblance of the Bear Mountain granodiorite and Paraiso-Paloma quartz diorite, may mean that these two pairs are correlative. The relation is also strengthened by a small alaskitic mass in the center of the Sand Creek mass along the contact with the schist of Sierra de Salinas, which might be an analogue of the quartz monzonite of Pinyon Peak.

Hornblende-biotite quartz diorite of Soberanes Point--The hornblende-biotite quartz diorite of Soberanes Point is the largest single undisrupted granitic unit in the Santa Lucia Range, covering about 180 km^2. It is also probably the most homogeneous granitic mass in the range--it invariably has both biotite and hornblende, generally with biotite in excess. Most specimens contain some K-feldspar, and a number contain enough to qualify as granodiorite. The Soberanes Point mass has the general appearance of a genuine intrusive pluton in contrast to its two probable correlatives, the Bear Mountain and Paraiso-Paloma masses, which are both intimately mixed with metamorphic rocks and in part have gneissic texture. One could theorize that the Bear Mountain and Paraiso-Paloma masses are nearer to an anatectic formation area, whereas the Soberanes Point mass is more "mature" and has become more homogenized and presumably migrated upward from the gneissic root zone where it formed.

Pegmatites with salmon-pink K-feldspar and associated areas of granitic rock with salmon-pink K-feldspar phenocrysts are present within the Soberanes Point mass. These areas have indistinct margins and look like areas penetrated by late K_2O-rich solutions. Some poorly exposed areas richer in K-feldspar, originally interpreted as late plugs, now seem more likely to be a facies of the Soberanes Point mass. These K-feldspar-rich rocks in places bear a close resemblance to the porphyritic granodiorite masses of Junipero Serra Peak and Sand Creek. By analogy I suggest that all of these K-feldspar-rich areas are not separate intrusive bodies, but facies of the three main quartz diorite bodies. This makes an even better case for the correlation of the Bear Mountain and Paraiso-Paloma masses with the quartz diorite of Soberanes Point.

Granodiorite of Cachagua--The granodiorite of Cachagua occurs in a rather narrow arcuate belt between the Soberanes Point and Monterey masses, and in a broader belt between the Paraiso-Paloma and Monterey units. It is a variable unit in both mineral content and texture; the variability and local resemblance to the adjoining rocks make its definition difficult.

The resolution of what the Cachagua unit really was came after repeated traverses along Malpaso Creek, where good roadcuts expose a section from the Soberanes Point unit through the Cachagua unit and well into the Monterey unit. My observations suggest that the Cachagua is a transitional zone between the Monterey mass and the adjoining quartz diorite, that the Monterey mass intruded a relatively coherent but not yet solidified quartz diorite terrane, and that the granodiorite of Cachagua represents the mushy mixed zone between these units. The Malpaso Creek section, though in an area of mostly granitic rocks, may be the key to the general contact relations in much of the mixed granitic and metamorphic terrane of the Santa Lucia Range. If the whole terrane was so hot and plastic that the earlier plutonic units were not rigid enough to form sharp contacts when younger masses were intruded, gradational, mixed contacts like those along Malpaso Creek would have resulted. Only somewhat later were the rocks rigid enough to allow the extensive diking that characterizes the felsic rocks of the range.

Porphyritic granodiorite of Monterey--The porphyritic granodiorite of Monterey is undoubtedly the most distinctive granitic unit in the Santa Lucia Range, with K-feldspar phenocrysts that are as long as 15 cm, but more commonly stubby crystals that are 3 to 10 cm long. It forms spectacular seacoast exposures around Monterey Peninsula and on Point Lobos. The mass probably extends continuously southeastward from Monterey Peninsula for about 30 km, but large areas are covered by younger rocks; it extends an additional 15 km southeastward as discontinuous plugs in the metamorphic terrane. Dredging in the Monterey Bay area suggests that the mass extends some 15 km northwest from Monterey Peninsula to the walls of the submarine Monterey Canyon. If the submarine extension is included, the total outcrop area of the Monterey unit is at least 500 km^2, making this by far the most extensive granitic formation in the Santa Lucia range.

The Monterey unit is relatively homogeneous and easily recognizable, but there is a considerable range in the ratio of plagioclase to K-feldspar based largely on the irregular distribution of phenocrysts--in places the mass is not porphyritic. Admittedly part of the variation is due to the difficulty of making modal analyses of these coarsely porphyritic rocks.

To the south and east the porphyritic granodiorite grades through a zone I have named the granodiorite of Cachagua into hornblende-bearing quartz diorite. Trask (1926, p. 134) noted that porphyritic variety "apparently grades into the main quartz diorite mass of the region, and hence is probably a differentiate of the quartz diorite." I first suspected that Trask was wrong, and that two such different rock types probably were in sharp intrusive contact; yet my field observations have confirmed Trask's interpretation that those units are gradational. It is still problematic whether the Monterey unit is an in-place differentiate of the quartz diorite (a core facies) or whether the Monterey unit is a somewhat later intrusion mixed along its margin with the still mushy quartz diorite. The isolated plugs of Monterey rock in the metamorphic terrane suggest that the Monterey type was a later intrusion; a central differentiated core facies may have sent offshoots into the metamorphic terrane, but this seems less likely.

Variable quartz monzonite-granodiorite of Big Pines and Island Mountain (Wiebe, 1966) and similar(?) mass of Willow Creek--Four separate masses whose relations to one another are poorly known are arbitrarily lumped in the variable quartz monzonite-granodiorite of Big Pines and Island Mountain. Garnet, which is found in much of the felsic granitic rock of the Santa Lucia Range, appears to be absent in these four masses. The northernmost, and largest, mass is tentatively separated from the Soberanes unit largely because Wiebe (1966) separated the southern part, which is in his map area. This mass is most probably a felsic variant that grades northward into the Soberanes unit. All four of the masses are characteristically mixed with metamorphic rocks at their margins and the contacts shown on the map are somewhat arbitrary.

Garnetiferous quartz monzonite of Little Sur and South Ventana Cone (Wiebe, 1966) and possibly related rocks near Arroyo Seco--A group of felsic bodies characterized by small red garnet crystals makes up the garnetiferous quartz monzonite of Little Sur and South Ventana Cone. The bodies are generally elongate and sill-like. Numerous garnet-bearing bodies too small to map and similar dikes and sills are in part related to this unit, but some garnet-bearing "sills" are really metamorphic layers with rounded garnet eyes as large as 10 mm across.

Garnetiferous quartz monzonite of Pine Canyon--Along the north side of the Sierra de Salinas the garnetiferous quartz monzonite of Pine Canyon, a relatively homogeneous felsic rock with small amounts of small red garnet crystals crops out over an area of about 20 km^2.

In outcrop appearance and in modal composition it closely resembles the Little Sur garnetiferous unit and may well be correlative with it. The Pine Canyon mass has been shown separately largely because it is 25 km from the nearest mass of the Little Sur unit.

The rocks mapped as quartzofeldspathic metamorphic rocks (belt 1 of fig. 3) east of the Pine Canyon mass could as well be shown as part of the Pine Canyon mass (they have been shown as granitic rock on previous maps). However, there are significant amounts of schist, gneiss, and particularly marble and calc-hornfels migmatitically mixed with the granitic material. Though the granitic rock probably is predominant, the mapping follows my policy of showing mixed metamorphic and granitic rocks as metamorphic.

Heterogeneous granitic complex of Wiebe (1966)--This unit was designated by Wiebe (1966) to show several areas of granitic rocks that had great lithologic variety and where data were insufficient to draw internal contacts. The rocks included are dominantly quartz monzonite and granodiorite with lesser leucocratic quartz diorite and gabbro and diorite. Thin septa of metasedimentary rocks are included, but generally metamorphic rocks make up less than 1 percent of the complex.

The granitic complex is limited to the area mapped in detail by Wiebe (1966) with minor extensions by me. The unit exemplifies the frustrations of trying to define and delineate poorly exposed granitic formations in a complex terrane. I have seen very little of the outcrop area of this unit; from Wiebe's (1966) descriptions I suspect that many of the rocks may be correlated with the Big Pines and Little Sur units. Possibly the texturally and mineralogically variable masses of the quartz monzonite of Pinyon Peak are also similar. The heterogeneous granitic complex plus the units mentioned above and probably also the Pine Canyon mass coupled with the bulk of the dikes, sills, and migmatitic admixtures too small to map, show that felsic, relatively K_2O-rich granitic material is an important fraction of the granitic basement of the Santa Lucia Range (fig. 4).

NOTES ON SOME STRUCTURAL RELATIONS

This study of the basement rocks of the Santa Lucia Range has consciously emphasized the petrology and chemistry at the expense of the structural geology. My rationale for this emphasis was that in a limited time I would get more data applicable to regional correlations (my goal) from rock-type distribution patterns for the whole range than I would from detailed structural studies. And quite frankly my interest and competence lean more toward petrology than toward structural geology. Discussion of the structural patterns of parts of the range and what they mean can be found in Compton (1966a,b) and Wiebe (1970a,b). The following brief discussion mostly concerns the relative coherence of the Santa Lucia Range basement. Regional reconstruction models need specific restraints: what parts of the basement may and may not be moved relative to other parts to "undo" structural movements along the continental margin.

Probably the most noteworthy structural feature in the northern Santa Lucia Range is the family of northwest-trending faults, some of which are continuous for tens of kilometres (sheet 1 and fig. 5). It is important to note that basement rock patterns restrict the possibility of any significant postgranitic basement rock disruptions (that is, strike-slip movement) within the Salinian block to faults 1 or 8 (fig. 6).

Fault 1 juxtaposes quite dissimilar basement rocks, and the metamorphic trends are also discordant across the fault. The basement rock relations, as I have interpreted them, permit large basement movement along fault 1 but certainly do not require it.

The basement is relatively coherent across faults 2 through 7 and faults 9 and 10 (fig. 6). There are certainly vertical displacements measurable in thousands of metres across some of these faults (Dickinson, 1965; Compton, 1966,b), but mappable granitic and metamorphic units are traceable across these faults with only minor offset.

The Palo Colorado-Coast Ridge fault zone (8 on fig. 6), however, could possibly be a major strike-slip basement dislocation. The Coast Ridge metamorphic belt shows marked contrasts with the metamorphic terrane to the east. The contrast may mark only a stratigraphic difference, but the presence of the rather continuous Palo Colorado-Coast Ridge fault zone separating the different metamorphic terranes suggests something more. Earlier compilations, such as Jennings and Strand's (1959), did not connect the Palo Colorado and Coast Ridge faults. The "dashed" connection I show on the geologic map is based on an interpretation of ERTS imagery (Ross, 1976) which suggests that these faults are parts of one throughgoing lineament. The southward continuation of this zone to where it converges with the Sur fault is highly speculative. It is worth noting that, on the basis of geophysical data, this fault zone has been postulated by Greene, Lee, McCulloch, and Brabb (1973) to continue northward along Carmel Canyon and across Monterey Bay to join the San Gregorio fault. They note that earthquakes as recently as 1971 and 1972 along this zone reflect right-lateral fault displacement similar to that along the San Andreas fault and speculate that the Palo Colorado-San Gregorio fault zone should be considered a branch of the San Andreas fault system. No estimates have been made of the possible magnitude of right-lateral movement on this zone, and none are possible at this time from the basement pattern in the Santa Lucia Range.

An older pregranitic disruption of the Santa Lucia basement rocks may be present along the west side of the schist of Sierra de Salinas. The schist of Sierra de Salinas is strikingly different from the rest of the metamorphic rocks of the range (Ross, in press) and granitic rocks appear to be intruded along the contact between the two. It is also possible that the Chupines and Tularcitos fault zones (faults 2 and 3, fig. 6) may reflect reactivation of this old fault zone.

The structural trends of the metamorphic rocks (fig. 6), though admittedly grossly overgeneralized, show generally parallel northwest trends on both sides of the range and a central core zone that is much more structurally contorted. One could almost visualize a gigantic right-lateral shear between the Coast Ridge belt (west of the Palo Colorado-Coast Ridge fault zone; 8 of fig. 6) and the possibly more rigid schist block of the Sierra de Salinas (between faults 1 and 2, fig. 6). Although that idea is rather speculative, there is certainly a more contorted zone running through the central part of the Santa Lucia Range that has not been fully appreciated in the past. On the other hand, the zone of most contortion also somewhat coincides with the areas of the detailed studies of Compton (1966a,b) and Wiebe (1970,b). Perhaps detailed studies of the seemingly less contorted eastern and western belts would reveal similar contortions.

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