PETROLOGY OF BASEMENT ROCKS
OF THE CALIFORNIA CONTINENTAL BORDERLAND AND THE LOS ANGELES BASIN

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Basement rocks of the California Continental Borderland and the Los Angeles Basin are: 1) the Catalina Schist, a relatively high-pressure, low-to-moderate temperature metamorphic terrane, and 2) island arc rocks metamorphosed at relatively low pressure and low-to-moderate temperature, which include the Willows Plutonic Complex, the Santa Cruz Island Schist, and the Santa Monica Formation.

## CATALINA SCHIST

The Catalina Schist terrane consists of three tectonic units. A tectonic melange unit, characterized by blueschist facies metamorphism, is overlain by a thrust sheet of greenschist facies rocks, this sheet is overlain by an amphibolite facies unit. Previous workers (Platt, 1975; Earle, 1980; Elliot, 1976) consider the terrane as a thermal aureole developed in the downgoing slab beneath a hot, peridotitic hanging wall during initial subduction.

### AMPHIBOLITE FACIES

The upper amphibolite unit consists of a structurally coherent 300 meter thick slab of gneissic plagioclase and zoisite amphibolite, of gabbroic composition, overlain by serpentinite which contains tectonic inclusions of amphibolite facies metabasites. Present as inclusions within the serpentinite and as interlayers in the amphibolite are rare garnet-bearing quartzites and semi-pelitic schists. Chemistry and mineral assemblages indicate relatively high-pressure and moderately high-temperature metamorphism of gabbro and basalt lithology with minor cherty and argillaceous sediments.

Localities: (Sorenson, 1984)

(1) Airport-Empire Landing Road. At the locality listed "Stop 2" in Figure 1, one of the larger tectonic-block inclusions within the serpentinite and chlorite/actinolite/talc melange of the Catalina amphibolite unit is exposed. It is gneissic, with layering dominated by garnet + clinopyroxene and garnet + hornblende, although nearly monomineralic garnet layers also occur. The garnets may be rimmed by plagioclase ($An_{20-30}$). Rosettes of anthophyllite + tremolite ± talc ± chlorite may be found in the float surrounding the block. This block does not appear to have a rind.

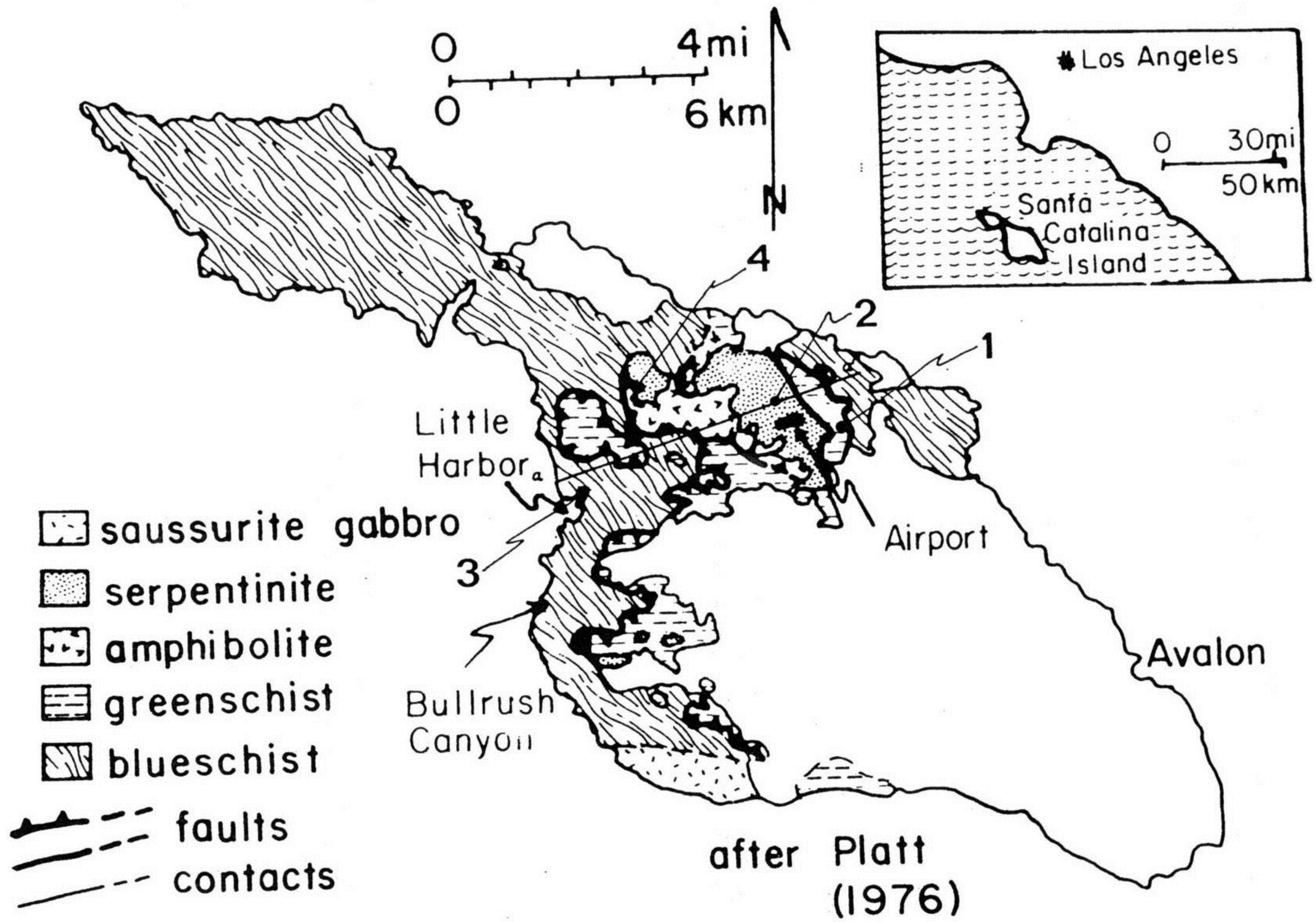


Fig. 1. Basement geology of Santa Catalina Island after J. Platt (1976). Line a-a' in Figure I-1 is the approximate line of section for Figure 2. Locations of field trip stops 1-4 are shown by their appropriate number.

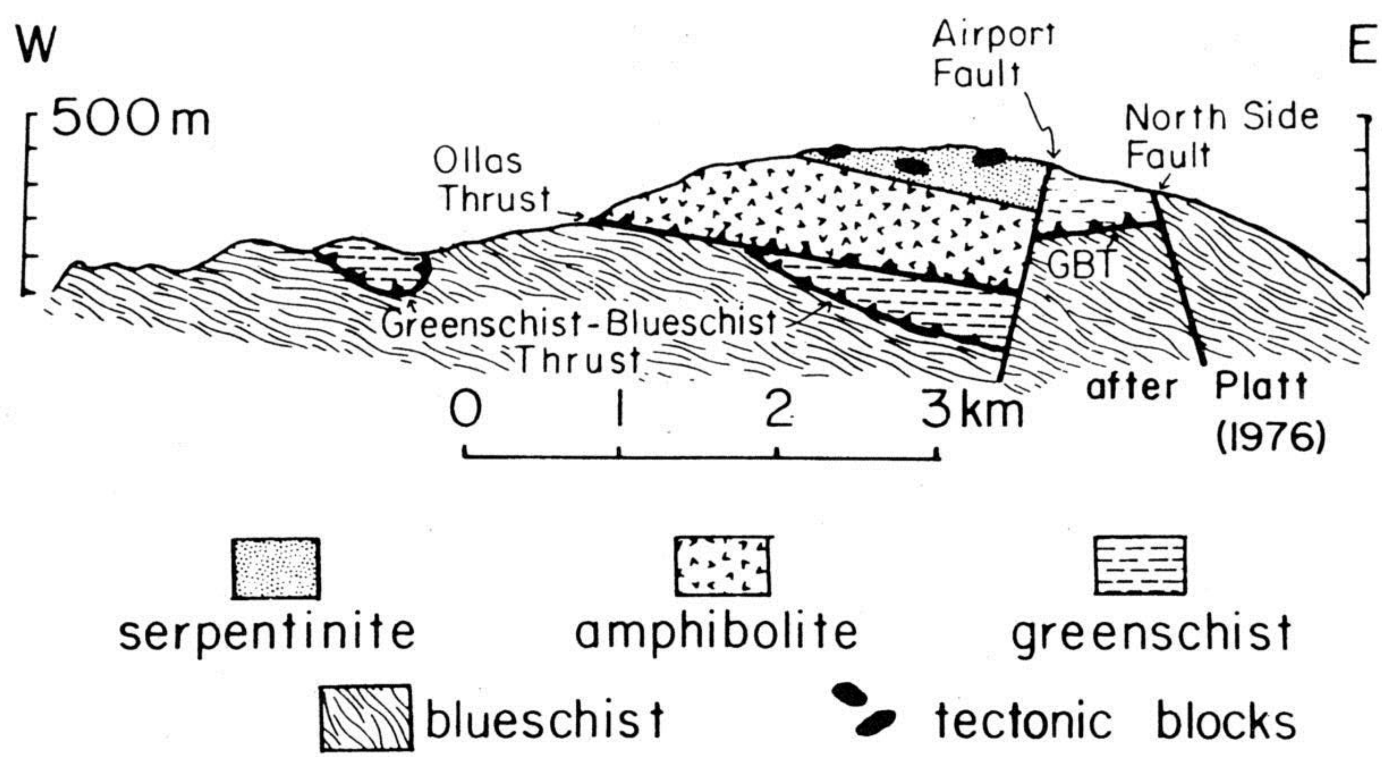


Fig. 2. Diagrammatic cross section of Santa Catalina Island after J. Platt (1976). Line a-a' in Figure I-1 is the approximate line of section.

(2) Little Harbor - Two Harbors road spur to Buffalo Corral Reservoir. At the locality listed "Stop 4" in Figure 1, mafic amphibolite of the Catalina amphibolite unit is overlain by sepentinite. The latter has a basite texture with crysotile veinlets. This unit overlies the blueschist and greenschist units exposed at Little Harbor and in the two forks of Little Springs Canyons.

During recrystallization, the rocks were associated with periodotite and subjected to metasomatism (at temperatures greater than 600 degrees Centigrade and pressure of 8-12 kilobars) which produced reaction zones or rinds surrounding the metabasites.

Detailed petrologic and geochemical study of two rind-bearing blocks within this unit was performed to determine the nature of these metasomatic effects. The extent and scale of chemical exchange between the Catalina metabsite blocks and the enclosing periodotite is much larger than that demonstrated in previous studies on sea-floor metamorphic effects on basalt and on metasomatism accompanying rodingitization. (Humphris & Thompson, 1978; Evans et al, 1981)

The lower amphibolite unit was found to be similar to fresh and altered gabbros from ophiolite suites and metamorphosed mid-Atlantic ridge gabbros in major element and REE geochemistry. Retrograde metamorphism is possibly manifested in amphibole core-to-rim zonation from horblendic to actinolitic compositions. Within the minor semipelitic schist, mineral chemistry suggests an overprint of high-fluid-pressure, lower-temperature metamorphism over the high-pressure and moderate-temperature recrystallization.

The upper unit was described by Platt (1976) as serpentinite with tectonic blocks and by Bailey (1941) as clorite/actinotlite/talc melange, serpentine, and brown hornblende. The blocks range in size from less than 0.5m to about 100 m in diameter, and vary in composition; generally tholeiitic and bearing garnet + hornblende ± clinopyroxene ± plagioclase or zoisite mineral assemblages. Some eclogitic tectonic blocks have schisctose rinds, predominantly of amphibole and layer silicates. Rinds were formed by hydration of the eclogitic mineral assemblages of the block accompanied by element exchange with surrounding ultramfic rocks, both at high temperatures and pressures,(greater than 600 degrees C and 8-12 kb) and at relatively lower pressure and temperature conditions.

The principal major-element metasomatic effect at high temperatures is Mg addition to the block, transition zone, and rind system; at relatively lower temperatures, addition of Ca is the predominant effect. Many minor and trace elements appear to have been mobile during rind formation. Rare earth elements were released from blocks, probably by breakdown of sphene during reactions linked to rind formation, and were deposited in the transition zones and rinds. Ni and Cr may have been derived from olivine, orthopyroxene, and/or clinopyroxene in peridotite. Some of the "coherent" behavior of the incompatible elements in the reaction of peridotite and basalt at elevated pressures and temperatures may result from metasomatism between basalt and peridotite.

Structurally below the amphibolite facies rocks are the Catalina greenschist facies and the underlying blueschist facies melange.

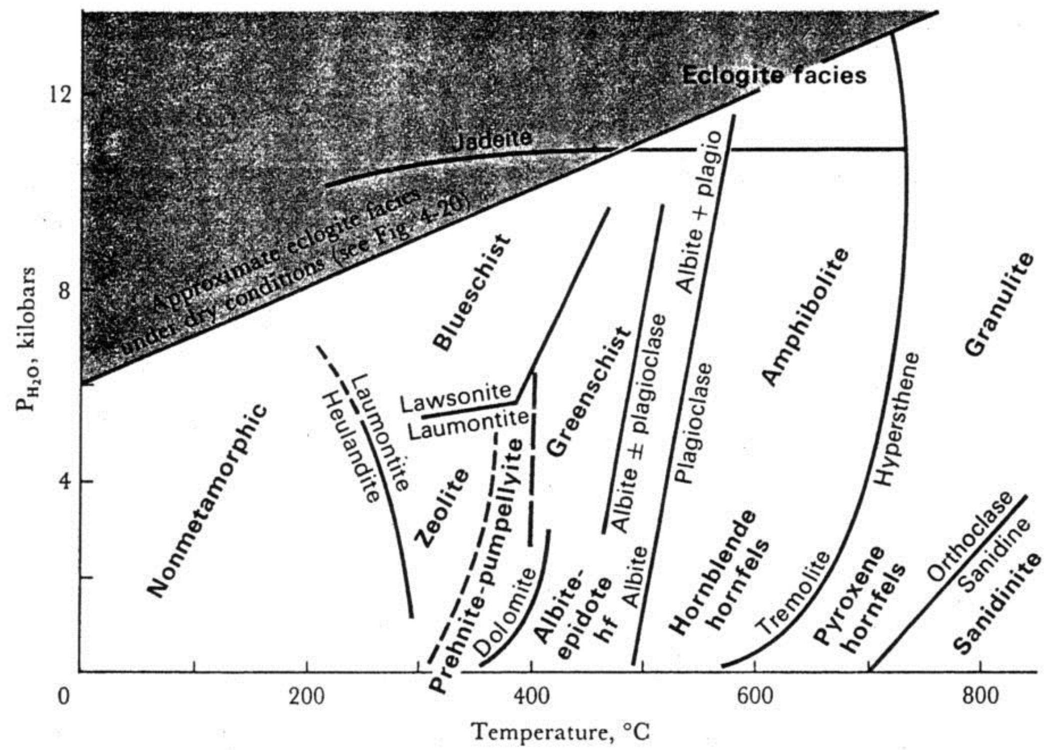


Figure 3: Metamorphic facies boundaries largely as defined by Fyfe, Turner, and Verhoogan (1958). Metamorphic facies are designated by boldface type.

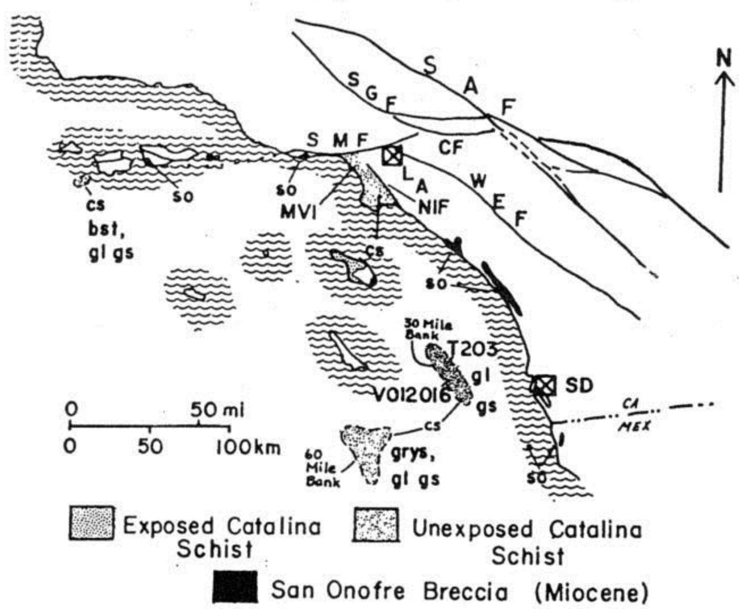


Figure 4: Generalized locations of Catalina Schist materials.

## BLUESCHIST FACIES

Blueschist facies metamorphism arises under the relatively high pressures and low temperatures of subduction zones as indicated by various petrologic and geophysical evidence (Ernst, 1977 a, b; Cloos, 1981; Carlson & Rosenfeld, 1981; Earle, 1980). Subduction zone metamorphic belts, however, also contain greenschist facies rocks, with the crossitic blue amphiboles known to be characteristic of pressure and temperature conditions transitional to those of the blueschist facies.

The predecessor rocks of these two Catalina units (blueschist and greenschist) are similar, and consist of basaltic igneous rocks, clastic, argillaceous, and cherty sediments. Seventy-five percent of the blueschist unit is metagraywacke, whereas only about forty percent of the greenschist unit consists of metagraywacke (Platt, 1976). In the blueschist rocks, relict protolithic features are retained; the greenschist rocks are thoroughly recrystallized and lack relict textures.

The blueschist melange contains metagraywacke, metashale, metaconglomerate, greenstone, quartz schist, blueschist, and eclogite blocks within a fine-grained, schistose matrix. The chemical and mineralogic characteristics of the matrix indicates that it is recrystallized from a mixture of ultramafic and clay-rich quartzose detritus. The characteristic blueschist glaucophane-lawsonite assemblage is developed in nearly all bulk compositions, including that of the matrix. This ubiquitous glaucophane + lawsonite, with a paucity of chlorite in the graywackes suggest relatively higher temperatures and/or lower pressures of recrystallization for Catalina graywackes than for the Franciscan Complex metagraywackes of Panoche and Pacheco Passes.

The best exposures of blueschist melange crop out in the canyons and cliffs of west-central Catalina Island. Figure 3 shows an exposure of melange in the spillway of the Lower Buffalo Corral reservoir, about 2 miles northeast of Little Harbor . Meter-sized blocks of blueschist, metagraywacke, and quartz schist are surrounded by schistose melange matrix, and have the boudinage features and "tadpole" shapes characteristic of melange blocks in the Coast Ranges Franciscan Complex (Cloos, 1981.)

Locality: Little Harbor seacliff. At the locality listed as "Stop 3" in Figure 1, a blueschist facies metaconglomerate block, greenstone block, and metagraywacke block are exposed in the north seacliff of Little Harbor. These can be viewed from the spit across the harbor. The melange matrix is black to gray in color, and is predominantly serpentine and chlorite.

## GREENSCHIST FACIES

The greenschist unit consists of metabasite schist (about 50%), graywacke-composition grayschist (about 40%), and quartz schist(about 10%). All three occur interlayered in a single outcrop on a scale of a centimeter to several meters. It has a limited areal extent and relative thinness (approx. 200 meters) on Santa Catalina Island, but is significant on a regional scale.

Locality: Avalon-Airport roadcut. At the locality shown as "Stop 1" in Figure 1, the Catalina greenschist unit is exposed along the Avalon-Airport road in a fault block bounded by the Airport Fault on the west, and the North Side Fault on the east (Figures 1 & 2). The roadcuts reveal grayschists, quartz schists, and mafic schists. The mafic schists are glaucophanic greenschists. The sodic amphibole crossite occurs as inclusions in epidote or albite porphyroblasts, but only rarely (if at all) in the matrix of these schists. Most matrix amphiboles are sodic actinolites or barroisites. Crossite evidently crystallized before the relatively more calcic amphiboles.

The metabasites contain mineral assemblages which indicate that structurally low glaucophanic greenschists intially recrystallized at pressure and temperature conditions approaching those of the blueschist facies, whereas structurally high metabasites originally were epidote amphibolites. Both are overprinted by relatively high-pressure greenschist facies minerals.

Platt (1976) noted the slight differences in metamorphic mineralogies in the greenschist unit. In exposures of the greenschist unit between the North Side Fault and the Airport fault blue amphibole is abundant near the lower contact with the blueschist unit, whereas biotite and garnet occur near the upper contact with the amphibolite unit. These relationships are seen at other exposures of these contacts.

A comparative study of bulk-rock geochemical data suggests that the majority of metabasites from both tectonic units are derived from ocean-floor tholeiites. Mineral chemistry of white micas indicate that the blueschist unit crystallized under relatively higher pressure and/or lower temperature conditions than did the greenschist unit. The mineral chemistry of amphiboles from greenschist unit metabasites reveals an overprint of glaucophanic greenschist crossites, barroisites, and sodic actinolites and epidote amphibolite hornblendes by rims which are relatively actinolitic in composition. Glaucophanic greenschist crossites probably formed at somewhat higher temperatures than the crossites from lawsonite + glaucophane-bearing metabasites of the blueschist unit.

## ISLAND ARC-LIKE ROCKS FROM THE CALIFORNIA CONTINENTAL BORDERLAND AND LOS ANGELES BASIN

Jurassic igneous and metamorphic rocks in part underlie the southwestern Transverse Ranges region, which includes Santa Cruz Island, the Santa Monica Mountains, and the northern-northeastern margins of the Los Angeles Basin. Among these are the Willows Plutonic Complex, the altered saussurite gabbros, the metavolcanic Santa Cruz Island Schist, and the metasedimentary Santa Monica Formation. Saussurite gabbros occur in other locations in the California Continental Borderland, notably on Santa

Catalina Island and in the subsurface of the western Los Angeles Basin. Amphibolite and greenschist facies metabasites form the basement at the northeastern margin of the Los Angeles Basin; Santa Monica Formation pelitic schist and calc-alkaline oligoclase-epidote amphibolite are juxtaposed in an oil well in the northern L.A. Basin. The petrographic and petrologic similarity of the greenschist facies metavolcanics of the Puente Hills basement and the Santa Cruz Island Schist are evidence for a relationship between these basement rocks.

Whole-rock major, minor, and trace element compositions indicate that the plutonic and metavolcanic rocks are calc-alkaline and may be parts of an island-arc complex. Saussurite gabbros of the Willows Plutonic Complex are chemically and petrologically indistinguishable from other saussurite gabbro occurrences in the California Continental Borderland.

No igneous or detrital plagioclase and pyroxene are presevedin the metavolcanics or metasediments, but relict igneous amphiboles from the metamorphic rocks resemble the amphiboles from the plutonic suite, and could have been dereived from a source like the Willows Plutonic Complex. Metamorphic chlorite, ubiquitous in the metasediments and metabasites, varies in composition, parallel with host-rock bulk chemistry. White micas from metasediments are richer in paragonite and poorer in celadonite than those in metabasites. The celadonite in metabasite micas indicates recrystallization temperatures of less than 400 deg. C at pressures less than 5 kb; the paragonite in metasediment micas suggests upper garnet to lower staurolite zone metamorphism, which is consistent with estimates of metamorphic temperatures between 400 and 550 deg. C based on the pelitic mineral assemblages. These temperatures and pressures result from a contact aureole, spatially related to pre-Late Cretaceous silicic plutons, superimposed upon regional greenschist facies (chlorite to biotite zones) metamorphism.

According to the petrologic and geochemical data, the Willows Plutonic Complex, the Santa Cruz Island Schist, and the Santa Monica Formation are probably fragments of one or more island arc-like igneous and sedimentary terranes of calc-alkaline geochemistry and relatively low-pressure greenschist-to amphibolite facies metamorphism. The greenschist and amphibolite facies rocks from the northern Los Angeles Basin also resemble island arc rocks. The saussurite gabbros of the California Continental Borderland are indistinguishable from altered portions of the calc-alkaline Willows Plutonic Complex.

The general similarities in age, petrology, and chemistry of prebatholithic suites of the Sierran and Peninsular Ranges suggest that the Santa Cruz Island Schist and Santa Monica Formation have a comparable origin. The relationship of these entities with the relatively high-pressure metamorphic terranes of the Franciscan Complex, Pelona Schist, and Catalina Schist remains problematical.

## REFERENCES CITED

Bailey, E.H., 1941, Mineralogy, petrology, and geology of Santa Catalina Island, Unpublished Ph.D. dissertation, Stanford University, 193 pp.