THE PELONA-OROCOPIA SCHIST AND VINCENT-CHOCOLATE MOUNTAIN THRUST SYSTEM, SOUTHERN CALIFORNIA[1]

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ABSTRACT

The Pelona-Orocopia schist (=the Pelona, Orocopia, and Rand Schists) crops out in the southeastern corner of California and in southwesternmost Arizona, along the southern San Andreas fault system in the central Transverse Ranges, and along the Garlock fault. Metamorphism of the Pelona-Orocopia schist occurred in Paleocene (or Late Cretaceous) time; the age of the Pelona-Orocopia protolith is unknown. The lower-greenschist- to lower-amphibolite-facies schist is predominately metagraywacke, with subordinate metapelite, metabasite, ferromanganiferous metachert, marble, and meta-ultramafic rock. These oceanic rocks are tectonically overlain, along the mylonite-marked Vincent-Chocolate Mountain thrust, by nappes consisting of Precambrian through Mesozoic gneissic and granitic rocks. These sheets of continental crust are interpreted as pieces of a single (hypothetical) regional allochthon which extends from southwesternmost Arizona to the western Mojave Desert. Overthrusting is inferred to have been toward the northeast. In several areas which have received detailed study, metamorphic grade and grain size within the schist increase upward toward the thrust, and lineation in the cataclastic and retrograde rocks at the base of the upper plate is parallel to lineation in the schist. These relations indicate that metamorphism of the Pelona-Orocopia schist took place beneath the upper plate of the Vincent-Chocolate Mountain thrust and was broadly contemporaneous with movement along the thrust.

A palinspastic reconstruction of southern California prior to 300 km of late Cenozoic right slip along the San Andreas fault system shows that the Pelona-Orocopia schist lies largely along and beneath the eastern margin of the Cretaceous Sierra Nevada-Salinia-Peninsular Ranges batholithic belt; the schist is thus spatially distinct from the Franciscan Complex of western California. The Pelona-Orocopia schist is apparently unrelated to any of the other widespread tectonic-lithologic units of southeastern California and adjacent areas. The presence of the oceanic rocks of the Pelona-Orocopia schist in their present tectonic position in southern California seems anomolous. The Pelona-Orocopia protolith may have accumulated outboard of a continental margin, in southern California or elsewhere, and been subsequently tectonically trapped inboard of the continental basement that now lies to the west of the Pelona-Orocopia schist. Alternatively, the protolith may have accumulated in an ensimatic intracontinental basin within southern California.

INTRODUCTION

The Paleocene (or Upper Cretaceous) Pelona, Orocopia, and Rand Schists have long been one of the least understood elements of the geology of southern California. Field and petrologic studies completed in the decade since the summary by Ehlig (1968) have added to our knowledge of the geologic history of the schists, confirmed the conclusion of Ehlig (1958) that the metamorphism of the schists is closely related to the overlying Vincent-Chocolate Mountain thrust system, and extended the known distribution of the Orocopia Schist southeastward into the southwestern corner of Arizona. However, the significance of these schists and their protolith in the tectonic evolution of southern California and adjacent areas is still uncertain.

In this paper we summarize the evidence for correlation of the Pelona, Orocopia, and Rand Schists (collectively, the Pelona-Orocopia schist) with one another; describe the geology of the Pelona-Orocopia schist and the Vincent-Chocolate Mountain thrust system; discuss the tectonic setting and possible subsurface distribution of the schist; outline the uncertainties regarding the paleogeographic significance of the schist; and conclude with some suggestions for future study. In describing the schist we emphasize the terranes with which we are most familiar: the Orocopia Schist of the southern Chocolate Mountains (Dillon, 1976) and the Picacho-Peter Kane Mountain area (Haxel, 1977) northwest and north of Yuma, Arizona, and the Pelona Schist of the eastern San Gabriel Mountains, to which we have been introduced by Perry Ehlig.

THE PELONA-OROCOPIA SCHIST

Distribution and Lithology

The Pelona Schist occurs on either side of and within the greater southern San Andreas fault system (Crowell, 1975a) in the central Transverse Ranges (Fig. 1) from the area of Mount Pinos (schist body 3, Fig. 2, Table 1) southeast to the north side of San Gorgonio Pass (8). One body of the Pelona Schist occurs as a sliver within the Garlock fault zone in the southwestern Tehachapi Mountains (4); the Rand Schist (5) crops out south of the Garlock fault in the Rand Mountains. The Orocopia Schist forms a discontinuous belt, east of the San Andreas fault, extending from the Orocopia Mountains (9) southeast through the Chocolate Mountains (10, 11) to the Picacho-Peter Kane Mountain area (12) and thence eastward at least as far as Neversweat Ridge (15) in

[1]The stratigraphic nomenclature used in this report is from several sources and may not necessarily follow the usage of the U.S. Geological Survey.

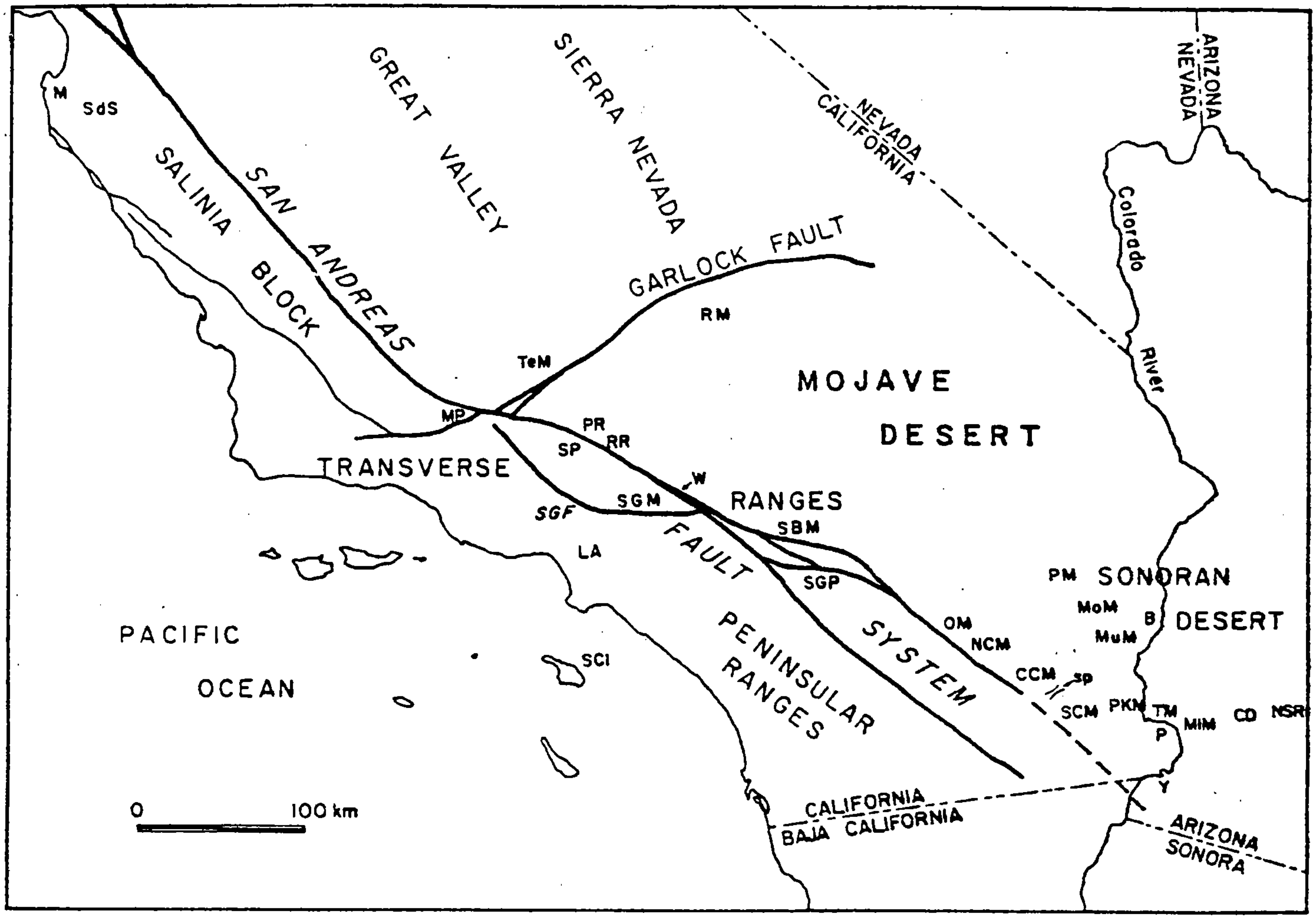

Figure 1. Index map showing most of the geographic features and localities referred to in the text. CCM, central Chocolate Mountains; CD, Castle Dome Mountains; LA, Los Angeles; M, Monterey; MiM, Middle Mountains; MoM, McCoy Mountains; MP, Mount Pinos; MuM, Mule Mountains; NCM, northern Chocolate Mountains; NSR, Neversweat Ridge; OM, Orocopia Mountains; P, Picacho; PKM, Peter Kane Mountain; PM, Palen Mountains; PR, Portal Ridge; RM, Rand Mountains; RR, Ritter Ridge; SBM, San Bernardino Mountains; SCI, Santa Catalina Island; SCM, southern Chocolate Mountains; SdS, Sierra de Salinas; SGF, San Gabriel fault; SGM, San Gabriel Mountains; SGP, San Gorgonio Pass; sp, Salvation Pass; SP, Sierra Pelona; TeM, Tehachapi Mountains; TM, Trigo Mountains; W, Wrightwood; Y, Yuma.

central Yuma County, Arizona.

These fifteen schist bodies are considered to be correlative because each body is characterized by most or all of the following features (Ehlig, 1968; Haxel, 1977; references in Table 1):

(1) The most abundant rock type is a monotonous but distinctive light- to dark-gray, flaggy quartzo-feldspathic schist, with a little interlayered mica schist, characterized by ubiquitous flysch-like compositional layering (Fig. 3) derived from sedimentary bedding. This gray schist (of Ehlig, 1958) is predominantly metagraywacke, probably in part volcaniclastic, with a little metapelite and meta-arkose.

(2) Subordinate to minor rock types are, in order of decreasing overall abundance, metabasite as greenschist, albite amphibolite, amphibolite, or, very locally, garnet amphibolite; ferromanganiferous metachert; siliceous marble; and meta-ultramafic rock as antigorite serpentinite, very coarse grained actinolite-rock, talc-actinolite schist, or, locally, talc-rock.

(3) Two distinctive "index minerals" are present: porphyroblasts of gray to black albite, the color of which is due to included graphite, and aggregates of bright green fuchsite (chrome muscovite).

(4) Most of the schist bodies are overlain by thrust sheets of gneissic and granitic rock (Fig. 2).

(5) The schist bodies are only very sparsely intruded (see below) by Mesozoic granitic rocks (Ehlig, 1968; see also Ross, 1976). In contrast, Mesozoic plutons are common in the thrust sheets overlying the schist; these plutons are truncated by the thrusts.

Table 1. Pelona-Orocopia Schist Bodies

Map no.	Location	Name of schist	Metamorphic facies of schist	Name of thrust	Rocks of upper plate	References
1	Sierra Pelona(*)	Pelona	gsf, aea, amp	Vincent	PC gn, mig, an-sy; Mz gr	Muehlberger and Hill, 1958; Dibblee, 1961a; Crowell, 1962; Ehlig, 1968; Harvill, 1969; Graham, 1975; Graham, and England, 1976
2	Portal and Ritter Ridges, Quartz Hill	Pelona	amp, aea	--	---	Evans, 1966, 1978; Ross, 1976; Dibblee, 1967
3	Mount Pinos, Mount Abel	Pelona	gsf or aea	no name	gn, mig, gr-gn, gr; Mz gr	Crowell, 1962
4	Tehachapi Mountains	Pelona	gsf, aea, amp	no name	gn, gr	Wiese, 1950; Crowell, Ehlig, and Dillon, reconnaissance 1973
5	Rand Mountains(*)	Rand	gsf, aea	Rand	Pz(?) gn; Mz gr	Vargo, 1972; Hulin, 1925; Dibblee, 1967; Ehlig, 1968
6	Eastern San Gabriel Mountains (southwest of San Jacinto fault)	Pelona	gsf	Vincent	PC gn, mig; Pz(?) gn; Mz gr	Ehlig, 1958, 1968, 1975a, b
7	Blue Ridge to Crafton Hills (between San Jacinto and San Andreas faults)	Pelona	gsf	Vincent	gn	Ehlig, 1968; Noble, 1954
8	North side of San Gorgonio Pass	Pelona	aea	Vincent	gn	Allen, 1957; Dibblee, 1964
9	Orocopia Mountains(*), Mecca Hills	Orocopia	gsf, aea	Orocopia	PC gn, mig, gr-gn, an-sy; Mz gr	Crowell, 1962, 1975c; Raleigh, 1958
10	Central Chocolate Mountains	Orocopia	aea?	Chocolate Mountain	PC(?) gn, mafic gn, gr-gn	Murray and Crowe, 1976
11	Southern Chocolate Mountains	Orocopia	gsf, aea, amp	Chocolate Mountain	PC(?) gn, mafic gn, gr-gn; Mz gr	Dillon, 1976
12	Picacho-Peter Kane Mountain area, California; Trigo Mountains, Arizona	Orocopia	aea, amp	Chocolate Mountain	PC(?) gn, gr-gn	Haxel, 1977
13	Middle Mountains, Arizona	Orocopia	?	Chocolate Mountain	gn	Dillon and Haxel, reconnaissance, 1974
14	Castle Dome Mountains, Arizona	Orocopia	?	?	?	Dillon and Haxel, reconnaissance, 1974
15	Neversweat Ridge, Arizona	Orocopia	?	?	?	Crowell, Ehlig, Dillon and Haxel, reconnaissance, 1973

NOTE.--Schist bodies 1 through 9 as in Ehlig (1968, Fig. 1). Areas (1-11) not designated as Arizona are in California. Asterisks (*) designate the type locality for each schist. Abbreviations: gsf, greenschist facies, aea, albite-epidote amphibolite facies; amp, amphibolite facies; gn, gneiss; gr, "granite"; gr-gn, granitic gneiss; mig, migmatite; an-sy, anorthosite-syenite complex; Pz, Paleozoic; Mz, Mesozoic; PC, Precambrian based on U-Pb isotopic age determinations by L. T. Silver and coworkers (1971; oral commun., 1974, 1977); PC(?), probable or possible Precambrian based on lithologic correlation by the authors or by Jennings and Strand (1969) or Rogers (1967). Metamorphic facies are from the references cited and P. L. Ehlig (written commun., 1976).

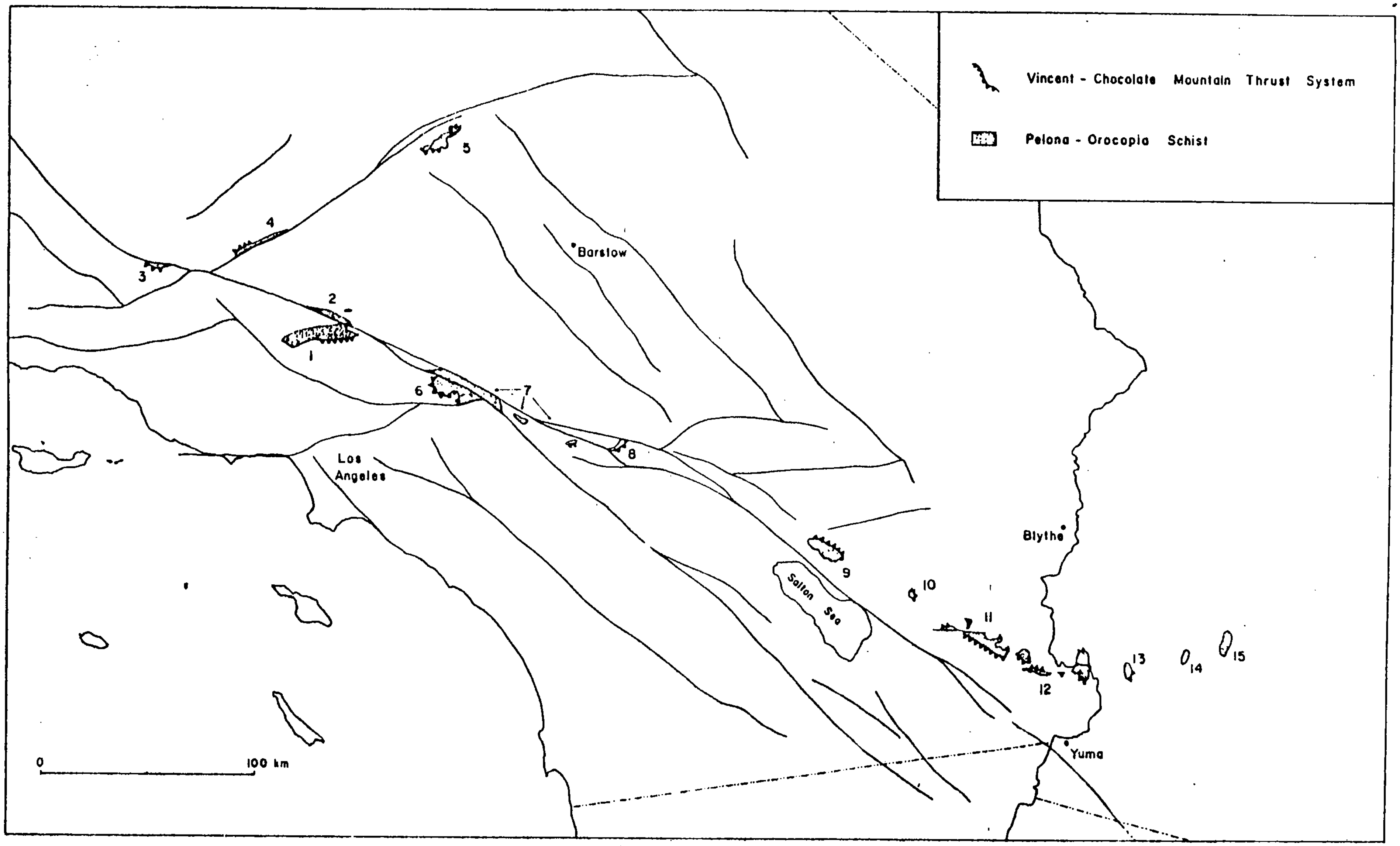

Figure 2. Distribution of the Pelona-Orocopia schist and Vincent-Chocolate Mountain thrust system (after Jennings, 1973; Ehlig, 1968; Dillon, 1976; Haxel, 1977) and Cenozoic strike-slip faults (after Jennings, 1973; Crowell, 1975a) in southern California and southwesternmost Arizona. Schist bodies are numbered as in Table 1; schist bodies 1 to 9 are the same as shown by Ehlig (1968, fig. 1). Some of the smaller schist bodies are shown slightly exaggerated in size and the geometry of most of the thrust faults is simplified.

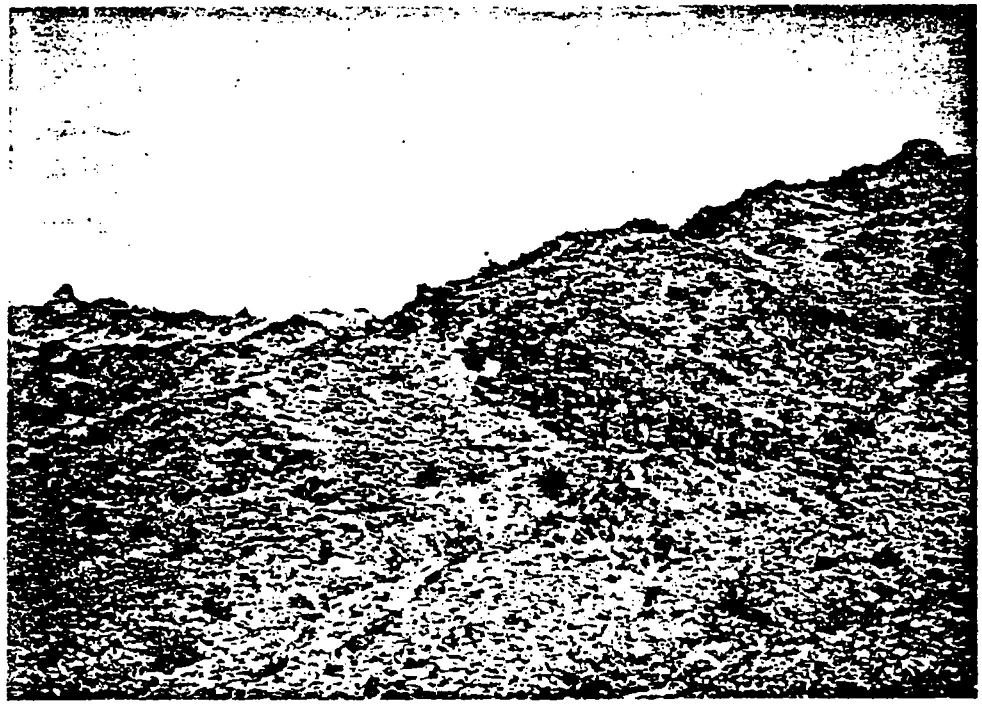

Figure 4. Chocolate Mountain thrust zone, 3 km southwest of Picacho, California. From upper right to lower left: Precambrian banded gneiss, cliff composed of mylonite and ultramylonite at base of upper plate, thrust at base of cliff, Orocopia Schist below thrust. Geologist on center skyline provides scale.

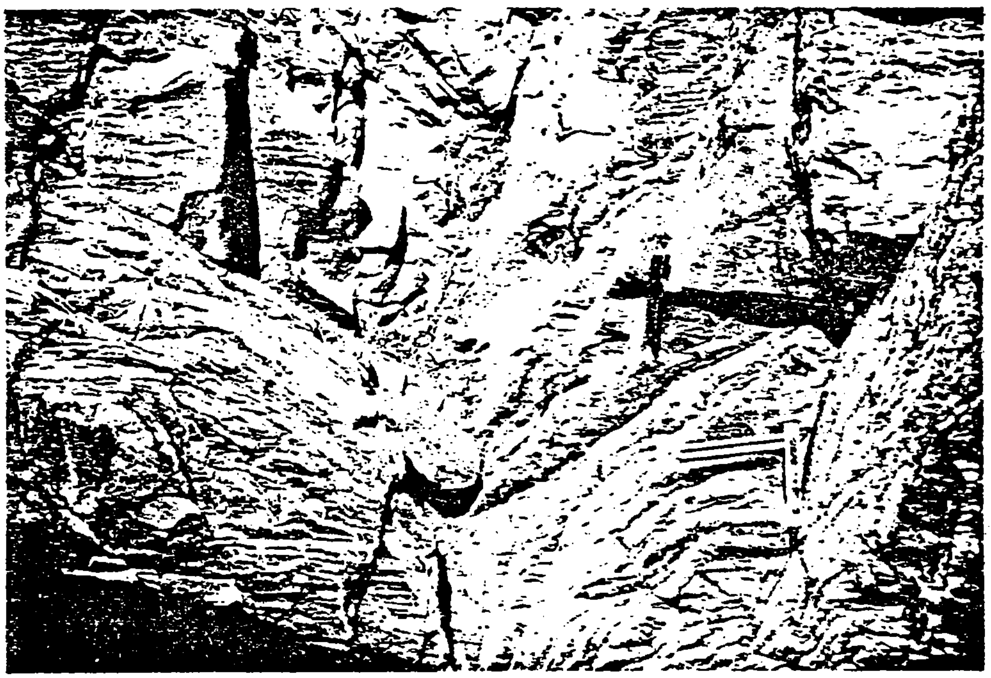

Figure 5. View looking downward on an outcrop of the Chocolate Mountain thrust (at hammer) showing parallelism of lineation in protomylonitic gneiss above thrust and metabasite schist of Orocopia Schist below thrust. Southern Chocolate Mountains, 2.5 km northeast of Mary Lode mine. Hammer is 32 cm long.

Orocopia Schist that is notably coarser grained than, and grades structurally downward into, the normal schist further below the thrust. Locally this coarse schist has protomylonitic (Higgins, 1971) textures in thin section, but in most areas the schist appears to be crystalloblastic right up to the thrust. Lineation in the normal schist, in the coarse schist, and in the cataclastic and retrograde rocks above the thrust are all parallel to one another (Fig. 5).

The Chocolate Mountain thrust zone contains scattered to locally abundant mesoscopic drag folds, most of which occur in the cataclastic rocks near the base of the upper plate. Some of these drag folds are isolated S-folds or Z-folds which have a unique vergence (sense of rotation; sense of asymmetry). Figure 7 shows the orientation and vergence of drag folds measured at some 25 localities along the 80-km length of the southern Chocolate Mountains and Picacho-Peter Kane Mountain area, from Salvation Pass southeastward to the Colorado River. From the collective asymmetry of these drag folds we infer, using the method described by Hansen (1967), that the direction of overthrusting along the Chocolate Mountain thrust was approximately northeastward.

Roughly northeastward overthrusting along the Vincent thrust in the eastern San Gabriel Mountains is suggested by the orientation and sense of overturning of a macroscopic synform in the underlying Pelona

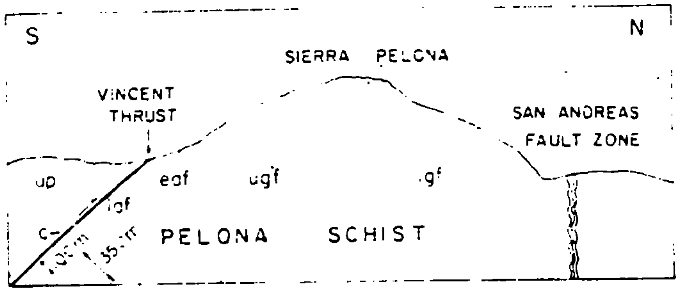

Figure 8. Schematic section showing inverted metamorphic zonation in the Pelona Schist of Sierra Pelona, after Graham and England (1976, fig. 2). Not to scale. Up, gneiss and granite of upper plate; c, cataclastic rocks; laf, lower amphibolite facies; eaf, epidote amphibolite facies; ugf, upper greenschist facies; lgf, lower greenschist facies. Dashed contacts are gradational.

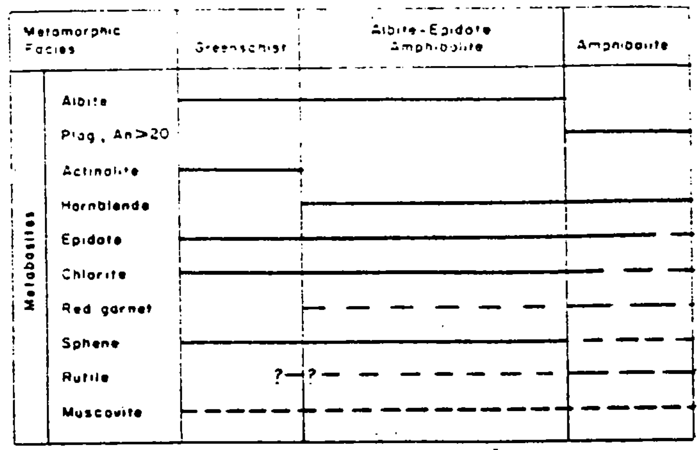

Figure 9. Mineral assemblages of metabasites in the Orocopia Schist of the southern Chocolate Mountains and Picacho-Peter Kane Mountain area. Details of the transitions between facies are poorly known because of the sporadic distribution of metabasite bodies. Length of dashes schematically represents frequency of occurrence of minerals. Not shown are the common accessory minerals quartz, calcite, biotite, magnetite, and apatite.

lower plate during prograde metamorphism of the Pelona-Orocopia schist apparently moved upward and was incorporated into hydrous minerals in the retrograde zone above the thrust (Ehlig, 1958; Conrad and Davis, 1977).

These relationships, which are comparable to those observed for a number of other crystalline overthrust sheets (Armstrong and Dick, 1974), have been interpreted in terms of metamorphism of the schist during thrusting (Ehlig, 1958, 1968), metamorphism of the schist as a consequence of tectonic burial beneath the upper plate of the thrust (Haxel, 1977; see also Bickle and others, 1975), and incipient subduction of the schist (Graham, 1975; Graham and England, 1976; Dillon, 1976). The inverted metamorphic zonation within the schist (Fig. 8) probably resulted from strain heating along the Vincent-Chocolate Mountain thrust (Graham and England, 1976).

Metamorphism

Metabasite mineral assemblages in the Pelona-Orocopia schist are those of the greenschist and albite-epidote amphibolite facies and, less commonly, the lower amphibolite facies or transitional greenschist-blueschist facies (Table 1, Fig. 9). Except for the Pelona Schist of Portal and Ritter Ridges, amphibolite-facies schist apparently occurs only in proximity to the Vincent-Chocolate Mountain thrust. The common major-mineral assemblages of the metagraywacke that makes up the bulk of the Pelona-Orocopia schist are albite + quartz + muscovite + clinozoisite + chlorite at lower metamorphic grades, and albite + quartz + muscovite ± microcline ± biotite + clinozoisite ± chlorite ± garnet at higher grades. Most of the gray schist contains at least a trace of graphite. Metachert assemblages are highly variable; the metacherts of the Orocopia Schist of the southern Chocolate Mountains and Picacho-Peter Kane Mountain area are typically spessartite-magnetite-riebeckite or spessartite-magnetite-hornblende quartzites. Piedmontite is a characteristic accessory mineral in greenschist-facies metachert (Ehlig, 1968). Metapelitic rocks are sparse and none of the three Al_2SiO_5 polymorphs are known to occur in the schist.

Metamorphism of the Orocopia Schist apparently took place at temperature-pressure conditions intermediate between those lying on the medium-pressure (Barrovian) and high-pressure-I facies series trajectories of Miyashiro (1973) (Haxel, 1977). On the basis of detailed electron-microprobe mineralogical studies, Graham and England (1976) estimate that metamorphic temperature and pressure in the epidote-amphibolite-facies Pelona Schist of Sierra Pelona were 420°C to 500°C and 6 to 7.5 kilobars (20 to 27 km depth). Glaucophane-bearing and crossite-bearing metachert, some of which also contains epidote, calcite, or acmite occurs in the Mount Baldy area (Ehlig, 1958; M. C. Blake, Jr., oral commun., 1977), and crossite(?)-bearing metachert occurs very locally in the southern Chocolate Mountains, but no unequivocal blueschist-facies parageneses (Ernst, 1963) have been reported from the Pelona-Orocopia schist. Although metamorphic pressure within the schist was relatively high, temperatures were apparently too high, at the structural levels now exposed, to permit blueschist-facies metamorphism (see Graham and England, 1976). The high pressure is attributed simply to the thickness of the upper plate of the Vincent-Chocolate Mountain thrust, that is, to the depth to which the schist was subducted or tectonically buried.

Structure

The compositional layering visible throughout the gray schist of the Pelona-Orocopia schist (Fig. 3) is defined by variations in color which are caused mainly by variations in the content of graphite and graphitic albite. This layering clearly is derived from sedimentary bedding. The consistent positive correlation between the abundance of graphite and of micas and chlorite results from the concentration of organic material in the more pelitic layers of the protolith. Compositional graded bedding is locally preserved, and this grading reflects the original upward increase of pelitic and organic material within graded beds of graywacke.

Within the Orocopia Schist compositional layering and foliation (schistosity) are uniformly parallel except in the hinges of rare to locally abundant mesoscopic, strongly appressed, isoclinal intrafolial folds with axes consistently parallel to the mineral lineation of the schist. The foliation is axial-planar to the folds. The presence of these intrafolial folds suggests that bedding has been transposed into foliation on an outcrop scale (Haxel, 1977); this suggestion is consistent with several detailed structural studies (Raleigh, 1958; Evans, 1966; Harvill, 1969; Vargo, 1972) showing that the Pelona-Orocopia schist has undergone an episode of synmetamorphic isoclinal folding. Whether this transposition is local or general is unclear and controversial (P. L. Ehlig, written commun., 1976).

In most of the areas for which systematic structural data are available (Table 1), the lineation of the schist plunges gently to moderately to the northeast—southwest or north-northeast—south-southwest, and is thus subparallel to the inferred direction of overthrusting along the Vincent-Chocolate Mountain thrust.

The detailed structural studies cited above show that the Pelona-Orocopia schist has been subjected to several phases of postmetamorphic folding. For example, the Pelona Schist of Sierra Pelona (Harvill, 1969) contains a set of postmetamorphic parasitic folds formed during flexural-slip folding of the Sierra Pelona antiform (see below), and a later set of folds related to shear zones transecting the antiform.

On a regional scale the foliation of the Pelona-Orocopia schist has low to moderate dips, and in most of the larger schist bodies the foliation defines a postmetamorphic antiform or anticlinorium. The largest of these is the narrow, discontinuous, complexly faulted middle Tertiary Chocolate Mountain anticlinorium, which runs the length of the southern Chocolate Mountains and Picacho-Peter Kane Mountain area and extends eastward to the Middle Mountains (schist body 13) of southwesternmost Arizona. Broad, relatively simple antiforms are present in the Sierra Pelona (Dibblee, 1961a; Harvill, 1969), the Orocopia Mountains (Crowell, 1962, 1975c), and the Rand Mountains (Dibblee, 1967). The Vincent-Chocolate Mountain thrust crops out chiefly on the flanks of these antiformal structures (Fig. 2), although several small klippen occur along the crest of the Chocolate Mountain anticlinorium.

Age of Metamorphism

The Pelona-Orocopia schist was long regarded as probably (Muelberger and Hill, 1958) or certainly (Hershey, 1912; Hulin, 1925; Simpson, 1934; Miller, 1946) of Precambrian age, on the basis of this argument: Nearby Paleozoic rocks are unmetamorphosed or affected only by local contact metamorphism; therefore, there can have been no Phanerozoic regional metamorphism in southern California. This argument is invalid if the schist and the Paleozoic rocks were juxtaposed by overthrusting, with the schist undergoing metamorphism beneath the Vincent-Chocolate Mountain thrust and the unmetamorphosed Paleozoic rocks riding on the crystalline rocks of the upper plate of the thrust. (Also, some Paleozoic rocks in southern California are now known to be metamorphosed and intensely deformed; for example, see Hamilton, 1971). Rocks in southwesternmost Arizona now recognized as Orocopia Schist (Table 1) were mapped, along with several other rock types, as "Mesozoic schist" by Wilson (1933, 1960).

Ehlig (1958, 1968) showed that, because the metamorphism of the Pelona Schist was directly related to the Vincent thrust and the Vincent thrust cuts isotopically dated mid-Cretaceous plutonic rocks, the metamorphism of the schist must have occurred during Late Cretaceous or early Tertiary time (Table 2). The Orocopia Schist must be older than the unconformably overlying lower Oligocene Quechan Volcanic Formation (of Crowe, 1973, 1978).

The Pelona Schist and mylonitic rocks from the Vincent thrust zone have yielded six K-Ar and Rb-Sr dates ranging from 47 to 59 m.y. (Table 2). These dates come from areas within or adjacent to an incompletely delineated region of "reduced" K-Ar cooling ages in the eastern Transverse Ranges and adjacent Mojave Desert (Miller and Morton, 1975). This region includes a "zone of anamolous cooling ages" between approximately 55 and 80 m.y. in the San Bernardino and eastern San Gabriel Mountains (Miller and Morton, 1978). Pending clarification of the relation of these reduced cooling ages to the metamorphism of the Pelona Schist, a Late Cretaceous age for the schist can not be ruled out. However, the concentration of both K-Ar and Rb-Sr isotopic ages from the Pelona Schist and Vincent thrust zone in the interval from 50 to 60 m.y. (Table 2) strongly suggests that the metamorphism of the Pelona-Orocopia schist occurred in Paleocene time.

Relations to Granitic Plutons

One of the peculiar characteristics of the Pelona-Orocopia schist is that it is only very sparsely intruded by Mesozoic granitic rocks (Ehlig, 1968). The Rand Schist is intruded, just south of Randsburg, by a small (~2 km^2) body of metagranite of probable Mesozoic age (R. W. Kistler, oral commun., 1977; see Miller and Morton, 1977, p. 644). (The Mesozoic granitic rocks on the southwest and southeast sides of the Rand Mountains (Dibblee, 1967, pl. 1) are in the upper plate of the Rand thrust (Ehlig, 1968).) The Orocopia Schist of the southern Chocolate Mountains contains a single very small plug of epidote-garnet metagranite or metarhyolite (Dillon, 1976), and the Pelona Schist is known to contain two small metarhyolite dikes (P. L. Ehlig, oral commun., 1977). The oldest known postmetamorphic intrusion into the Pelona-Orocopia schist is the lower Tertiary(?) Marcus Wash Granite of the Picacho district (Haxel, 1977). In the eastern San Gabriel Mountains and the central and southern Chocolate Mountains the Pelona and Orocopia Schists are intruded by small, epizonal, granitic plutons, which were once assumed to be of Mesozoic age (Noble, 1954; Jennings, 1967). However, the plutons in the southern Chocolate Mountains are genetically related to the mid-Tertiary silicic volcanic rocks of the area (Dillon, 1976), and both sets of plutons have yielded concordant Miocene K-Ar dates (Miller and Morton, 1977).

Previous Distribution of the Schist

A schematic reconstruction of southern California prior to approximately 300 km of late-Cenozoic right slip on the San Andreas fault system (Crowell, 1973, 1975a; Dickinson, Cowan, and Schweickert, 1972; Nilsen and Clarke, 1975), including the San Gabriel fault (Crowell, 1975b), was produced by graphically reassembling the Orocopia-Soledad-Tejon terrane (Crowell, 1962; Silver, 1971), the northern

Table 2. Age data for the Pelona-Orocopia Schist

Rock	Locality	Relation to Pelona-Orocopia schist and Vincent-Chocolate Mountain thrust	Radiometric age (m.y.)	Method	References
Mount Lowe Granodiorite	San Gabriel Mountains	Cut by Vincent thrust	220±10	U-Pb	Silver, 1971; Ehlig, 1968, 1975a, b
Quartz diorite correlative with the quartz diorite of El Dorado Ridge and Ontario Peak	San Gabriel Mountains	Cut by Vincent thrust	105±10	Rb-Sr biotite age	Hsu, Edwards, and McLaughlin, 1963; Ehlig, 1968
Plutons correlative with the Mount Josephine Granodiorite	San Gabriel Mountains	Cut by Vincent thrust	80±10	U-Pb	Carter and Silver, 1972; P. L. Ehlig, oral commun., 1974
Quechan Volcanic Formation	Picacho district; Chocolate Mountains	Rests nonconformably on Orocopia Schist	~35 (several dates)	K-Ar	Daniel Krummenacher, written commun., 1976; Crowe, 1973, 1978; Dillon, 1976
Quartz monzonite; quartz monzonite of Mount Barrow	San Gabriel Mountains; Chocolate Mountains	Post-metamorphic intrusions into Pelona and Orocopia Schists	14-19; 20-23	K-Ar	Miller and Morton, 1977; Dillon, 1976; Haxel, 1977
Quartzo-feldspathic Pelona Schist	Sierra Pelona; San Gabriel Mountains	--	47±1 52±1	K-Ar whole rock	Ehlig, Davis, and Conrad, 1975
Quartzo-feldspathic Pelona Schist	Sierra Pelona	--	53±2	Rb-Sr mineral isochron	Ehlig, Davis, and Conrad, 1975
Metachert, Pelona Schist	San Gabriel Mountains	--	59±1	Rb-Sr mineral isochron	Gary Lass, written commun., 1978
Mylonite, Vincent thrust zone	San Gabriel Mountains	—	53±0.5	K-Ar whole rock	Ehlig, Davis, and Conrad, 1975
Blastomylonite, Vincent thrust zone	San Gabriel Mountains	—	58.5±4	Rb-Sr mineral isochron	Conrad and Davis, 1977

Chocolate Mountain-Mint Canyon Formation-Caliente Formation paleo-drainage system (Ehlig, Ehlert, and Crowe, 1975), and the Pinnacles-Neenach volcanic field (Huffman, Turner, and Jack, 1973; Matthews, 1976). Sixty kilometers of left slip along the Garlock fault (Smith, 1962; Davis and Burchfiel, 1973) was also restored. The resulting palinspastic map (Fig. 10) shows the probable approximate middle-Tertiary positions of the present day Pelona-Orocopia schist outcrops (Fig. 2) relative to one another and to several other tectonic elements of the California continental margin. Most of the schist bodies are alined in two subparallel, west- to west-northwest-trending anticlinoria in southeastern California and southwestern Arizona. Because the right-slip faults in the western Mojave Desert have displacements of, at most, a few tens of kilometers (Dibblee, 1961b; Garfunkel, 1974), the schist along the Garlock fault (schist bodies 4 and 5) probably always has been several hundred kilometers north of the schist of southeastern California and southwestern Arizona (Ehlig, 1968). The Pelona Schist of Portal and Ritter Ridges forms a sliver within the San Andreas fault system (Wallace, 1949), but the occurrence of similar schist at Quartz Hill several kilometers to the northeast in Antelope Valley

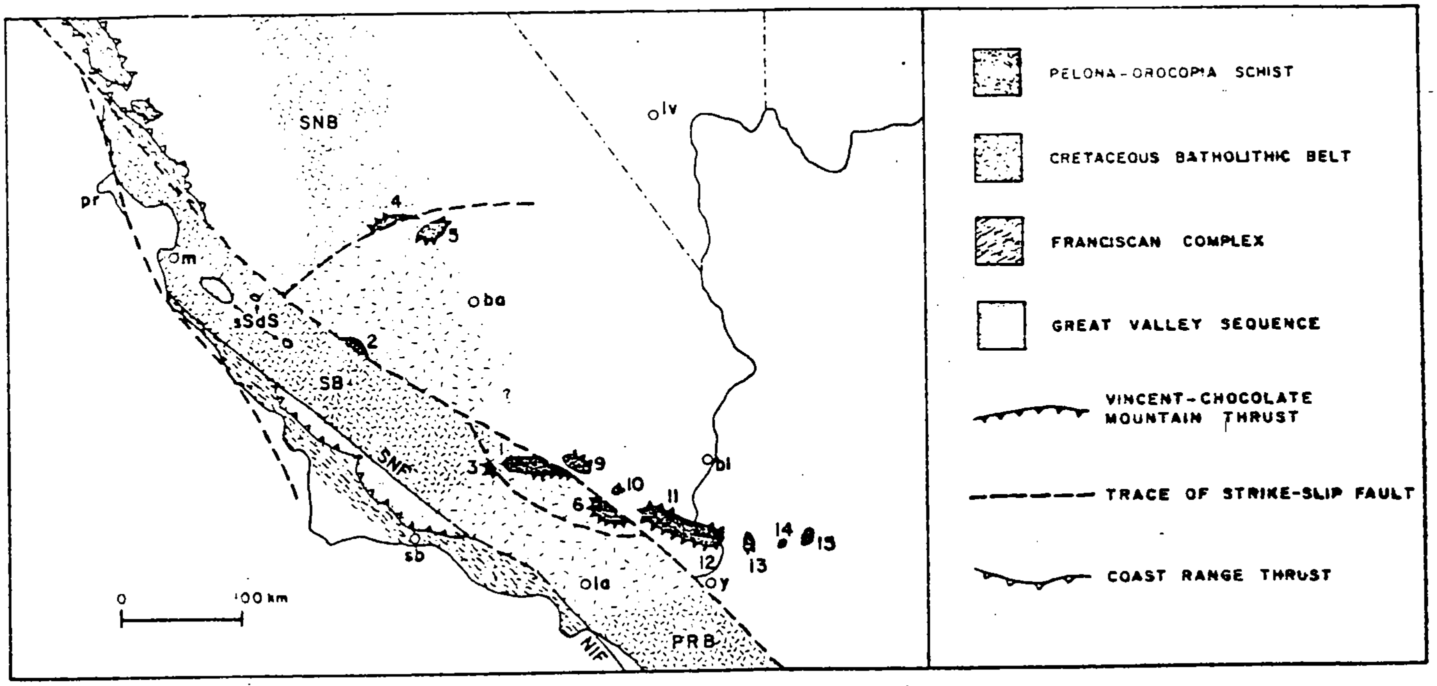

Figure 10. Palinspastic reconstruction showing present day outcrops of the Pelona-Orocopia schist and Vincent-Chocolate Mountain thrust restored to their approximate relative positions prior to late Cenozoic strike slip along the San Andreas fault system. Schist bodies numbered as in Figure 2 and Table 1, but bodies 7 and 8 are omitted. Distribution of Franciscan Complex, Great Valley Sequence, and Coast Range thrust simplified after Bailey, Blake, and Jones (1970), and Jones, Blake, and Rangin (1976). Restoration of San Gregorio-Hosgri fault after Graham and Dickinson (1978). Cretaceous batholithic belt after Kistler (1974). NIF, Newport-Inglewood fault; PRB, Peninsular Ranges batholith; SB, Salinian block; SNB, Sierra Nevada batholith; SNF, Sur-Nacimiento fault; sSdS, schist of Sierra de Salinas; ba, Barstow; bl, Blythe; la, Los Angeles; lv, Las Vegas; m, Monterey; pr, Point Reyes; sb, Santa Barbara.

suggests that schist body 2 may be more or less in place with respect to the Mojave Desert. Although correlation of the schist of Sierra de Salinas with the Pelona-Orocopia schist is equivocal, the probable restored position of the schist of Sierra de Salinas is shown (sSdS, Fig. 10) for reference.

The palinspastic map of the Pelona-Orocopia schist and Vincent-Chocolate Mountain thrust shows, more clearly than does the present day distribution of the schist, that the Pelona-Orocopia schist lies largely along and beneath the diffuse eastern margin of the Sierra Nevada-Salinia-Peninsular Ranges Cretaceous batholithic belt (Hamilton, 1969a, b; Kistler, 1974). The Pelona-Orocopia schist thus occupies a fundamentally different tectonic position than the lithologically similar Franciscan Complex, and the lithologically dissimilar Great Valley Sequence, which form separate and much more extensive belts on the west side of the batholithic belt in western California and Baja California (Bailey, Irwin, and Jones, 1964; Berkland and others, 1972; Ernst and others, 1970; Suppe, 1972; Jones, Blake, and Rangin, 1976). The Franciscan Complex includes the Catalina Schist of Santa Catalina Island (Platt, 1975, 1976). In spite of certain lithologic similarities between the Catalina Schist and the Pelona-Orocopia schist (Ehlig, 1968; Crowell, 1968) the above argument, and the fact that the metamorphic age of the Catalina Schist (Suppe and Armstrong, 1972) is appreciably older than that of the Pelona-Orocopia schist (Table 2), strongly suggests that the two schists are not directly related (Platt, 1976, p. 5). Consistent with these conclusions, the inferred direction of overthrusting along the Vincent-Chocolate Mountain thrust is roughly opposite to that along the Coast Range thrust overlying the Franciscan Complex (Bailey, Blake, and Jones, 1970; Ernst, 1970; Platt, 1975).

Subsurface Extent of the Schist

There are two possible interpretations of the subsurface extent of the Pelona-Orocopia schist. The schist of southeastern California (as palinspastically reconstructed in Fig. 10) and southwestern Arizona and the schist along the Garlock fault (schist bodies 4 and 5) may be disjunct; this would require that these unique and virtually identical rocks (Simpson, 1934; Ehlig, 1968; Vargo, 1972) originated independently in two areas at least 200 km apart (Ehlig, 1968). We prefer the tectonically simpler interpretation that all of the schist bodies were, prior to offset along the San Andreas and Garlock fault systems, connected at depth beneath a regional allochthon. This hypothesized allochthon extends from southwesternmost Arizona to the westernmost Mojave Desert and comprises the pre-Tertiary crystalline rocks (other than the schist) of the eastern Transverse Ranges, southwestern Mojave Desert, northwesternmost Sonoran Desert, northeasternmost Peninsular Ranges, and southern Salinian block (Figs. 2, 10).

We thus infer that the bulk of the Pelona-Orocopia schist is still deeply buried, chiefly beneath the southwestern Mojave Desert. The occurrence of most exposures of the schist along the San Andreas and Garlock fault systems (Fig. 2) is then due to strong uplift and deep erosion along these strike-slip faults, for example in the Transverse Ranges where the Pelona-Orocopia schist was first exposed to subaerial erosion in Miocene time (Ehlig, Davis, and Conrad, 1975). Inherent in this "single allochthon" interpretation is our treatment of the Vincent, Chocolate Mountain, Orocopia, and Rand thrusts as segments of a single thrust fault.

The allochthon is a fragment or flake (in the sense of Oxburgh, 1972) of continental crust with a complex and diverse Precambrian through Mesozoic geologic history (for example, Silver, 1971; Dibblee, 1967; Crowell, 1962; Ehlig, 1975a, b; Dillon, 1976; Allen, 1957), which contrasts with the distinctly simpler history of the tectonically underlying Pelona-Orocopia schist (Crowell, 1968). It is this striking contrast in variety of rock types and complexity of geologic history across the thrust that shows that the Vincent-Chocolate Mountain thrust is a major crustal discontinuity.

If the "single allochthon" interpretation is correct, then the allochthon must have a northeastern boundary somewhere in the southwestern Mojave Desert and northwesternmost Sonoran Desert. Future field studies in these areas may locate this suture zone; part of it may be represented by the thrust faults exposed in the Palen, McCoy, and Mule Mountains west of Blythe, California (Pelka, 1973a, b).

The Pelona-Orocopia Protolith

The metagraywacke of the Pelona-Orocopia schist is quartzo-feldspathic, rather than mafic, in composition (Ehlig, 1958; Haxel, 1977; Vargo, 1972), contains detrital zircon and allanite, and must have had a continental provenance. In most of the schist metagraywacke strongly predominates over metapelite, indicating that the Pelona-Orocopia protolith had a high sand-to-shale ratio. This suggests that the clastic sedimentary rocks that made up the bulk of the protolith were deposited, presumably by turbidity currents, in a proximal environment (Walker, 1967), but the virtual absence of metaconglomerate in the schist is puzzling.

The thick layers of metabasite in the Pelona-Orocopia schist were probably derived from submarine lava flows, and relict pillow structures have been found in the metabasite of Sierra Pelona at one locality (P. L. Ehlig, oral commun., 1977). Thin layers of metabasite within metagraywacke or metachert probably were derived from mafic tuff. A small body of metadiorite or metagabbro occurs in the Orocopia Schist of the southern Chocolate Mountains. Some isolated blocks of metabasite may originally have been olistoliths within the graywacke of the Pelona-Orocopia protolith.

The deposition of small amounts of limestone and ferromanganiferous chert in an environment of dominantly clastic deposition was probably related to the submarine volcanism now represented by the metabasites of the Pelona-Orocopia schist. The common spatial association of metachert and marble with metabasite suggests that the chert and limestone accumulated, above the reach of clastic sedimentation, on submarine volcanic topographic highs (Garrison, 1974), presumably as biogenic debris (Wise and Weaver, 1974).

No direct evidence, isotopic or palentologic, as to the age of the Pelona-Orocopia protolith is known to us.

The basement upon which the protolith of the Pelona-Orocopia schist accumulated has not been identified and apparently is not exposed. Metamorphosed ultramafic rocks, now serpentinite and actinolite-rock, are widespread and locally abundant (for example, near Wrightwood, California) in the schist. The presence of these ultramafic rocks, and the association of graywacke, shale, basalt, ferromanganiferous chert, and ultramafic rock, indicate that the protolith accumulated on oceanic or semi-oceanic crust.

Regional Uniqueness of the Schist

None of the Precambrian rock units of southeastern California and adjacent areas (see, for example, the descriptions given by Hunt and Mabey, 1966; Silver, 1971; Silver and others, 1977; Anderson and Silver, 1976; Babcock, Brown, and Clark, 1976; Ford and Breed, 1976; Shride, 1967; Anderson and Silver, 1971; Cooper and Silver, 1964) appears to warrant consideration as the Pelona-Orocopia protolith, because none consists of graywacke or metagraywacke in combination with the minor rock types characteristic of the protolith. The Pelona-Orocopia schist obviously was not derived from the limestone, dolomite, shale, and orthoquartzite of the Paleozoic and uppermost Precambrian miogeocline and craton (Stewart and Poole, 1974, 1975; Burchfiel and Davis, 1972, 1975); and the Antler flysch belt (Poole, 1974) is likewise lithologically dissimilar to the protolith (Ross, 1976). Furthermore, the northwest-trending Pelona-Orocopia schist belt (Figs. 2, 10) lies athwart the southwesterly trend of these Paleozoic belts.

Most of the Mesozoic supracrustal rock units of southeastern California and adjacent areas (Jones, Blake, and Rangin, 1976; Burchfiel and Davis, 1972, 1975; Abbott, 1971; Grose, 1959; Dibblee, 1967; Gastil, Phillips, and Allison, 1975) differ from the Pelona-Orocopia protolith and schist in that they include appreciable proportions of silicic or intermediate volcanic rocks and (or) shallow marine or nonmarine sedimentary rocks. Some of the lower Mesozoic country rocks of the Peninsular Ranges batholith (Gastil, Phillips, and Allison, 1975), specifically the Bedford Canyon Formation (Schwarcz, 1969; Larsen, 1948) and the Julian Schist (Merriam, 1958; Donnelly, 1934), have a limited degree of similarity to the Pelona-Orocopia protolith but, again, apparently lack the distinctive minor rock types characteristic of the protolith. Facies changes might be invoked to allow correlation of these rocks with the Pelona-Orocopia protolith, but such a correlation seems rather unlikely. Finally, there are the Mesozoic supracrustal rocks, other than the schist itself, of the northwestern Sonoran Desert (Hayes, 1970; Miller and McKee, 1971; Hamilton, 1964; Pelka, 1973a, b; Wilson, 1933). Of these, the Palen Formation (Pelka, 1973a) is somewhat similar to the Pelona-Orocopia protolith, and the McCoy Mountains Formation is comparable to the Pelona-Orocopia schist in that it is overlain by a crystalline thrust sheet (Pelka, 1973a, b). Either or both of these units may be related to the Pelona-Orocopia schist or to the Vincent-Chocolate Mountain thrust (Haxel, 1977; Dillon, 1976), but neither is obviously a facies of the protolith.

These comparisons suggest that the Pelona-Orocopia schist—plus, possibly, the schist of Sierra de Salinas—is regionally unique, in the sense that it was not derived from any of the other widespread tectonic-lithologic units of southern California and vicinity. The Pelona-Orocopia schist belt has no counterpart to the north on the east side of the Sierra Nevada batholith in east-central California and southern Nevada. The schist belt extends eastward an unknown, but probably not great, distance into southwestern Arizona, and apparently has no counterpart to the south in northwestern Mexico (see: Salas, 1968; Merriam, 1972; Gastil, Philips, and Allison, 1975; Cooper and Arellano, 1946; Anderson, Silver, and Cordoba M., 1969; Anderson and Silver, 1971; Cserna, 1970; Salas, Cordoba, M., and Avila, 1974; Clark, 1975; Gastil and Krummenacher, 1977; Gastil, Krummenacher, and students, 1974). The Pelona-Orocopia schist thus appears to be endemic to the region of southern California and southwesternmost Arizona.

PALEOGEOGRAPHIC SIGNIFICANCE OF THE PELONA-OROCOPIA SCHIST: A STATEMENT OF THE PROBLEM

The presence of the oceanic rocks of the Pelona-Orocopia schist in their present tectonic position along the eastern margin of the Cretaceous batholithic belt, where they are surrounded and tectonically overlain by Precambrian through Mesozoic gneisses and granites of typically continental aspect, seems anomolous, especially since the Orocopia Schist extends as far inland as the southwestern corner of Arizona. The Pelona-Orocopia schist, as such, is the product of a Paleocene (or Late Cretaceous) orogenic event in which the protolith of the schist was overridden, along the Vincent-Chocolate Mountain thrust, by a northeast-directed flake of continental crust. However, the origin of the Pelona-Orocopia protolith and the paleogeographic significance of the orogenic event that converted it into the schist are unclear because of uncertainty as to the place of origin of the Salinian block (Compton, 1966; Ross, 1972a) and of the slab of continental crust that now constitutes the allochthon overlying the Pelona-Orocopia schist.

The conventional hypothesis is that Salinia and the crystalline rocks of northwestern and southeastern southern California were originally alined between the Sierra Nevada and Peninsular Ranges batholiths (Hamilton, 1969a, b). The present configuration of crystalline rocks in southern and western California is then explained by a possible 150 or more km of Late Cretaceous and (or) early Paleocene right-slip along the proto-San Andreas fault system and 300 km of unequivocal right slip along the late Cenozoic San Andreas fault system (Crowell, 1973, 1975a; Nilsen and Clarke, 1975; Graham and Dickinson, 1978). However, some of the distinctive rocks of the allochthon may not have counterparts elsewhere in southwestern North America (Silver, 1971; Silver and others, 1977) and the pre-intrusive and intrusive rocks of Salinia may not have counterparts in the expected areas east of the San Andreas fault in the western Mojave Desert and southern Sierra Nevada (Ross, 1977, 1978). This raises the possibility that Salinia and the allochthon comprise an exotic microcontinent, or two separate exotic microcontinents, that collided with southern California (for example, Hsu, 1971; Nur and Ben-Avraham, 1978) or reached southern California by large-scale Mesozoic strike-slip faulting (for example, Silver and Anderson, 1974; Kistler and Peterman, 1978).

This in turn raises the possibility that the Pelona-Orocopia protolith may itself be exotic, having accumulated elsewhere and been tectonically introduced into southern California sometime after the truncation of the continental margin there in Late Permian or Early Triassic time (Hamilton and Myers, 1966; Hamilton, 1969a; Burchfiel and Davis, 1972, 1975). There appear to be two broad alternatives for the origin of the Pelona-Orocopia protolith: (1) The oceanic rocks of the protolith accumulated outboard of a continental margin, in southern California or elsewhere, and were subsequently tectonically trapped in their present position inboard of the granitic and gneissic continental rocks that now lie to the west of the Pelona-Orocopia schist. (2) The protolith accumulated inboard of the continental margin, in an intracontinental ensimatic basin within southern California. The presently available geologic, geochronologic, and isotopic data do not allow a clear-cut choice between these alternatives, and only partially constrain the several protracted tectonic scenarios possible under the first alternative.

The second alternative leads to tectonic models of the sort we have presented previously. We have suggested that the Pelona-Orocopia protolith accumulated in a Late Cretaceous ensimatic intracontinental back-arc basin formed by crustal dilation above a mantle diapir (Dillon and Haxel, 1975) or by oblique rifting associated with right-lateral transform faulting along the proto-San Andreas fault system (Haxel and Dillon, 1977). In either model overthrusting (or incipient subduction) along the Vincent-Chocolate Mountain thrust resulted from closing of the back-arc basin in response to the initiation of subduction of the Farallon plate beneath southern California (Atwater, 1970). Although these back-arc basin models provide a straightforward explanation for the existence of the Pelona-Orocopia schist in southern California, they are, in view of the uncertainties outlined above, obviously speculative at this time.

In conclusion, we offer the following suggestions for future study of the tectonic aspects of the Pelona-Orocopia schist. (1) The northeastward direction of overthrusting inferred for the Chocolate Mountain thrust and the Vincent thrust of the eastern San Gabriel Mountains should be verified in other areas. (2) The hypothesis that the upper plates of the Vincent, Chocolate Mountain, Orocopia, and Rand thrusts constitute a single large allochthon should be critically evaluated. (3) The geometric relation of the hypothesized allochthon to the distribution of Paleozoic sedimentary facies in southern California and southwestern Arizona (Stewart and Poole, 1975) should be investigated. (4) The lithologic correlation of the Rand Schist with the Pelona and Orocopia Schists should be tested by isotopic dating of the Rand Schist. (5) The relationship, if any, of the Vincent-Chocolate Mountain thrust to the thrust faults west of Blythe (Pelka, 1973a), the Alamo Mountain movement zone (Crowell, 1968), the Mill Canyon mylonite zone and window (Carter and Silver, 1972; Ehlig, 1975a), the cataclastic rocks about Cucamonga Canyon (Hsu, 1955; Ehlig, 1975a), and the Santa Rosa mylonite belt (Theodore, 1970) needs to be clarified. (6) The relation of the schist of Sierra de Salinas (Ross, 1976) to the Pelona-Orocopia protolith and schist should be given further study. (7) It is very important to determine the age of the Pelona-Orocopia protolith. (8) The origin and paleogeographic significance of the Pelona-Orocopia schist cannot be understood until it is known whether the Salinian block and the allochthon atop the schist are indigenous or exotic to southern California.

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